The thermal assessment of window assemblies, curtain walling and non-traditional building envelopes
(Second Edition)

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This document has been published by the Centre for Window and Cladding Technology in collaboration with the Council for Aluminium in Building under the guidance of a joint working group. It is based on the best information available at the time of publication and is given as a reference in Approved Documents ADL-2A (2006) and ADL-2B (2006) as ways of showing compliance with the Building Regulations.

It provides practical guidance on determining the U-values of non-traditional building envelopes for input into a building energy model.

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Foreword

This document is intended for use by the building design team, building envelope designers and building inspectors. It allows the early estimation of building envelope U-values, details the information required in a specification, and describes methods for showing compliance of the final building envelope design with the requirements of Parts L-2A and L-2B of the Building Regulations, which are referred to as ADL-2A and ADL-2B. It is expected that similar provision will be included in the Building Regulations for Scotland and Northern Ireland in due course.

The appendices show how detailed calculations should be undertaken to establish component U-values and the properties of their associated thermal bridges, and how these should be incorporated into a detailed calculation of the equivalent U-value of a zone of the building envelope.

Finally, the document shows how the equivalent U-value of a zone of building envelope may be used as an input into software that models building energy use.

This document was updated in 2010 to coincide with the revisions to Part L of the Building Regulations.

CONTENTS

1 SCOPE

1.1 Types of construction

The following non-traditional forms of construction are included:

- Curtain walling:
  - Stick system construction,
  - Unitised walls,
  - Bespoke walls,
  - Panellised walls.

- Insulated panel walling,

- Rainscreen walling:
  - Integral rainscreens,
  - Rainscreen overcladding.

- Slope glazing.

1.2 Appropriate timing of decisions

1.2.1 Planning stage

ADL2-A suggests a preliminary energy calculation for a building to be prepared prior to seeking planning consent. Energy use and carbon dioxide production will depend on many factors but are greatly influenced by the building envelope. Energy use is particularly affected by:

- Type of envelope construction,
- Envelope layout,
- Area of glass,
- Air permeability,
- Orientation of glass,
- Shading devices.

Software packages are available to model the energy performance of buildings on the basis of simplified inputs for the purpose of planning. However, it is important that realistic inputs are used, to ensure that the building for which planning consent has been achieved can eventually be built.

At the planning stage it is necessary to assume values for:

- U-values of the individual cladding packages,
- Areas of glass,
- Types of glass,
- Shading devices,
- Air permeability.

1.2.2 Costing

The cost of non-traditional building envelopes will be greatly influenced by:

- Type of glass,
- Shading devices,
- Proportion of glass,

- Proportion of frame.

Decisions about the building envelope at the planning stage should be reflected in cost calculations. All too often preliminary construction budgets do not allow for the costs of high performance glasses and the like.

1.2.3 Detailed design

At the detailed design stage it is possible to achieve minor improvements to the energy performance. However the opportunity to achieve larger improvements by the use of different wall dimensions and shading devices is seldom available after the planning stage.

The detailed design can only be developed in the context of earlier decision-making and ‘the art of the possible’. Over-optimistic assumptions of U-values may not be deliverable at the detailed design stage.

1.2.4 Building envelope design

Only at the design stage is it possible to calculate an accurate U-value for the building envelope. U-value calculations will be based on component U-values, appropriate edge heat transfer corrections (ψ-values), appropriate localised heat transfer corrections (χ-value) and the precise geometry of the construction.

This document describes the calculation methodology to be used for calculating the U-value of a zone of a building envelope.

1.2.5 Building inspection

Verification of envelope performance for building control purposes requires calculation, testing and inspection. This document details the methods of calculation that are required to determine overall U-values of a building envelope.

Guidance on expected U-values for different construction types and geometries is given for the purpose of checking preliminary calculations and identifying gross error or over-optimism in the calculation of U-values.

2 THERMAL PRINCIPLES

2.1 Energy transfer

Building envelopes contribute to energy efficient buildings by:

- Providing thermal insulation to limit heat transfer due to conduction (allowing for heat radiated and convected between internal surfaces within the construction);
- Limiting energy transfer due to air leakage;
- Allowing natural light into a building while controlling solar gain;
- Providing ventilation for cooling.

2.2 Solar gain

Solar transmission through glazing materials heats the contents and internal fabric of a building. This often leads to a cooling requirement within the building. Cooling may be provided by natural ventilation or air conditioning. ADL-2A states:

- Solar gains to be limited during the summer period to either reduce the need for air-conditioning, or to reduce the installed capacity of any air-conditioning system that is installed.
  - This can be achieved by demonstrating that the solar gains through the glazing are no greater than would occur for a number of different reference cases.
  - This applies to all buildings, irrespective of whether they are air conditioned or not.

It should be noted that even if the above criterion is satisfied in the context of natural ventilation it is not evidence that the internal environment will be satisfactory.

Compliance may be best achieved by:

- Using solar control glasses;
- Reducing the area of glass in particular walls or the roof depending on orientation;
- Providing adequate cooling by natural ventilation.

Solar control glasses will also reduce the amount of daylight admitted to the building. This is taken into account in the whole building energy calculation.

Use of air conditioning is inefficient as mechanically cooling a building through 1^{o}C uses approximately four times the energy required to warm a building through 1^{o}C.

2.3 Radiation transfer

Heat may transfer through the building envelope by long wave radiation. The contents and internal fabric of the building radiate long wave thermal radiation that escapes through the building envelope during the heating season. Low emissivity glasses are used to limit long wave radiation heat transfer.

Long wave radiation heat transfer is included in the U-value calculation of the glazing and other building elements.

2.4 Air leakage

Air leakage through the building envelope adds to energy transfer, as heated (or cooled) air is lost from the building. ADL-2A requires buildings to have an overall air leakage no greater than 10 $m^3/hr/m^2$ at a pressure difference of 50 Pa. However, lower air leakage rates may be set to compensate for lower standards elsewhere in the building.

Curtain walls meeting the requirements of the CWCT 'Standard for systemised building envelopes' will have air permeability less than either 0.45 $m^3/hr/m^2$ or 0.28 $m^3/hr/m^2$. The principal concern is air leakage at the interfaces with other types of construction. However, depending on the complexity and number of interfaces, whole building air leakages of less than 10 $m^3/hr/m^2$ can be achieved.

Any reduction in heat transfer achieved by constructing a less permeable building envelope may be taken into account when calculating whole building energy performance. However, any presumed air permeability should be achieved by the as-constructed building envelope. ADL-2A requires a whole building air leakage test for all buildings with floor area greater than or equal to 500 m^2. However, it may be economic to test smaller buildings as the default air leakage for energy modelling of untested buildings is 15 $m^3/hr/m^2$.

2.5 Ventilation

Ventilation may be required to:

- Provide fresh air,
- Remove combustion products from gas appliances,
- Provide natural ventilation for cooling.

Ventilation requirements are given in Part F of the Building Regulations, England and Wales. Inclusion of opening lights in the building envelope will increase the area of glazing frame, which increases the U-value and decreases the incoming daylight if it results in a smaller area of glazing. However, proper ventilation should not be sacrificed by omitting opening lights purely to gain a more favourable U-value.

2.6 U-value

U-values are used to describe the rate of heat transfer due to temperature difference across the building envelope. Expressed in W/m^2K the U-value is independent of the temperature difference across the building envelope and is a property of the components of the building envelope.

U-value is a measure of the heat flow rate from the inside air to the outside air.

2.7 Lateral heat flow

Heat does not always flow directly from one surface of the wall to another. Heat flows along the route of least resistance and may flow in the plane of the building envelope; this is termed lateral heat flow. It occurs at all discontinuities in the envelope including edges of glazing, edges of panels, framing members and interfaces between different envelope types.

When calculating the heat flow through a wall it is common practice to divide the envelope into elements so that no heat travels laterally from one element to another and a true U-value is calculated.

2.8 Centre panel U-values

Centre pane/panel U-values ignore the effects of lateral heat flow and underestimate the total heat loss through a glazing unit or panel. They ignore additional heat loss that occurs around the perimeter due to lateral heat flow. Manufacturers use them to show the theoretical minimum heat loss through their product but they are U-values that can never be realised in practice. They are used because:

- True U-values depend on panel size and edge condition;
- They are a useful way of comparing products;
- If used with appropriate ψ-values they can give a realistic U-value for a given size of panel and edge condition.

2.9 Additional heat transfer at panel edges and other linear thermal bridges

More heat transfer occurs at the edge of panels, and glazing units, than at the centre due to lateral heat flow. This is represented by the linear thermal transmittance, ψ, and can be calculated by either:

- Determining the heat transfer by two-dimensional simulation, or
- Calculating the heat transfer through the panel by including the additional heat transfer, as a standard ψ–value, at the edge to that calculated using the centre panel U-value.

The overall U-value of a panel, U_{panel}, is then calculated from:

$$A_p U_{panel} = A_p U_p + P_p \psi$$

Where A_p is the area, P_p is the perimeter and ψ is the rate of additional heat transfer per unit length of perimeter. The ψ-value depends on the edge detailing of the panel and any framing member at the perimeter. The centre panel U-value, $U_{p,}$ is calculated by one-dimensional analysis.

The use of standard ψ-values is simpler than using two-dimensional simulation as the centre panel U-value and standard ψ–value are independent of panel size.

Lateral heat flow also occurs at linear thermal bridges formed by framing members, and 2-D corners and the like. The additional heat flow due to linear thermal bridges can also be calculated using ψ-values.

2.10 Additional heat transfer at localised thermal bridges

Localised thermal bridges are created by the presence of corners or localised support brackets within insulation and fixings through insulation. A localised thermal bridge will give rise to greater heat transfer and this can be calculated by:

- Determining the heat transfer by three-dimensional simulation;
- Calculating the heat transfer through the element by including the additional heat transfer at the localised thermal bridge to that calculated using the U-value for the non-locally bridged element.

The element U-value is then:

$$A_{element} U_{element} = A_{panel} U_{panel} + \chi$$

Where χ is the additional heat transfer due to the localised thermal bridge. Note that U_{panel} includes linear thermal bridges as described in Section 2.9.

2.11 Weighted U-value calculations

U-values of a zone of the building envelope may be calculated by summing the heat transfer through all elements, edges, interfaces, linear and localised thermal bridges. The U-value for a zone of the building envelope is then:

$$A_{zone}U_{zone} = \sum_{zone} A_{element}U_{element} + \sum_{zone} P_{interface}\,\psi_{interface} + \sum_{zone} \chi_{interface}$$

Where:

$$A_{element}U_{element} = \sum_{element} AU + \sum_{element} P\psi + \sum_{element} \chi$$

$$A_{zone} = \sum_{zone}(A_{element} + A_{interface})$$

This is the familiar area-weighted method with the addition of edge and localised losses.

3 DESIGN AND SPECIFICATION OF BUILDING ENVELOPES FOR COMPLIANCE WITH ADL-2A AND ADL-2B

3.1 Design

ADL-2A and ADL-2B set limits for the energy use of the building in terms of carbon dioxide emissions. They also set limiting U-value standards for components of the building envelope.

Note that simply meeting the limiting U-value standards is unlikely to lead to a building with acceptable carbon dioxide emission levels.

Whole building modelling is used to calculate the carbon dioxide emissions of the building. This takes account of energy used for lighting, heating, cooling, and other servicing of the building. These are determined in part by the building envelope.

The amount and distribution of glass in the envelope must be considered at the preliminary design stage. Decisions on the glazing will include consideration of the type of glass and any shading devices to be incorporated in the building envelope.

At the design stage different forms of construction will be chosen for each zone of the building envelope so that:

- Appropriate areas of glass can be included for daylighting;
- Appropriate shading devices can be included to limit solar gain;
- Energy transfer by heat conduction/convection/radiation through the envelope, the U-value, is limited;
- No component, or group of components, has a U-value greater than the limiting value given in ADL-2A and ADL-2B.

Other factors affecting the choice of construction type are:

- Appearance,
- Method and speed of construction,
- Costs.

Performance characteristics of the building envelope have to be assumed to enable whole building energy modelling. These values should be realistic so that when they are specified it is possible to build a compliant building envelope.

3.2 Notional building

ADL-2A defines a notional building to calculate the allowable performance of the building being constructed. The procedure is as follows:

- A notional building is defined of the same size and shape as the actual building, constructed to a concurrent specification;
- The Target Emissions Rate (TER) is set equal to the CO_2 from this notional building.

The specified properties used in the notional building are set out in the 2010 NCM Modelling Guide.

This approach to target setting has been adopted because the level of improvement that can be reasonably expected varies significantly by building sector, and so a blanket improvement factor would be inequitable. The specification delivers an overall 25 per cent reduction in CO_2 emissions across the new-build mix for the non-dwellings sector. Some buildings will be required to improve by more than 25 per cent, some by less, but all should achieve the required level of improvement at approximately the same cost of carbon mitigation. The TER is no longer based on an improvement factor.

Developers are still given the freedom to vary the specification, provided the same overall level of CO_2 emissions is equalled or bettered.

The target may be attained by improving either the services, or the envelope, or both.

Large extensions to existing buildings, as defined in ADL-2B, use the same procedure.

3.3 ADL-2B

ADL-2B has introduced a new method of calculating the allowable U-value of a curtain wall in smaller extensions. The overall U-value should be no greater than the better of 1.8 W/m^{2}K or a limiting U-value, U_{limit}, given by:

U_{limit} = 0.8 + {(1.2 + (FOL x 0.5)) x GF}

where FOL is the fraction of opening lights and GF is the glazed fraction.

This means that if an area of curtain walling is to be 60 per cent glazed and 40 per cent opaque, with 50 per cent opening lights, the allowable U-value would be:

0.8 + (1.2 + 0.5 x 0.5) x x0.6 = 1.7 W/m^{2}K.

3.4 Quality of construction and commissioning

Buildings should be constructed so that performance is consistent with the calculated Building Emission Rate (BER). As part of this requirement the building fabric should be constructed so that there are no reasonably avoidable thermal bridges in the insulation layers caused by gaps within the various elements, at the joints between elements and at the edges of elements, such as those around a window or door opening.

Thermal bridges should be calculated according to the relevant Standards and guidance. In addition, the builder would have to demonstrate that an appropriate system of site inspection is in place to give confidence that the construction procedures achieve the required consistency. Ways of demonstrating that reasonable provision had been made are:

- To adopt a quality-assured accredited construction details approach in accordance with a scheme approved by the Secretary of State. If such a scheme is utilised then the calculated linear thermal transmittance can be used directly in the BER calculation;

- To use details that have not been subject to independent assessment of the construction method. In this case the linear thermal transmittance should be calculated in the appropriate way, and then the value increased by 0.02 W/mK, or 25 per cent whichever is greater, before being used in the BER calculation;

- To use unaccredited details, with no specific quantification of the thermal bridge values. In such cases the generic linear thermal bridge values as given in IP 1/06 increased by 0.04 W/mK or 50 per cent whichever is the greater must be used in the BER calculation.

3.5 ‘As designed’ and ‘as constructed’ BER

Before work starts on a project a calculation has to be submitted to the building control body (BCB) showing the BER is less than the TER. In addition a list of specifications of the building envelope and fixed building services (internal and external lighting, heating, hot water, air conditioning and mechanical ventilation) used in the calculation of the BER should be submitted.

After work has been completed the BCB must be notified of the TER and BER and whether the building has been constructed according to the submitted specification. Any changes to the design stage specification must be listed so that BCB can establish if the building is compliant with the Regulations.

3.6 Specification

A zone of building envelope is normally defined by general arrangement drawings and performance specification. The alternative of a fully prescriptive specification requires considerable knowledge on the part of the Specifier.

A performance specification has to set requirements that match the values used in the whole building energy model. This is necessary to ensure that the 'as-constructed' building envelope meets the requirements of ADL-2A or ADL-2B. A performance specification must set allowable values for:

- Light transmission of the glass,
- Solar transmission of the glass,
- Overall U-value of the building envelope zone including any interfaces,
- Air leakage rate.

Other aspects of thermal performance to be specified are:

- Conditions under which condensation should not form,
- Worst allowable localised U-values.

The previous practice of specifying that a zone of building envelope is required to 'Comply with Part L of the Building Regulations' is no longer adequate. Use of this simple form of specification, rather than specifying an overall U-value, may lead to one of the following responses from a Specialist Contractor.

1 If no target U-value is provided the Specialist Contractor can either:

   a Supply part of a building envelope in which the component U-values simply meet the limiting U-value standards given in ADL-2A and ADL-2B, presuming that compensating measures are being taken elsewhere in the building envelope's building services, or

   b Apply their own improvement factor to the limiting U-values standards given in ADL-2A and ADL-2B, for example supplying a curtain wall/window that has a 25 per cent better U-value than the limiting value.

Both approaches are likely to lead to a non-compliant building. The second approach may put undue cost into the building envelope and ignore the fact that more economical solutions are possible if the services and envelope are considered together.

A suitable specification for the thermal performance of non-traditional building envelopes is given in CWCT's 'Standard for systemised building envelopes', 2006.

4 CONSTRUCTION

4.1 Introduction

The form of building envelope construction will determine the:

- Areas of glass that can be used,
- Thermal performance achievable,
- Method of calculation of thermal performance.

There are many different forms of non-traditional construction, which may be broadly categorised as follows:

4.2 Window assemblies

Window assemblies, sometimes called composite windows, are constructed as a collection of windows assembled together with joining mullions or coupling bars to form a large glazed frame to fill a large window opening. Windows may be delivered to site as an assembly but are more likely to be assembled at site, particularly for larger assemblies. An assembly of windows has to have a perimeter frame to give it integrity for transportation whereas windows assembled at site can be fixed directly to the surrounding wall without the need for a perimeter frame.

Window assemblies with suitable structural elements can be used as:

- Bay windows,
- Conservatories,
- Ribbon glazing,
- Storey height screens,
- Full height glazing of stairwells.

Assemblies and composite windows comprise simple standard windows. Windows used to form horizontal ribbon glazing, Figure 4.1, may be fixed to the wall at their head and foot so that vertical mullions are required only to close and seal the gaps between adjacent windows. Many window systems include profiles and gaskets specifically for this purpose.

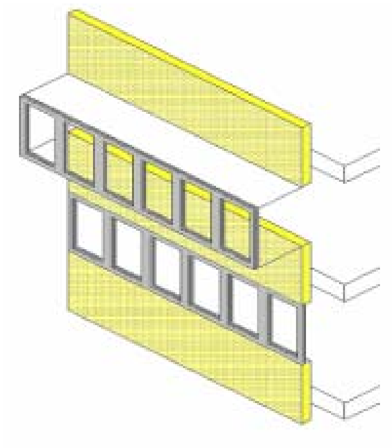


Figure 4.1 Horizontal ribbon glazing

The U-value of a window assembly will depend on the U-values of the individual windows and the U-value of the mullions, transoms or connecting bars. Methods for calculating U-values of window assemblies are given in Section 6.

4.3 Glazing screens

Glazing screens are generally storey height, or near storey height, constructions used either as partitions or as part of the building envelope. The glass may be supported in a frame or may be structurally glazed as bolted glass, fin wall or single spans of glass supported in ceiling and floor rails.

Glazing screens may be used in the building envelope as entrance screens set back from the surface of the wall on upper storeys or they may be used to form the walls of tall buildings, for instance to form a wall when the floor slab projects outside the building to form a balcony.

Framed glazing screens are similar to stick system curtain walling but with a lighter frame. They have distinct frames of greater depth than other components in the screen. Lateral heat flow occurs at the frames and the method for calculating U-values is the same as for stick system curtain walling described in Section 7.

Smaller areas of glazing of storey height or less will have a high perimeter to area ratio. Lateral heat flow at the perimeter of the glazing screen will be more significant than for larger areas of glazing, particular where a floor slab, balcony or internal partition wall projects through the building envelope.

Perimeter ψ-values will normally have to be calculated on a project-by-project basis to account for the surrounding components.

4.4 Display windows

Glazing screens and window assemblies may be used for the purposes of displaying goods. Display windows are often glazed with single glazing with U-values far higher than those achievable by insulated glazing units.

ADL-2A defines a display window as glazing within three metres of floor level, adjacent to a pedestrian thoroughfare and with no permanent workstation closer to it than the glazing height. Taller display windows are allowed where:

- The goods on display require a taller window.
- Planning consent is dependent on a taller window being used (for instance to match adjacent buildings).
- The window is part of an existing building.

4.5 Stick curtain walling

Stick curtain walling normally comprises vertical structural framing members, mullions, that span from floor to floor, Figure 4.2. The structural frame of the curtain wall may be in the plane of the glass and infill panels, in which case the glazing and infill are rebated into the frames and sealed to them. Alternatively, the structural frame may support the glazing and panels but lie in a plane behind the panels, which can then be sealed directly one to another. In the latter case, the glass is typically supported by a structural silicone perimeter joint or bolted connections.

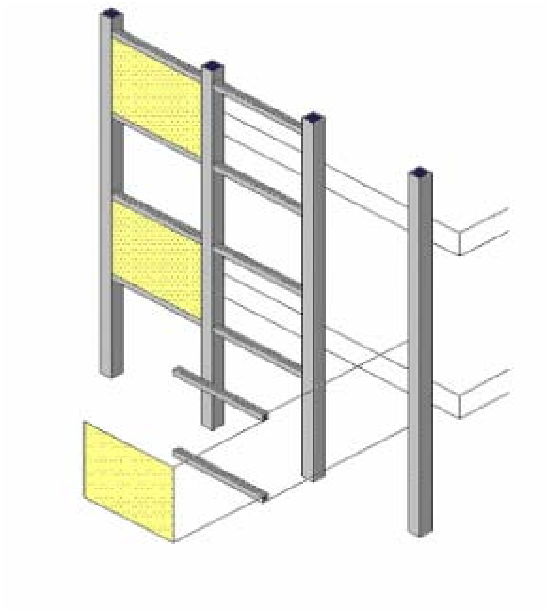


Figure 4.2 Typical stick curtain walling frame

Occasionally stick curtain walling is constructed with continuous transoms spanning horizontally rather than continuous mullions.

The method for estimating and calculating the U-value of a stick curtain wall is given in Section 7.

4.6 Unitised curtain walling

Unitised curtain walling comprises prefabricated elements of width equal to one, or occasionally two, glazing bays, Figure 4.3. They are normally one storey high, although examples of two storey units exist. They are installed on the building by fixing them to the edges of the floor slabs as for a stick curtain walling.

The horizontal construction joint between units may be at floor level to give one complete unit for each storey but it can be easier to put the horizontal joints at the cill or head of the glazing area so that a single opaque infill panel is used between the head of one window and the cill of the next.

The method for calculating U-values for unitised curtain walling is given in Section 8.

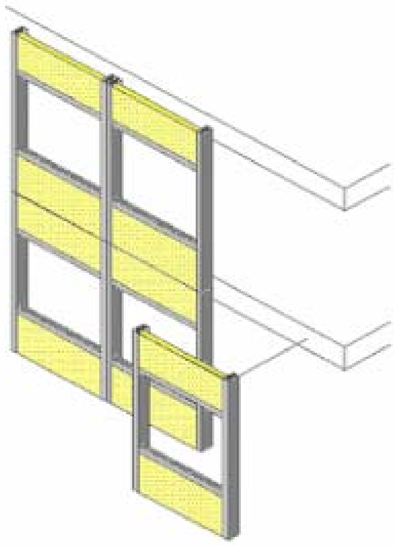


Figure 4.3 Typical unitised wall

4.7 Insulated panel wall

Insulated panels may be used to construct integral self-supporting walls, Figure 4.4. Integral panels have doors and windows incorporated into them that lie in the plane of the panels to create a whole façade.

Panels may be fabricated as storey height units with windows and doors included. These are similar to unitised curtain walling except that there is no distinct frame. Instead the insulated panel acts structurally spanning from floor to floor, or more normally bearing on vertical framing members. Alternatively, a modular approach may be adopted in which windows and panels are brought together separately and assembled at site on to a supporting frame.

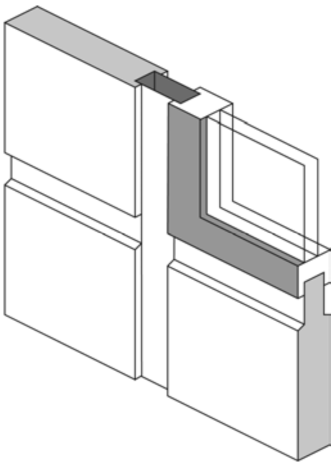
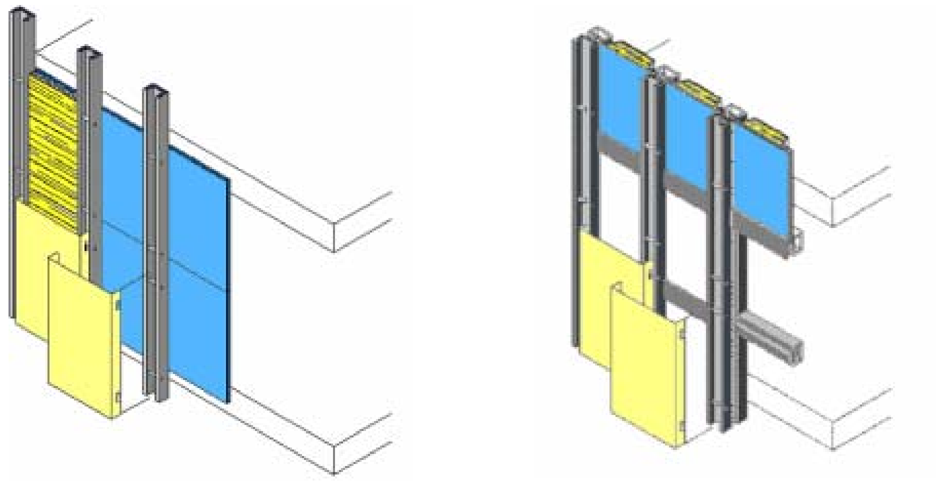


Figure 4.4 Integral insulated panel wall

The method for calculating U-values for an insulated panel wall is given in Section 9.

4.8 Integral rainscreen walling

Rainscreen walls can be constructed as integral walls in which the structural elements are mullions spanning between floor slabs to which the outer rainscreen and inner layers of the wall are attached, Figure 4.5. There are two distinct approaches to the construction of integral walls.



Internal lining Cassette panels

Figure 4.5 Integral rainscreen walling

The inner wall may be constructed from sheets attached to the back of the mullions to form an air barrier. Insulation is then placed between and around the mullions before a rainscreen outer layer is fixed in place using a system of support rails that allow fine adjustment of the panels.

Alternatively, the function of the inner wall may be achieved by the use of cassette infill panels. Cassette panels are installed in the plane of the mullions and stick curtain wall mullions may be used. This method of construction means that opening lights or fixed windows can also be installed into the mullions and sealed to the cassettes, with or with out intermediate transoms.

The method for calculating U-values for an integral rainscreen wall is given in Section 8.

4.9 Rainscreen overcladding

Rainscreen walls can be created by overcladding an existing building envelope or as new-build by overcladding new blockwork walls, Figure 4.6. Support rails are attached to the back wall, which acts as the structural element of the wall. The support rails commonly used include simple timber battens, cold-formed steel profiles and extruded aluminium profiles. For anything but the lowest quality work a metal framing system is used, incorporating brackets and fixings that allow for fine adjustment of position.

The method for calculating U-values for rainscreen overcladding systems is given in Section 8.

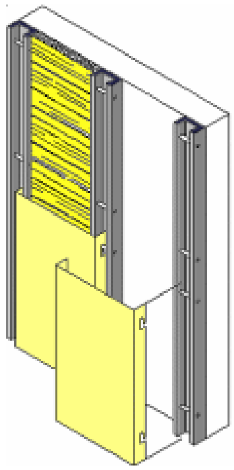


Figure 4.6 Rainscreen overcladding

5 GLAZING PERFORMANCE

5.1 Centre pane U-values for glazing units

U-values of glazing should be determined by:

- Calculation to BS EN 673;
- Guarded hot plate measurements to BS EN 674;
- Heat flow metering to BS EN 675.

Centre pane U-values are a measure of the one-dimensional heat flow at the centre of the pane and do not include additional heat losses associated with the edge-seal and frame. They should only be used with ψ-values appropriate to the edge and frame details.

Centre pane U-values and g-values (total solar transmittance) for some common glazing configurations are given in Table 5.1.

Type	Construction	Air filled	90% Argon filled	Typical g-value
Uncoated (ε_c=0.837)	4-16-4	2.69	2.56	0.76
	6-16-6	2.66	2.54	0.72
	10-16-6	2.64	2.51	0.67
	4-20-4	2.66	2.57	0.76
	6-20-6	2.63	2.54	0.72
	6.4-16-6	2.65	2.52	0.69
	8.8-16-6	2.62	2.50	0.65
One pane hard coated (ε_c=0.168)	4-16-4	1.68	1.49	0.72
	6-16-6	1.67	1.48	0.68
	10-16-6	1.66	1.47	0.63
	4-20-4	1.70	1.51	0.72
	6-20-6	1.69	1.50	0.68
	6.4-16-6	1.66	1.48	0.65
	8.8-16-6	1.65	1.47	0.61
One pane soft coated (ε_c=0.048)	4-16-4	1.40	1.18	0.63
	6-16-6	1.39	1.17	0.61
	10-16-6	1.38	1.16	0.57
	4-20-4	1.42	1.20	0.63
	6-20-6	1.41	1.19	0.61
	6.4-16-6	1.38	1.17	0.58
	8.8-16-6	1.37	1.16	0.56

(ε_c is the corrected emissivity).

Table 5.1 Centre pane U-values ($W/m^2/K$) and g-values

5.2 Specification of glass transmission properties

The relevant glass transmission properties are:

- Total solar energy transmittance (g-value);
- Visible light transmission.

The amount of solar energy and visible light transmitted into the building will depend not only on the properties of the glazing but also any shading devices fitted above or in front of the glass. Effective transmission properties are often used which include the effect of any shading devices.

The transmission properties of the glass alone should be calculated according to BS EN 410.

5.3 Shading devices

The design of shading devices and methods for calculating the effects of shading devices are described by Littlefair in 'Summertime solar performance of windows with shading devices', and in CIBSE TM37, 'Design for improved solar shading control'.

6 WINDOW ASSEMBLIES

6.1 Introduction

The U-value of a window assembly may be greater or less than the U-values of the individual windows depending on whether the mullions, transoms and connecting bars have a higher or lower U-value than the windows.

Note that the depth of mullions, transoms and connecting bars is determined mainly by the size of window assembly and wind load.

6.2 Method A

This method applies if the mullions, transoms or connecting bars do not project significantly beyond the surfaces of the windows and are of similar construction in terms of materials, thermal breaks and position of thermal break. It is often necessary for the mullion, transom or connecting bar to be deeper than the window frame to allow for coupling and sealing. This method may be used provided no connecting framing member has depth greater than 120 per cent of the window frame depth.

It can be assumed that lateral heat flow that occurs between the window frames and connecting bars can be neglected, and that the U-value of the assembly is:

$$A_{assembly}U_{assembly} = \sum_{assembly} A_w U_w + \sum_{assembly} A_{cb} U_{cb}$$

Where suffix wi refers to the windows and suffix cb to the connecting bars.

Methods of calculating U-values of windows and frames are given in BS EN ISO 10077-2.

6.3 Method B

If the conditions of Method A do not apply it is necessary to assume that lateral heat flow between the window frames and the connecting bars cannot be neglected. The U-value of the assembly may be:

- Determined by two-dimensional simulation,
- Calculated using the U-values of the separate components (including connecting members) and appropriate ψ-values.

$$A_{assembly}U_{assembly} = \sum_{assembly} A_w U_w + \sum_{assembly} A_{cb} U_{cb} + \sum_{assembly} P_{cb}\,\psi_{cb}$$

Note that the ψ-values are applied to the total perimeter of the windows, or to both edges of the connecting members. Methods of calculating U-values of windows and frames are given in BS EN ISO 10077-2.

Method B is similar to that described in detail for stick system curtain walling. Note, however, that the U-values of mullions and the associated ψ-values may differ from those normally associated with stick system curtain walling.

7 STICK CURTAIN WALLING

7.1 Factors affecting U-values

The U-value of a stick system curtain wall depends on:

- Centre pane U-value of glass,
- Area of glass,
- Mullion spacing,
- Framing U-values,
- Centre panel U-values of infill panels,
- Lateral heat flows.

Note that framing U-values, U-values of infill panels and lateral heat flow have a lesser effect and are not necessarily considered at the early design stage. All of the examples given in this document assume the use of thermally broken aluminium frames. Projected frame depths are assumed to lie in the range 80–120 mm and polyamide thermal breaks are assumed with a minimum separation of 15 mm. Deeper profiles will lead to slightly higher U-values.

7.2 Glazed area

The area of glass in a stick system curtain wall has the greatest influence on the overall U-value of a wall. This effect is shown in Figure 7.1, which is based on a typical thermally broken framing system and mullion spacing of 1500 mm. Doubling the glazed area from 30 per cent to 60 per cent may increase the U-value by 40 per cent from 1.20 W/m^{2}K to 1.65 W/m^{2}K. This effect is locked into the design at the architectural planning stage.

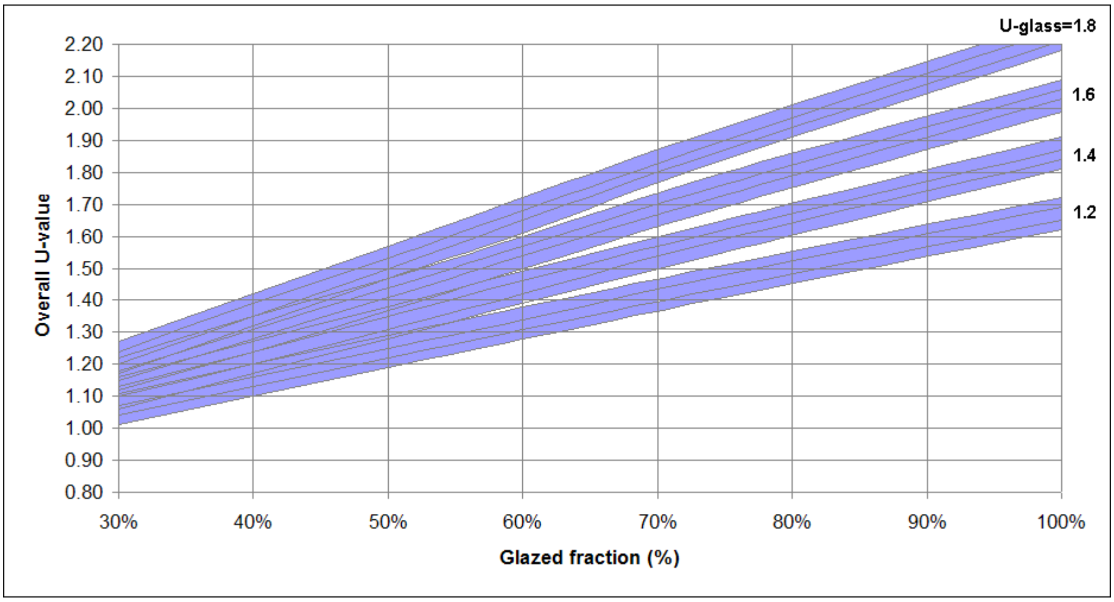


Figure 7.1 Effect of glazing area on overall U-value (U-values in W/m^{2}K)

7.3 Effect of centre pane U-value of glass

Centre pane U-values of IGUs vary from greater than 2.8 W/m^{2}K to less than 1.1 W/m^{2}K. The choice of glass has the second greatest effect on the U-value of a stick system curtain wall as shown in Figure 7.1. The choice of glass can typically make a difference of 30 per cent to the overall U-value of a stick system curtain wall. Centre pane U-values of different glass configurations are given in Section 6.

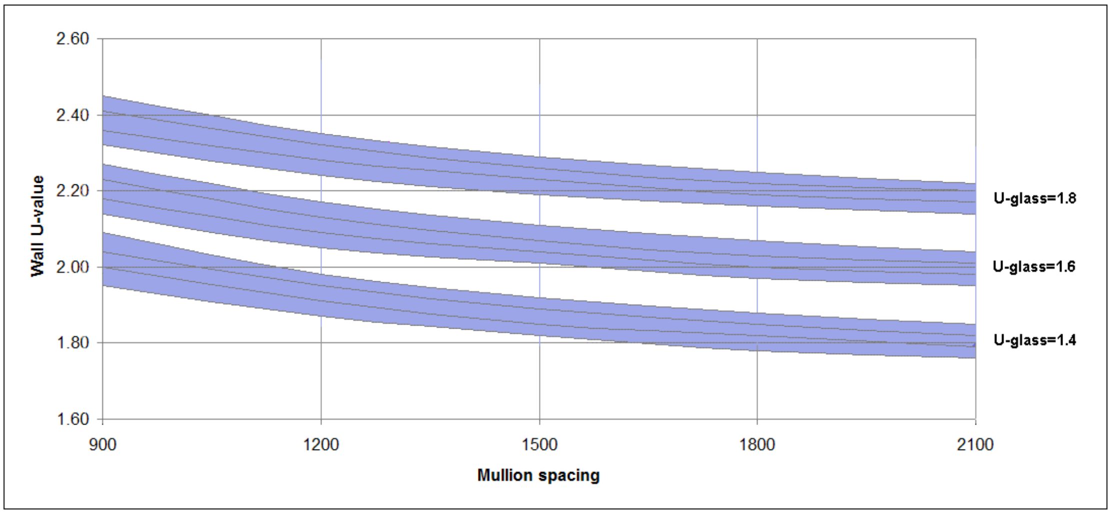


Figure 7.2 **Effect of glass type and mullion spacing on overall U-value of fully glazed wall (U-values in W/m^{2}K)**

7.4 Effect of mullion spacing

Increasing the spacing of mullions in a stick system curtain wall will lead to a lower overall U-value for the wall, Figure 7.2. This can make a difference of ten to fifteen per cent to the overall U-value for a fully glazed wall. The effect is more pronounced for a wall with a lower overall U-value. Note that whilst there are clear disadvantages to using mullion spacing below 1200 mm not all proprietary systems can be used at mullion spacing greater than 1500 mm for structural reasons.

7.5 Effect of transoms

Transoms are normally used at the horizontal interfaces between glazing and between glazing and opaque panels. This generally requires two transoms in each storey height of wall. Use of additional transoms will lead to higher overall U-values for the wall.

7.6 Estimating U-values

Appendix A gives a simplified method for estimating the achievable U-values of different wall configurations at the preliminary design stage. Note that this is not a substitute for accurate calculation when designing the building envelope in detail or verifying U-values for building control purposes.

7.7 Calculation of U-values

The overall U-value of a stick system curtain wall may be calculated using the weighted method given in Section 2:

$$A_{zone}U_{zone} = \sum_{zone} A_f U_f + \sum_{zone} A_g U_g + \sum_{zone} A_p U_p + \sum_{zone} P_g \psi_g + \sum_{zone} P_p \psi_p$$

Where:

U_f is the U-value of the curtain wall frame (excluding the edge effect),
ψ is the linear thermal transmittance at the junction between the frame and panel/glazing unit.

A worked example is given in Appendix B.

7.8 Calculation of component U-values

Mullions and transoms
U-values of curtain wall framing members should be calculated using the methodology given in BS EN ISO 10077-2.

Glazing
Centre pane U-values of glazing units should be calculated using the methodology, properties and other parameters given in BS EN 673, BS EN 674 or BS EN 675.

Infill panels
Centre panel U-values of infill panels should be calculated using the methods, properties and other parameters given in BS EN ISO 6946.

7.9 Standard ψ-values

The standard ψ-values given below differ from the ψ-values given in BS EN 13947. They are representative of the better curtain wall profiles available in the UK and are based on a report by Liao (2004). They assume that the curtain wall framing profiles are thermally broken aluminium profiles with polyamide thermal breaks giving a minimum aluminium separation of 15 mm and thermally improved pressure plates. The improved pressure plates comprise either fibre reinforced plastic profiles or aluminium profiles with butyl tape separators.

Glazing to frame
For a glazing unit glazed directly into a curtain walling transom or mullion the ψ-value may be assumed to be 0.11 W/mK or calculated in accordance with BS EN 13947.

Panel to frame
For insulated infill panels fixed directly into the glazing rebate of a mullion or transom the ψ-value may be assumed to be 0.09 W/mK provided there is no bridging of the panel insulation at the panel edge. Alternatively the ψ-value may be calculated in accordance with BS EN 13947.

7.10 Opening lights within curtain walling

Opening lights may be regarded as complex infill panels. The frame U-value of the opening light is calculated in accordance with BS EN ISO 10077-2 to include both opening and fixed frames, glazing, the ψ-value for the perimeter of the glazing and the ψ-value for the perimeter of the opening light frame, ψ_{wi}.

This U-value may be included in the overall U-value using the weighted method provided an appropriate ψ-value is used for the interface between the frame of the opening light and the mullions and transoms.

$$A_{zone}U_{zone} = \sum_{zone} A_f U_f + \sum_{zone} A_g U_g + \sum_{zone} A_p U_p + \sum_{zone} P_g \psi_g + \sum_{zone} P_p \psi_p + \sum_{zone} A_w U_w + \sum_{zone} P_{wi} \psi_{wi}$$

The ψ-value for the insert frame to the mullion or transom may be taken as ψ_{wi} = 0.09 W/mK if there are similar opening lights either side of the mullion or transom, or 0.22 W/mK if there is an opening light on only one side of the mullion or transom (note that ψ_g = 0.11 has also to be included in the calculation). Alternatively it should be calculated as described in Appendix C.

7.11 Penetrations through the wall

Curtain walls may be penetrated by brackets for brise soleil, signage, aerials, light fittings and so forth. Vents, ducts and service pipes may form penetrations through insulated infill panels.

Connections that breach the thermal break of a mullion or transom will form a significant localised thermal bridge. A χ-value for this localised thermal bridge should be calculated and used.

Penetrations through infill panels will form a significant thermal bridge. A χ-value for this localised thermal bridge should be calculated and used.

7.12 Structural sealant glazing systems

In structural sealant glazing systems the glazing is bonded to the frame, which is shielded from the external environment by the glazing. This reduces the thermal bridging effect of the framing members and structural sealant glazed curtain walls may be expected to have lower U-values than equivalent walls with rebated glazing.

Frame U-values and ψ-values for framing members can be calculated using the procedures described in Appendix B. Note that the calculated values may be heavily influenced by the value assumed for thermal conductivity of the sealant and the shape of the carrier frame to which the glazing is bonded.

7.13 Point supported glazing

Point supported glazing (‘Planar’) has no framing members penetrating the plane of the glazing and may be expected to have lower U-values than similar glazing supported by a frame. However, the bolted connections will form localised thermal bridges for which χ-values must be calculated. If insulated glazing units are used the glazing edge seals will form linear thermal bridges for which ψ-values must be calculated.

7.14 Stick curtain walling with rainscreen panels

Approach

Rainscreen panels are used with stick curtain walling to create integral rainscreen walls. Panels with an air cavity behind them must be excluded from U-value calculations according to BS EN ISO 6946. The U-value may then be calculated on the basis of the remaining framing components, glazing, opening lights and insulating panels. However, the external surface resistance is taken as $R_{se} = 0.13$ W/m^{2}K for cold surfaces protected by the rainscreen panels.

Note that any insulation in the cavity behind the rainscreen may be taken into account when calculating U-values. However, any framing members embedded in the insulation, or other narrowing of the insulation, should be treated as linear thermal bridges for which an appropriate ψ-value should be calculated and used. Similarly, any brackets passing through the insulation will form a localised thermal bridge for which an appropriate χ-value should be calculated and used.

Effect on the framing system

Rainscreen brackets or fixings that penetrate the thermal break of a mullion or transom will form a significant thermal bridge. A χ-value for this localised thermal bridge should be calculated and used.

8 UNITISED CURTAIN WALL

8.1 Factors affecting U-values

The U-value of a unitised curtain wall depends on:

- Centre pane U-value of glass,
- Area of glass,
- Mullion spacing,
- Framing U-values,
- Centre panel U-values of infill panels,
- Lateral heat flows.

Note that framing U-values, U-values of infill panels and lateral heat flow have a lesser effect and are not necessarily considered at the early design stage.

The effect of glazing U-value, glazing area and mullion spacing are described in Section 7.

8.2 Estimating U-values of unitised curtain walling

Unitised walls use wider mullions than stick system curtain walls. They are thermally broken in the same way and generally have a lower U-value but due to their greater width they may have greater heat flow than stick system mullions.

When making a preliminary estimate of the overall U-value of a unitised wall the method set out in Appendix A may be used but U-values of unitised walls are typically five per cent less than those expected for stick system curtain walls.

8.3 Calculating U-values of unitised curtain walling

U-values of unitised curtain wall framing members should be calculated using the methodology given in BS EN 13947.

If the frames and infill are symmetrical across a unit joint there will be no lateral heat flow and the unit joint is an adiabatic surface. Therefore the wall can be divided into units and a U-value calculated for each from:

$$U_{unit}A_{unit} = \sum_{unit} U_g A_g + \sum_{unit} U_{sp} A_{sp} + \sum_{unit} U_p A_p + \sum_{unit} P\psi + \sum_{unit} \chi$$

The U-value of a zone of wall is then given by:

$$U_{zone}A_{zone} = \sum_{zone} U_{unit} A_{unit}$$

8.4 Opening lights

Opening lights included within a unitised curtain wall are treated in the same way as opening lights in stick curtain walling as described in Section 7 and Appendix B.

8.5 Penetrations through units

Any penetrations should be treated as for stick curtain walling, see Clause 7.11

8.6 Rainscreen panels

Any rainscreen panels attached to the unit should be treated as for those on stick curtain walling, see Clause 7.14

9 INSULATED PANEL WALL

9.1 Factors affecting U-values

The U-value of an insulated panel wall depends on:

- Centre panel U-value of an insulated panel (excluding windows),
- Area of windows,
- U-values of windows,
- Lateral heat flows at panel edges,
- Lateral heat flows at window frames,
- Panel size.

Note that the U-values of the panel and glass and the proportion of the wall that is glazed have the most significant effect on the overall U-value for most insulated panel systems.

Additionally the area of glazing and the transmission properties of the glass will impact on carbon dioxide emissions from the building.

9.2 Edge of panel

For panels supported by a framing member that passes through the wall a U-value for the frame should be calculated in the same way that U-values are calculated for curtain walling mullions, Section 7.

If the panels meet without an intervening framing member there is an edge profile embedded within the panel to facilitate jointing. This will lead to increased heat flow at the panel edge. This effect may be included in U-value calculations by calculating an appropriate ψ-value in accordance with BS EN ISO 10211.

The overall U-value of a wall constructed solely of insulated panels is then given by:

$$A_{zone}U_{zone} = \sum_{zone} A_p U_p + \sum_{zone} P_p \psi_p$$

Where ψ_p is the linear thermal transmittance at the edge of the panel.

9.3 Inclusion of windows

Window U-values should be calculated in accordance with BS EN ISO 10077-1-1 and BS EN ISO 10077-2. Windows are fitted into insulated panels using edge profiles that mate with the edge of the insulated panel. These form a sub-frame into which the window is installed. Overall U-value calculations should include the U-value of the mating profiles. A ψ-value should be calculated to account for lateral heat flow at the interface between the panel and window.

The overall U-value of a wall is then given by:

$$A_{zone}U_{zone} = \sum_{zone} A_p U_p + \sum_{zone} A_w U_w + \sum_{zone} A_f U_f + \sum_{zone} P_f \psi_f + \sum_{zone} P_p \psi_p$$

Where:

ψ_f is the linear thermal transmittance of the sub-frame to the edge of the panel,
U_f is the U-value of the sub-frame.

10 RAINSCREEN

10.1 Construction effects

Rainscreen construction comprises an outer layer of panels and an air cavity to provide weather protection to other components of the wall. Rainscreen may be part of a stick, unitised or panellised wall or may be supported from a blockwork support wall. The air cavity is drained to the outer face and thus ventilated.

The temperature of the air in the cavity behind a rainscreen is the same as the external environmental temperature and so the rainscreen panels make no contribution to the thermal resistance of the wall.

Thermal resistance of a rainscreen construction depends solely on the inner components of the wall; insulation, support rails, support wall, and possible the fit-out. Rainscreen walls generally comprise opaque areas and punched-out windows. The resistance of the whole wall will depend on:

- Area of windows,
- U-value of windows,
- U-value of opaque wall,
- Edge effects (linear thermal bridging) at the window perimeters.

Additionally the area of glazing and transmission properties of the glass will impact on carbon dioxide emissions from the building.

10.2 Rainscreen overcladding

The U-value of the wall may be improved by:

- Maintaining the thickness of insulation behind the support rails;
- Increasing the thickness of the insulation;
- Improving the intrinsic insulation of the support wall;
- Increasing the distance between support rails;
- Thermally breaking or isolating the brackets;
- Increasing the distance between support rail brackets.

These are listed in the general order of their effectiveness:

Maintaining the thickness of insulation behind the support rails
Embedding the support rails within the insulation reduces the insulation thickness locally and increases the U-value.

Increasing the thickness of the insulation
This should not reduce the width of the ventilation and drainage cavity and longer/heavier support brackets will be required for greater thicknesses of insulation.

Improving the intrinsic insulation of the support wall
For blockwork walls lightweight insulating blocks may be used. Timber stud construction may be used instead of metal mullions but other aspects of the walls performance may be impaired. The framing members used in stick or stud construction will form linear thermal bridge. Increasing the distance between framing members will reduce the overall U-value of the wall.

Increasing the distance between support rails
Support rails attached to the face of a blockwork wall will act as a linear thermal bridge the effect of which may be magnified by a local thinning of the insulation.

Increasing the distance between support rails will reduce the overall U-value of the wall. However, the distance between support rails will depend on the ability of the rainscreen panels to span between them.

Increasing the distance between the support rails also reduces the number of brackets acting as localised thermal bridges.

Thermally breaking or isolating the brackets
Support rail brackets penetrate the insulation layer and act as localised thermal bridges. Furthermore, fixings into the support wall will act as localised thermal bridges within the support wall.

Isolating metal brackets from the support wall with a structural plastic spacer will reduce heat transfer through the bracket and reduce U-values.

Reducing the distance between support rail brackets
Increasing the distance between support rails and the spacing of brackets along each rail will reduce the number of thermal bridges and give lower overall U-values. However, heavier profiles may be required as support rails to span the greater distances.

10.3 Calculating U-values of rainscreen overcladding

Uniform insulation
If the support wall and insulation in a rainscreen construction are each of constant thickness and homogenous behind the support rails then only the brackets will form a thermal bridge through the insulation. The overall U-value of the rainscreen can be calculated by calculating the one-dimensional heat flow through the support wall and insulation, $U_{background}$, and adding to this the χ-value of the brackets and their fixings.

χ-values and U-values should be calculated as shown in Appendix D. The actual χ-value will depend on:

- Whether the bracket is thermally broken or isolated from the support wall,
- The size of the bracket,
- The material from which it is made.

For metallic brackets that are not thermally broken or separated χ-values typically lie in the range $0.20 < \chi < 0.4$ w/k. For metallic brackets that are isolated from the support wall by an insulating spacer χ-values typically lie in the range $0.05 < \chi < 0.15$ w/k. Lower values may be possible for non-metallic or thermally broken brackets.

The overall U-value of the opaque part of the rainscreen wall is then:

$$A_{zone}U_{zone} = \sum_{zone} A_{background}U_{background} + \sum_{zone} \chi$$

For a uniform support wall, $U_{background}$ can be calculated from the thermal conductivities and thicknesses of the layers, from:

$$R = \sum \frac{t}{\lambda} + R_{si} + R_{se}^{*}$$

and

$$U_{background} = \frac{1}{R}$$

For a support wall comprising 150 mm thickness of medium density blockwork with λ=1.35 W/mK and 150 mm thickness of insulation with λ=0.035 W/mK the background U-value is 0.215 W/m^{2}K.

Non-uniform insulation

If the insulation is thinner on the line of the support rail then it is necessary to calculate a virtual frame U-value in accordance with BS EN ISO 10077-2 or a ψ-value, as defined in BS EN ISO 10211, as well as the χ-value for the brackets. The insulation may be thinner at the support rail because it is embedded in the insulation or simply because an air gap is left behind the support rail.

The virtual frame U-value depends more on the thickness of insulation behind the support rail than on the shape and size of the rail. There is generally no benefit in thermally breaking the rail.

The virtual frame U-value will lie in a range from that of the more thickly insulated wall to that of the more thinly insulated wall.

The overall U-value of the opaque part of the rainscreen wall is then:

$$A_{zone}U_{zone} = \sum_{zone} A_{background}U_{background} + \sum_{zone} A_f U_f + \sum_{zone} \chi$$

or

$$A_{zone}U_{zone} = \sum_{zone} A_{background}U_{background} + \sum_{zone} L\psi + \sum_{zone} \chi$$

Where L is the length of the framing member.

10.4 Other applications of rainscreen panels

Rainscreen panels supported by stick, unitised or panellised walls are omitted from the envelope when calculating U-values as described above but the brackets have to be included as localised thermal bridges. Appendix D describes how three-dimensional simulation may be used to calculate the heat transfer through a bracket.

11 INTERNAL FIT-OUT OF THE WALL

11.1 Effect of fit-out on thermal performance

The internal fit-out, internal panels and finishes will affect the thermal performance of the wall in terms of:

- Heat transfer (U-value),
- Condensation risk.

The effect of the fit-out may be ignored when calculating overall envelope U-values but should never be ignored when performing a condensation risk assessment.

11.2 U-values of walls with internal fit-out

The fit-out is the ‘inner layer’ of the wall and for a well-insulated wall will have little effect on overall U-value. In a layered construction the U-value is governed by a dominant insulating layer and the fit-out has to have a similar thermal resistance to that of the external construction if it is to have a significant effect on the overall U-value.

Note also that the internal fit out will only modify the U-value of the opaque parts of a curtain wall in which the overall U-value is dominated by the glazing U-values.

If the fit-out isolates thermal bridges through the external construction from the internal environment it will have a greater effect on overall U-values. This may occur where the fit-out shields curtain wall mullions within the opaque part of the wall. Note, however, that lateral heat transfer will occur along the mullion past, say, a window board. Heat flow through this form of construction can only really be assessed using three-dimensional analysis.

11.3 Condensation risk

If the cavity between the external construction and the fit out is sealed from the internal environment then the cavity will be cooler then the room and either:

- A vapour control layer should be incorporated within the fit out, on the warm side of the cavity, or

- A condensation risk analysis should be performed.

12 SLOPE GLAZING

12.1 Factors affecting U-values

Thermally, slope glazing is similar to stick curtain walling but the U-values of components will differ, particularly the U-values of the glass.

The U-value of a slope glazing system depends on:

- Centre pane U-value of glass,
- Area of glass,
- Frame spacing,
- Framing U-values,
- Lateral heat flows.

Slope glazing is conventionally fully glazed with any opaque surrounding areas classified as roof. The overall U-value cannot therefore be modified by substituting opaque panels for some of the glazing units.

Many volumes enclosed by slope glazing are not fully conditioned spaces and their temperatures are allowed to vary, to some extent, with the external temperature changes. This may place a less onerous requirement on the thermal properties of the slope glazing. Methods of considering spaces that are not fully conditioned are given in ADL-2A.

12.2 Shading devices

Slope glazing is more nearly orthogonal to the suns rays and solar transmission through slope glazing is greater than that through similar glazing mounted in a vertical plane. For this reason coated glasses and shading devices have a greater effect on energy use and carbon dioxide emissions when used as part of slope glazing.

12.3 Effect of slope

The U-value of a slope glazing system is dependent on the slope of the glazing with higher U-values (greater heat transfer) associated with horizontal glazing than vertical glazing.

Centre pane U-values for glazing are given in Table 12.1 to illustrate this effect.

Glazing type	90^o	75^o	60^o	45^o	30^o	15^o	0^o
4-16-4 Ordinary (ε_c = 0.837)	2.69	2.78	2.83	3.14	3.20	3.24	3.27
4-16-4 Hard low-e (ε_c = 0.168)	1.68	1.90	2.00	2.28	2.28	2.75	2.40
4-16-4 Soft low-e (ε_c = 0.048)	1.40	1.65	1.76	1.92	2.03	2.11	2.17
4-16-4 Soft low-e and 90% argon filled (ε_c = 0.048)	1.18	1.39	1.49	1.60	1.70	1.76	1.81

Table 12.1 Centre pane U-values (W/m^{2}K) of sloping glazing
(Slope angles measured from horizontal)

U-values of glazing units vary with slope because of increased heat transfer by convection within the glazing cavity and the change in internal surface resistance. Manufacturers' stated U-values should be assumed to apply to vertical glazing unless a slope angle is given. (ADL-2A and ADL-2B allow the U-value for vertical orientation to be used when considering limiting U-values of components.)

U-values of the glass and framing members will vary with slope as a result of convection below and above the slope glazing. This has the effect of modifying the surface resistances used when calculating U-values. Surface resistances for sloping surfaces are given in Table 12.2.

Orientation	R_{si} unsheltered (m^2K/W)	R_{si} sheltered (m^2K/W)	R_{se} (m^2K/W)
Ceiling	0.10	0.13	0.04
Wall	0.13	0.20	0.04
Floor	0.17	0.31	0.04

Table 12.2 Surface resistance for sloping surfaces based on BS EN ISO 6946.

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APPENDIX A ESTIMATING U-VALUES OF STICK SYSTEM CURTAIN WALLS

Preliminary estimation of U-values for curtain walling

This Appendix allows building designers to estimate the U-value of a stick curtain wall at an early stage in building design. The U-value of a stick curtain wall depends on:

- The geometry of the wall:
  - Proportion of the wall that is glazed,
  - Mullion spacing.
- The U-values of separate components.
- Heat transfer between components (ψ-values).

The following procedure allows the designer to vary the geometry and glass properties, to include opening lights rather than fixed lights and to replace fixed lights with opaque insulated panels.

Unitised curtain walls will respond in the same way to design changes but may have slightly different U-values from those predicted for stick curtain walls.

It is assumed that the curtain wall comprises a spandrel zone of insulated panels and a glazing zone, which may contain a combination of fixed lights, openable lights or insulated panels. Each storey height contains two transoms, one at the head and one at the foot of the glazed zone.

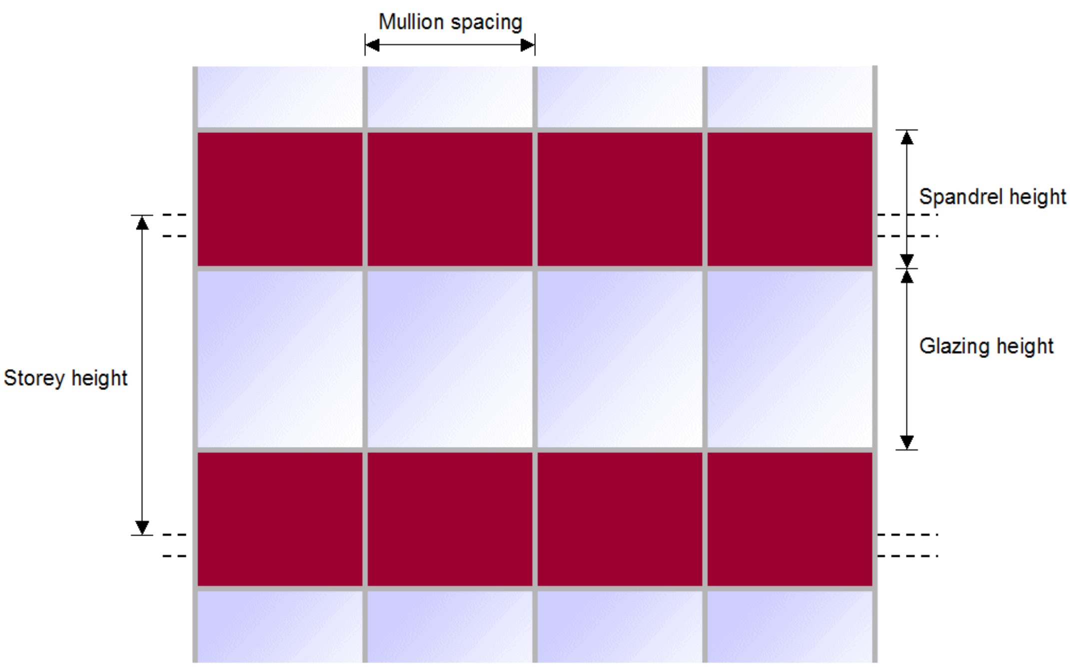

Figure A1 Stick curtain walling

The glazed fraction used in the look-up charts refers to a fully-glazed zone and is defined as:

Glazed fraction = Glazing height/storey height

The glazing height and mullion spacing are measured between the centre lines of the transoms and mullions respectively, Figure A1.

Estimation procedure

Figures A2a, A3a and A4a show the U-values with different glazed fractions and with glazing of different U-values. It is initially assumed that the glazing zone is glazed with all-fixed-lights (glazing units installed into the glazing rebate of the mullions and transoms). The dominant factors affecting the overall U-value of the wall are the fraction of glazing and the mullion spacing.

The U-value of the framing system has a secondary effect giving a range of U-values for any single combination of glass type and mullion spacing. The deep blue bands of Figures A2a, A3a and A4a relate to mullion U-values in the range 3.0 - 3.5 W/m^{2}K, which are typical values. The light blue bands relate to outlying mullion U-values in the ranges 2.5 - 3.0 W/m^{2}K and 3.5 - 4.0 W/m^{2}K.

Figures A2b, A3b and A4b show the effect on the overall U-value of replacing some of the fixed lights with openable lights. The U-value correction has to be added to the U-value calculated for all fixed lights. The dominant factor affecting the increase in U-value is the number of openable lights introduced into the glazing zone.

The U-value of the opening light frames (fixed and movable combined) has a secondary effect giving a range of U-values for each proportion of openable lights. The deep blue bands of Figures A2b, A3b and A4b relate to opening light frame U-values in the range 3.1 – 3.4 W/m^{2}K, which are typical. The light blue bands relate to outlying U-values of 2.8 – 3.1 W/m^{2}K and 3.4 – 3.8 W/m^{2}K.

Figures A2b, A3b and A4b assume that the glazing has a centre pane U-value of 1.6 W/m^{2}K. When a higher performance glazing is being used the U-value corrections will be higher. For a glass U-value of 1.2 W/m^{2}K they may be up to 0.05 W/m^{2}K greater if all lights are openable and up to 0.02 W/m^{2}K if one in two or one in three lights are openable.

Note that the need for opening lights will depend on the need for ventilation for fresh air and ventilation for cooling in a naturally-ventilated building.

The U-value of the curtain wall can be reduced by replacing some of the fixed lights with insulated panels. Note that this will impact on natural light levels within the building and may increase the amount of energy used for artificial lighting. The dominant factor affecting the overall U-value of the wall is the proportion of fixed lights replaced with insulated panels. The U-value corrections of Figure A5 should be added to the overall U-value of the wall with all-fixed-lights.

A secondary effect is the relative U-values of the glazing and insulated panels. For each ratio of insulated panels to fixed lights a range of U-value improvements are shown. The three lines in each case relate to values of (U_g – U_p) of 1.1, 1.3 and 1.5 W/m^{2}K.

Changing the U-values of the insulated panels in the spandrel zone has a small effect on overall the U-value. Figure A6 shows the correction to be added for panels with U-value different from 0.3 W/m^{2}K. This correction may be applied irrespective of mullion spacing.

Estimating U-values – mullion spacing 1200 mm

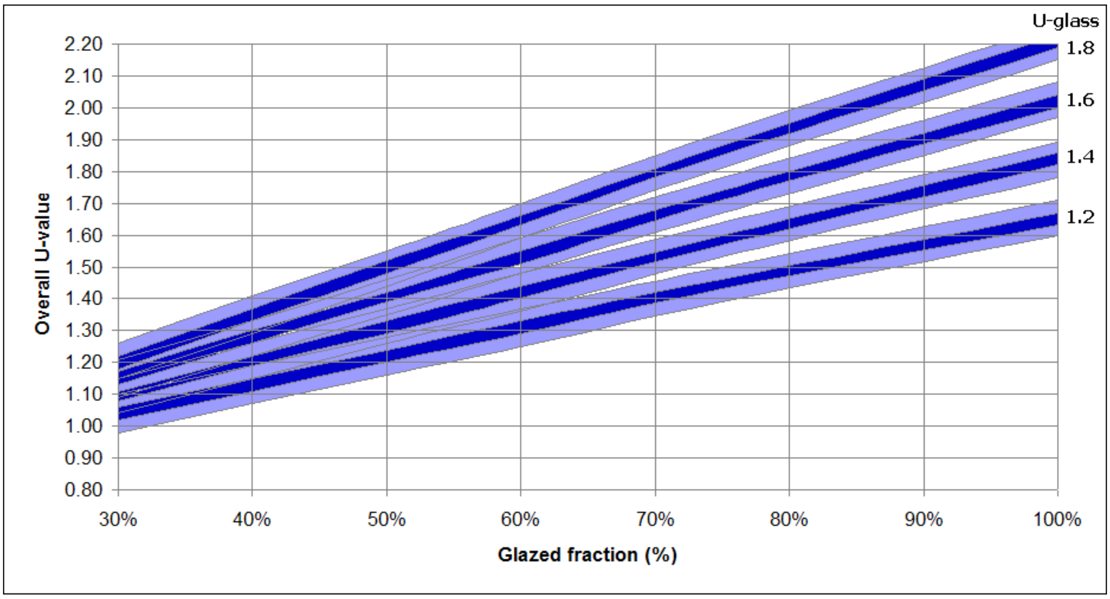

Figure A2a Basic U-values for mullion spacing of 1200 mm

$U_{mullion}$ = 2.50, 3.00, 3.50 and 4.00 W/m^{2}K
U_{panel} = 0.3 W/m^{2}K
$\psi_{glass\text{-}frame}$ = 0.11 W/mK
$\psi_{panel\text{-}frame}$ = 0.09 W/mK

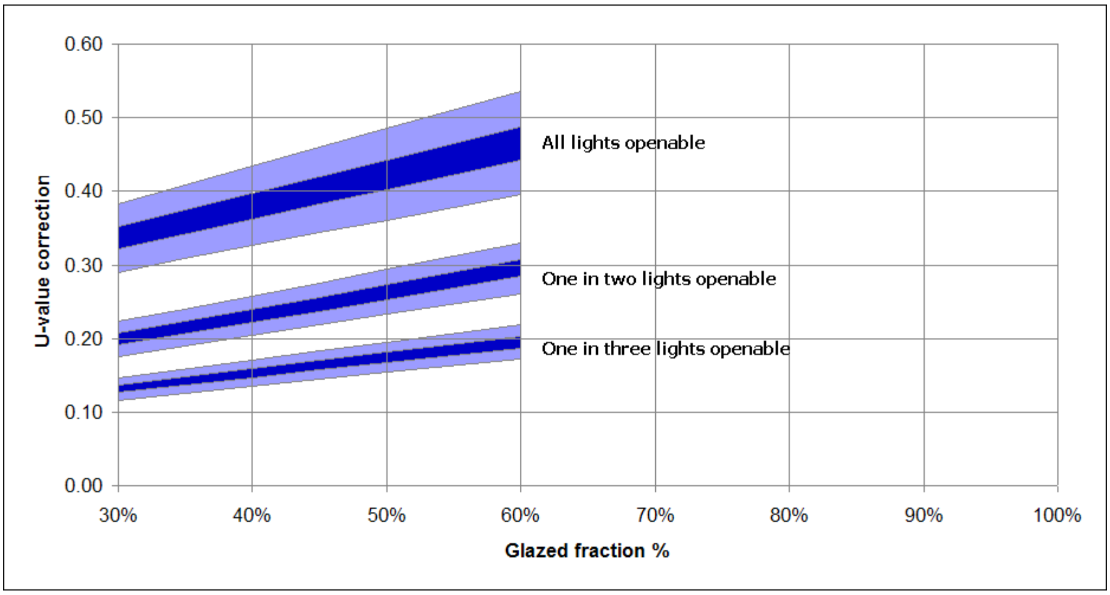

Figure A2b Corrections for openable lights (U_{glass} = 1.6 W/m^{2}K)

$U_{window\ frame}$ = 2.80, 3.10, 3.40 and 3.80 W/m^{2}K
$\psi_{frame\text{-}mullion}$ = 0.09 W/mK (Symmetric)
$\psi_{frame\text{-}mullion}$ = 0.22 W/mK (Asymmetric)

Estimating U-values – mullion spacing 1200 mm (cont'd)

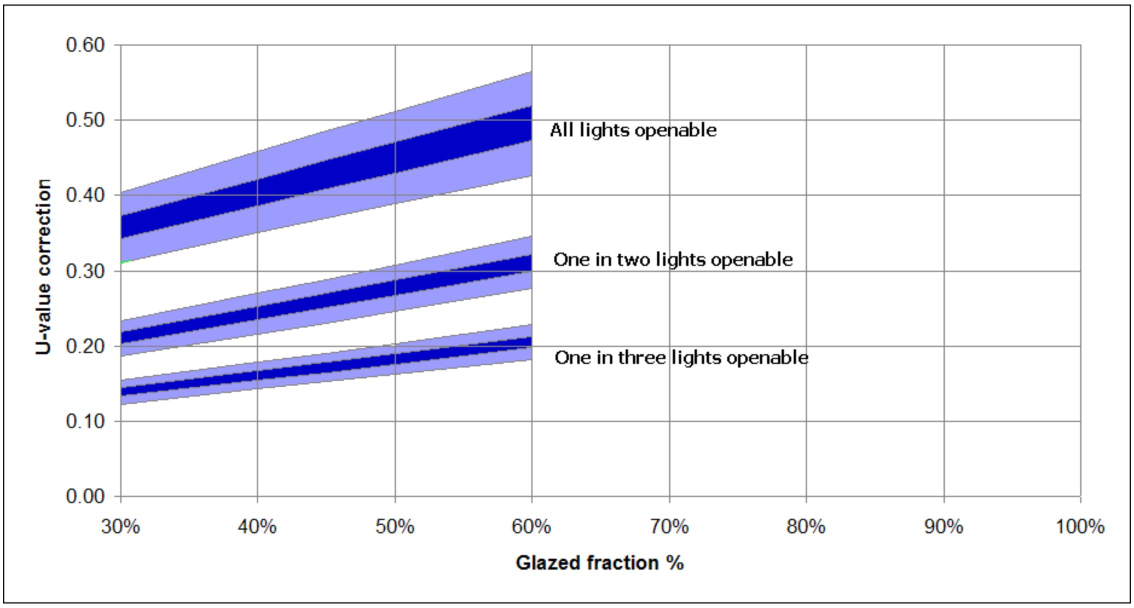

Figure A2c Corrections for openable lights (U_{glass} = 1.4 W/m^2K)

$U_{window\ frame}$ = 2.80, 3.10, 3.40 and 3.80 W/m^2K
$\psi_{frame\text{-}mullion}$ = 0.09 W/mK (Symmetric)
$\psi_{frame\text{-}mullion}$ = 0.22 W/mK (Asymmetric)

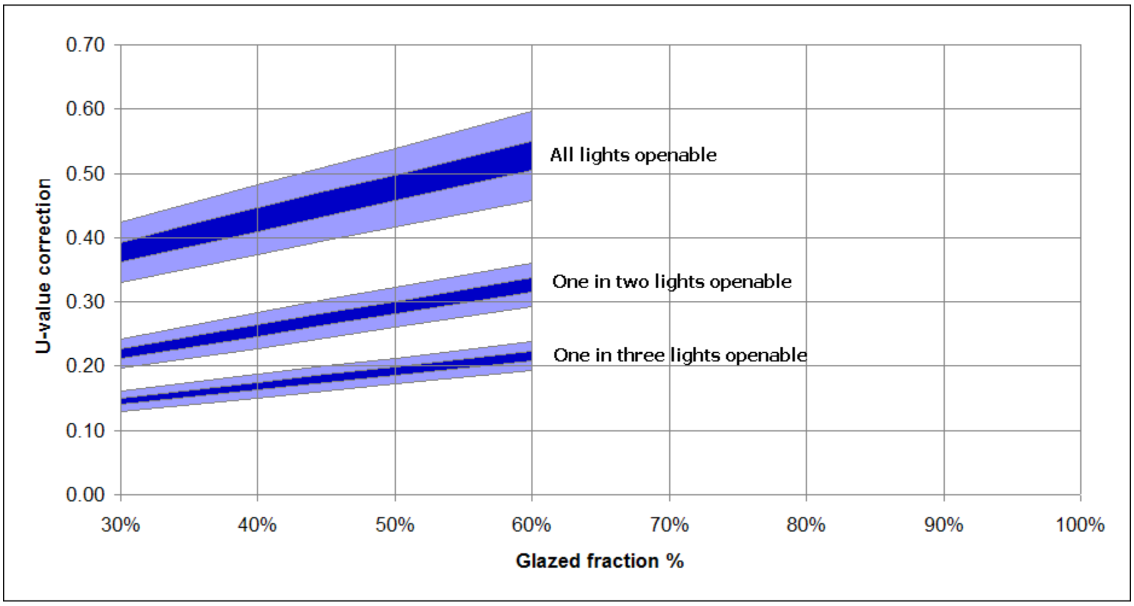

Figure A2d Corrections for openable lights (U_{glass} = 1.2 W/m^2K)

$U_{window\ frame}$ = 2.80, 3.10, 3.40 and 3.80 W/m^2K
$\psi_{frame\text{-}mullion}$ = 0.09 W/mK (Symmetric)
$\psi_{frame\text{-}mullion}$ = 0.22 W/mK (Asymmetric)

Estimating U-values – mullion spacing 1500 mm

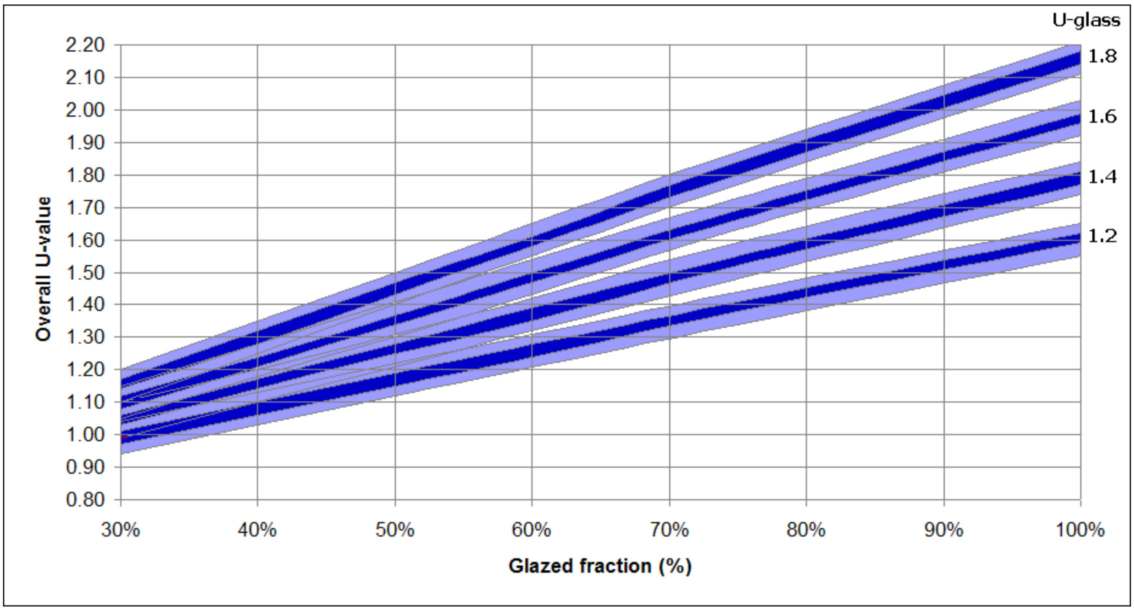

Figure A3a Basic U-values for mullion spacing of 1500 mm

$U_{mullion}$ = 2.50, 3.00, 3.50 and 4.00 W/m^{2}K
U_{panel} = 0.3 W/m^{2}K
$\psi_{glass\text{-}frame}$ = 0.11 W/mK
$\psi_{panel\text{-}frame}$ = 0.09 W/mK

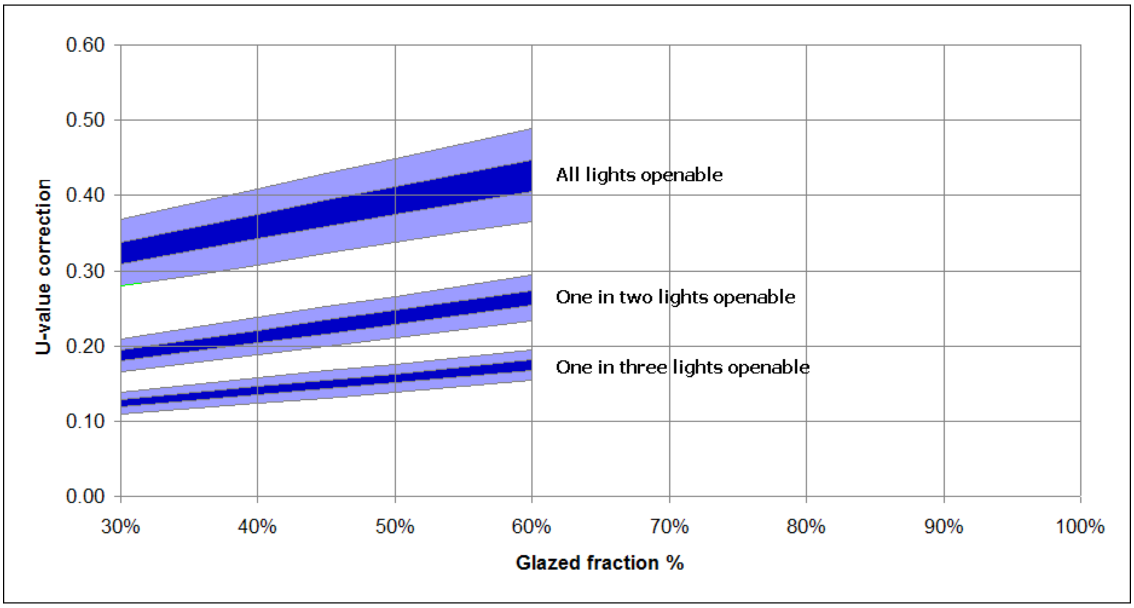

Figure A3b Corrections for openable lights (U_{glass} = 1.6 W/m^{2}K)

$U_{window\ frame}$ = 2.80, 3.10, 3.40 and 3.80 W/m^{2}K
$\psi_{frame\text{-}mullion}$ = 0.09 W/mK (Symmetric)
$\psi_{frame\text{-}mullion}$ = 0.22 W/mK (Asymmetric)

Estimating U-values – mullion spacing 1500 mm (cont'd)

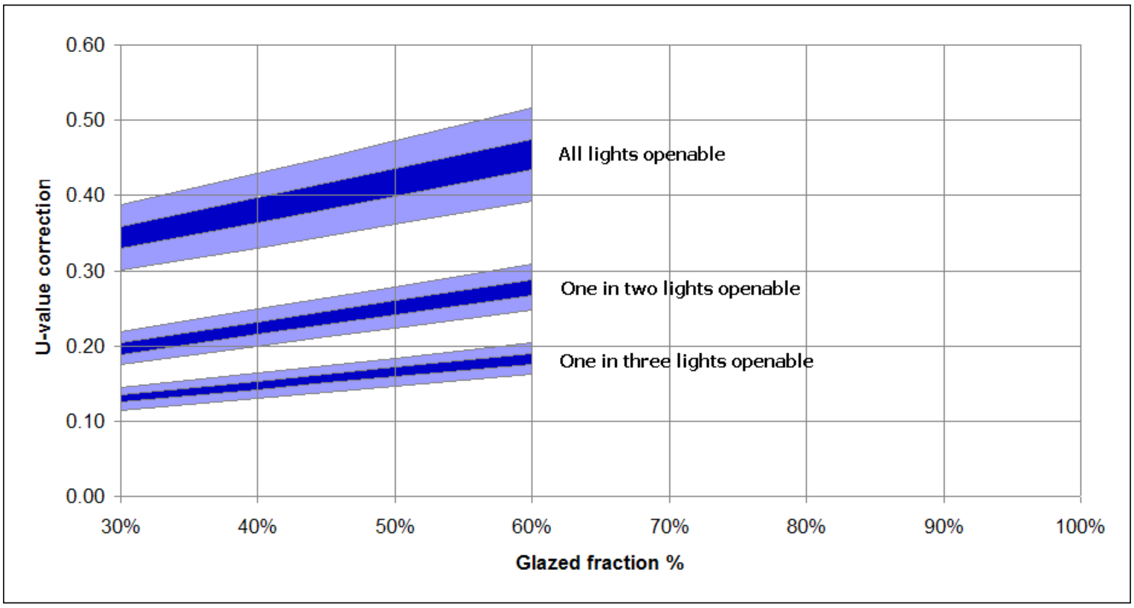

Figure A3c Corrections for openable lights (U_{glass} = 1.4 W/m^{2}K)

$U_{window\ frame}$ = 2.80, 3.10, 3.40 and 3.80 W/m^{2}K
$\psi_{frame\text{-}mullion}$ = 0.09 W/mK (Symmetric)
$\psi_{frame\text{-}mullion}$ = 0.22 W/mK (Asymmetric)

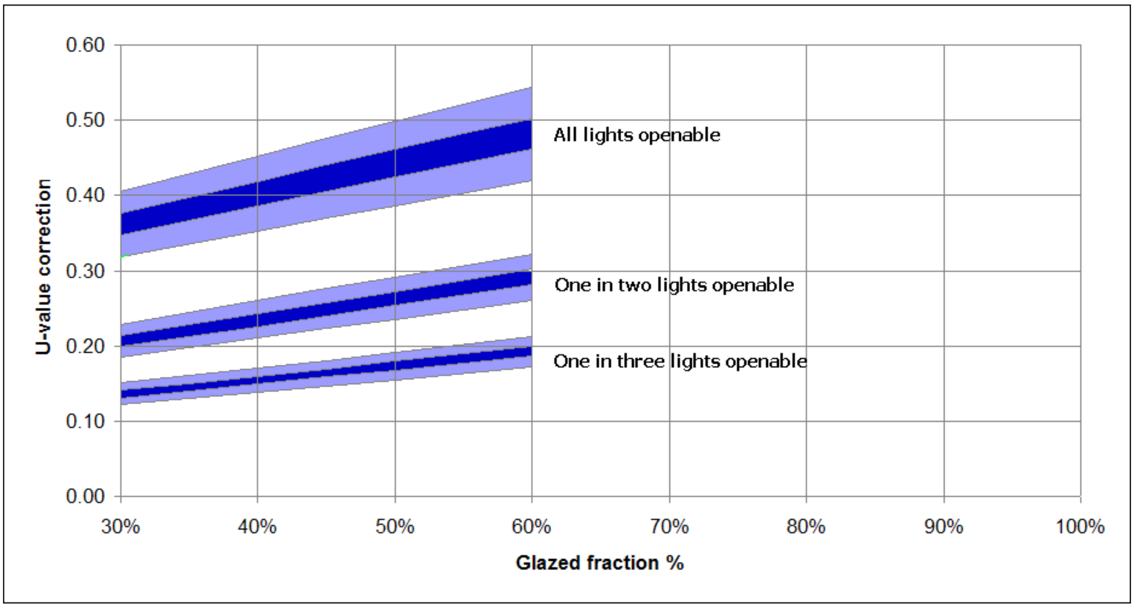

Figure A3d Corrections for openable lights (U_{glass} = 1.2 W/m^{2}K)

$U_{window\ frame}$ = 2.80, 3.10, 3.40 and 3.80 W/m^{2}K
$\psi_{frame\text{-}mullion}$ = 0.09 W/mK (Symmetric)
$\psi_{frame\text{-}mullion}$ = 0.22 W/mK (Asymmetric)

Estimating U-values – mullion spacing 1800 mm

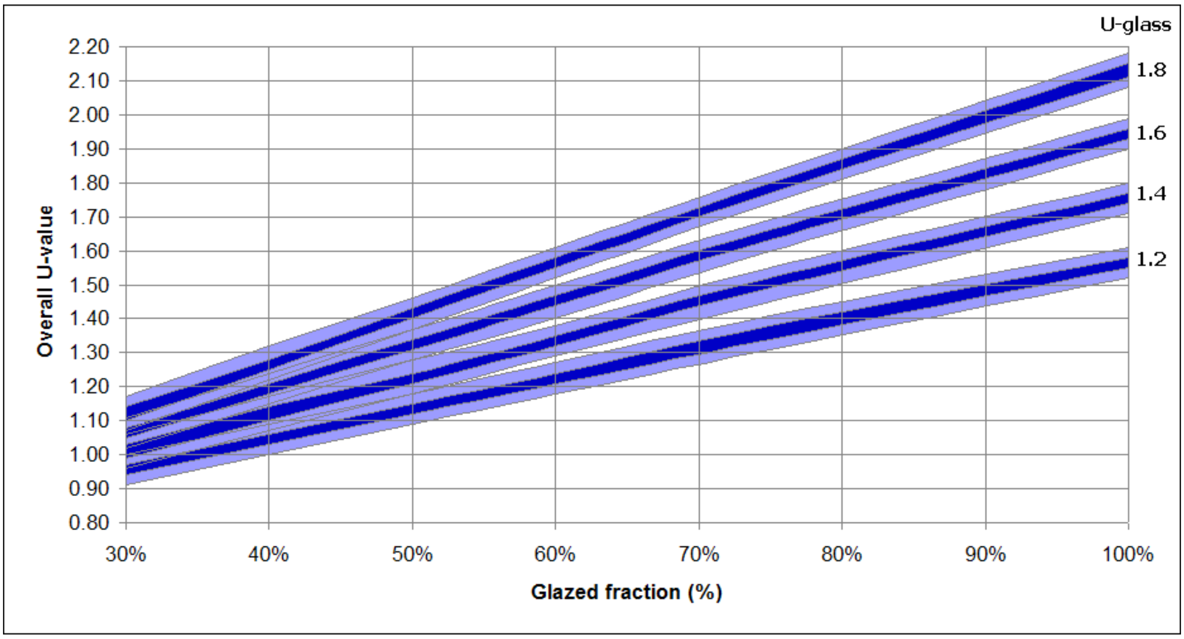

Figure A4a Basic U-values for mullion spacing of 1800 mm

$U_{mullion}$ = 2.50, 3.00, 3.50 and 4.00 W/m^{2}K
U_{panel} = 0.3 W/m^{2}K
$\psi_{glass\text{-}frame}$ = 0.11 W/mK
$\psi_{panel\text{-}frame}$ = 0.09 W/mK

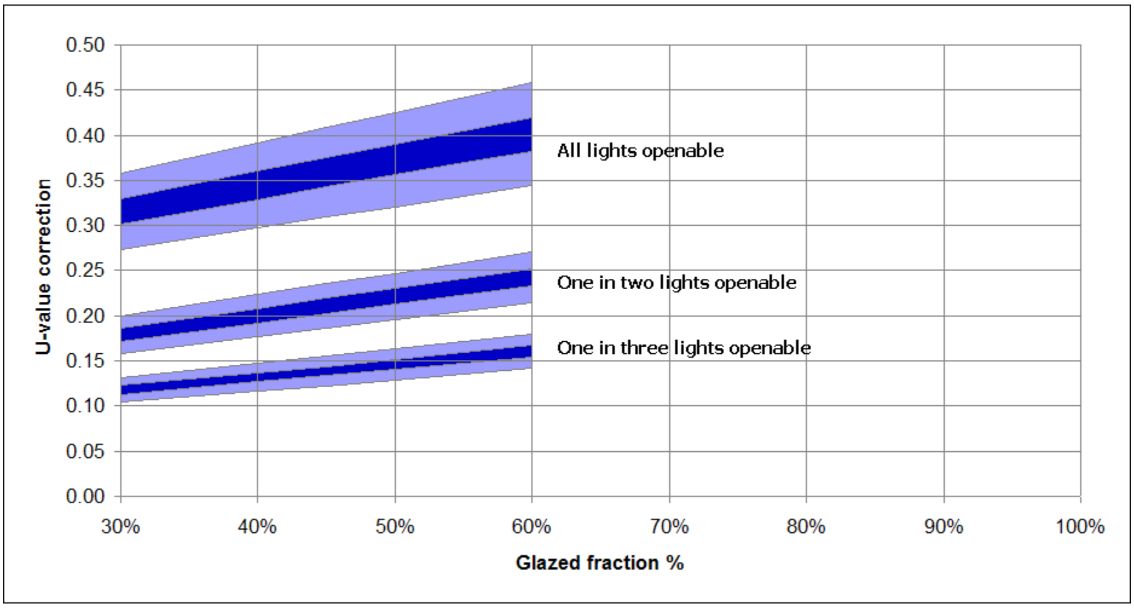

Figure A4b Corrections for openable lights (U_{glass} = 1.6 W/m^{2}K)

$U_{window\ frame}$ = 2.80, 3.10, 3.40 and 3.80 W/m^{2}K
$\psi_{frame\text{-}mullion}$ = 0.09 W/mK (Symmetric)
$\psi_{frame\text{-}mullion}$ = 0.22 W/mK (Asymmetric)

Estimating U-values – mullion spacing 1800 mm (cont'd)

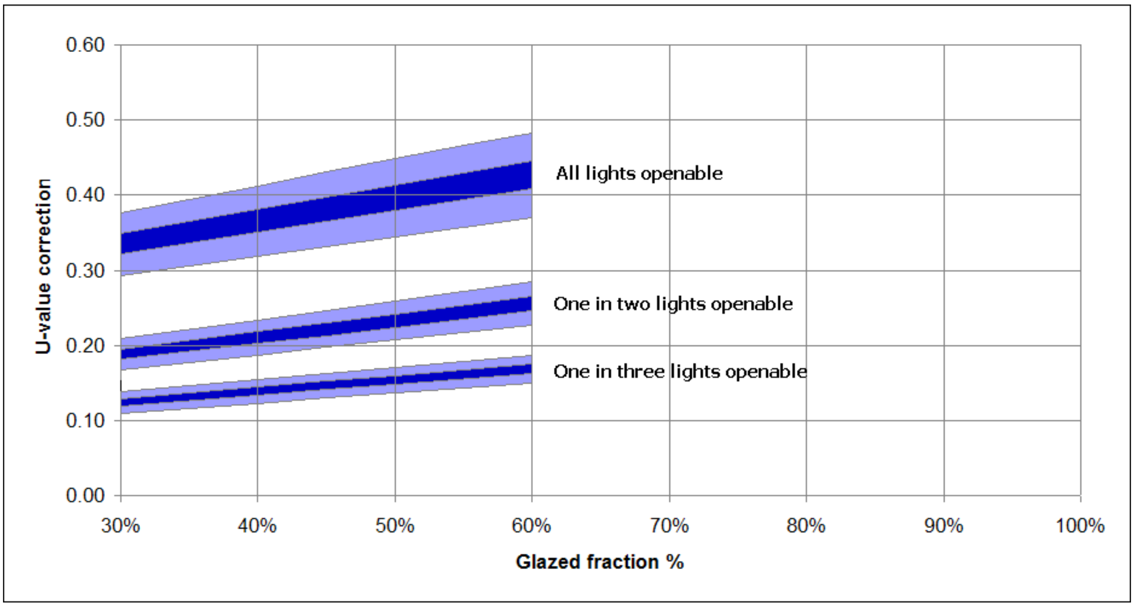

Figure A4c Corrections for openable lights (U_{glass} = 1.4 W/m^{2}K)

$U_{window\ frame}$ = 2.80, 3.10, 3.40 and 3.80 W/m^{2}K
$\psi_{frame\text{-}mullion}$ = 0.09 W/mK (Symmetric)
$\psi_{frame\text{-}mullion}$ = 0.22 W/mK (Asymmetric)

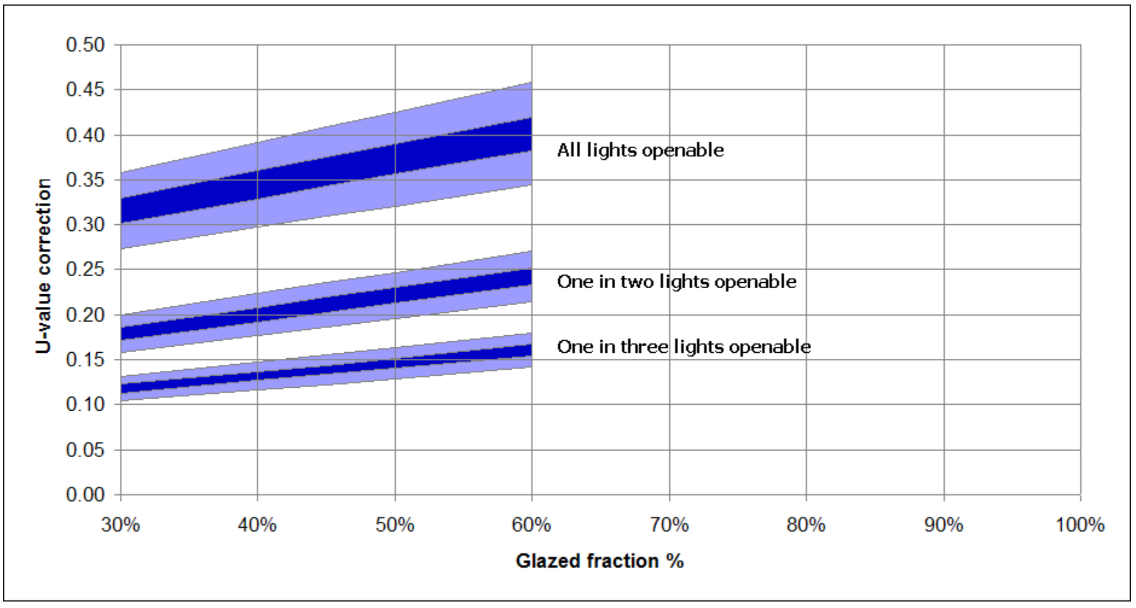

Figure A4d Corrections for openable lights (U_{glass} = 1.2 W/m^{2}K)

$U_{window\ frame}$ = 2.80, 3.10, 3.40 and 3.80 W/m^{2}K
$\psi_{frame\text{-}mullion}$ = 0.09 W/mK (Symmetric)
$\psi_{frame\text{-}mullion}$ = 0.22 W/mK (Asymmetric)

Estimating U-values – all mullion spacings

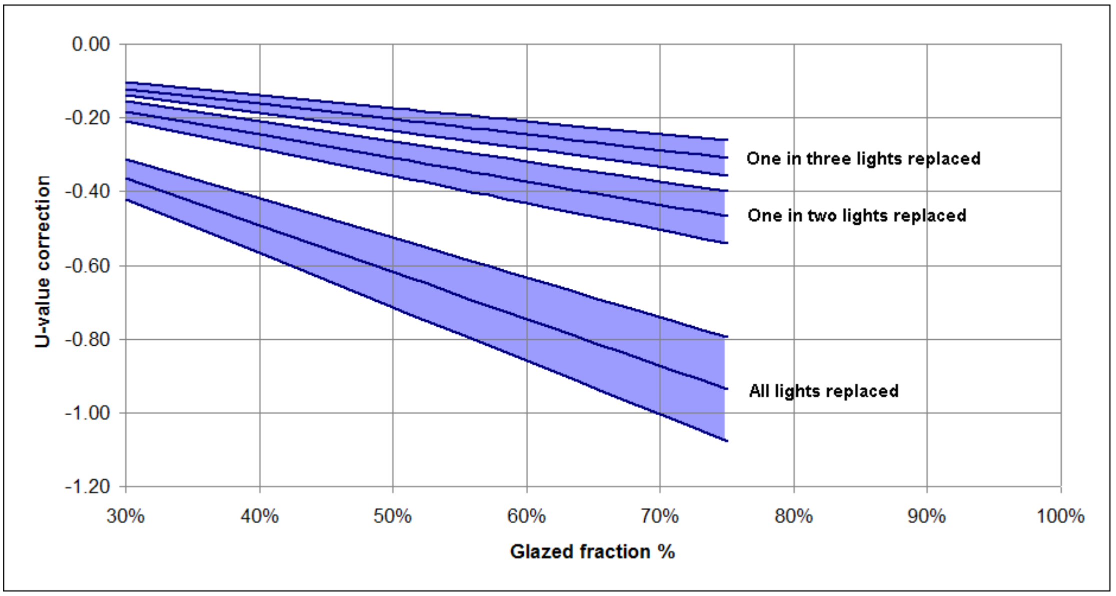

Figure A5 Corrections for additional opaque zones

U_{glass} - U_{panel}	= 1.1, 1.3 and 1.5 W/m^{2}K
$\psi_{glass\text{-}mullion}$	= 0.11 W/mK
$\psi_{panel\text{-}mullion}$	= 0.09 W/mK

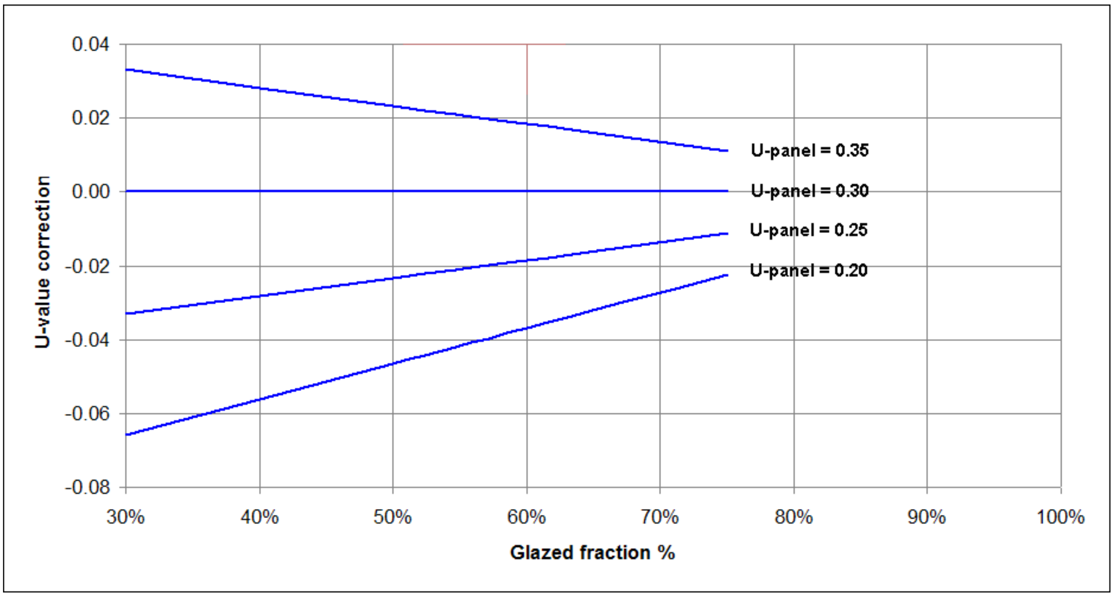

Figure A6 Corrections for opaque panels of different U-value (U in W/m^{2}K)

Example calculation

Mullion spacing = 1350 mm
Storey height = 2800 mm
Glazing height = 1400 mm

Glazed fraction = 50%

Opening lights required

Required U-value = 1.50 W/m^2K

Calculate for mullion spacing of 1200 mm and 1500 mm and take the average:

1200 mm spacing	1500 mm spacing
Calculate U-value with all fixed lights	
U_g = 1.4 W/m^2K U_f = 4.0 W/m^2K U_{zone} = 1.37 W/m^2K *(Fig A2a)*	U_g = 1.4 W/m^2K U_f = 4.0 W/m^2K U_{zone} = 1.31 W/m^2K *(Fig A3a)*
U_{zone} = 1.34 W/m^2K	
Include one in two opening lights	
U_{wi} = 3.1 W/m^2K U_{zone} = +0.26 W/m^2K *(Fig A2b)* U_{zone} = 1.63 W/m^2K	U_{wi} = 3.1 W/m^2K U_{zone} = +0.23 W/m^2K *(Fig A3b)* U_{zone} = 1.54 W/m^2K
U_{zone} = 1.595 W/m^2K	
Also replace one in three lights with insulated panels	
U_g = 1.4 W/m^2K U_p = 0.3 W/m^2K $U_g - U_p$ = 1.1 W/m^2K	
U_{zone} = -0.17 W/m^2K *(Fig A5)* U_{zone} = 1.46 W/m^2K	U_{zone} = -0.17 W/m^2K *(Fig A5)* U_{zone} = 1.37 W/m^2K
U_{zone} = 1.415 W/m^2K *OK*	
Alternatively include one in three opening lights	
U_{wi} = 3.1 W/m^2K U_{zone} = +0.16 W/m^2K *(Fig A2b)* U_{zone} = 1.53 W/m^2K	U_{wi} = 3.1 W/m^2K U_{zone} = +0.14 W/m^2K *(Fig A3b)* U_{zone} = 1.45 W/m^2K
U_{zone} = 1.49 W/m^2K *OK*	

To achieve a U-value of 1.5 W/m^2K proceed on the basis of one of the following:

Make 1 in 2 lights openable and 1 in 3 lights opaque	U_{zone} ~ 1.415 W/m^2K
Make 1 in 3 lights openable	U_{zone} ~ 1.49 W/m^2K
Use higher performance glass and re-calculate	
Use a smaller glazing height and re-calculate	
Use a wider mullion spacing	

Now proceed to a detailed U-value calculation on the basis of precise U-values for mullions, window frames and glass.

APPENDIX B CALCULATING U-VALUES OF STICK SYSTEM CURTAIN WALLS

U-values of curtain walling are calculated in the following steps:

1 Assess the U-values of the glazing and in-fill panels;
2 Assess the U-values and ψ-values of the framing members;
3 Calculate the U-value of a zone of wall.

Glazing

Centre pane glazing values should be assessed as described in Section 5 of this Guide.

In-fill panels

Centre panel U-values should be calculated using the methods given in BS EN ISO 6946.

Framing members

U-values of the framing members should be calculated as described in Appendix C.

ψ-values of the frame should be calculated as described in Appendix C or the default values given in paragraph 7.10 may be used.

U-value of a stick curtain wall

There are different ways to assess the overall U-value of an assembly according to the accuracy of the result required. Three methods are described below. Methods 1 and 2 are two-dimensional computer simulation based methods giving realistic results. Method 3 is a simplified method using default linear thermal transmittance. It can only give indicative results and should only be used at the early design stage.

Method 1 – approximate method

This method utilizes simulation results calculated as described in Appendix C. These are generally available from the system suppliers. It provides approximate results allowing quick comparison between products and a fairly close estimate of the overall U-value. It requires at least two computer simulations for each frame in order to calculate the frame U-values, U_f, excluding edge effect, and the linear thermal transmittances, ψ.

The overall heat transmittance, U_{zone}, for a glazed stick system with window insert is given by

$$U_{zone} = \frac{\sum A_g U_g + \sum P_g \psi_g + \sum A_{wi} U_{wi} + \sum P_{wi} \psi_{wi} + \sum U_f A_f}{A_{zone}}$$

Where:

U_f is the thermal transmittance of the curtain wall frame excluding edge effects, in W/m^2K;
U_{wi} is the thermal transmittance of the window frame including the visible part of the window insert, in W/m^2K;
U_{zone} is the thermal transmittance of the building elements, in W/m^2K;
A_g is the projected area of glazing viewed from inside, in m^2;

A_{wi}	is the visible projected area of window with window insert viewed from inside, in m^2;
A_f	is the projected area of stick system framing viewed from inside, in m^2;
ψ_g	is the linear thermal transmittance at the junction between the edge of the window frame and the glazing, in W/mK;
ψ_{wi}	is the linear thermal transmittance at the junction between the window insert and the stick system framing, in W/mK;
P_g	is the perimeter of the glazing where ψ_g applies, in m;
P_{wi}	is the perimeter of the window insert where ψ_{wi} applies, in m.

Method 2 – accurate method

This method simulates the assembly as a whole and calculates a U-value of the assembly that includes the edge effect. It requires one computer simulation for each frame combination, from which a frame U-value including edge effect, U_f, can be calculated.

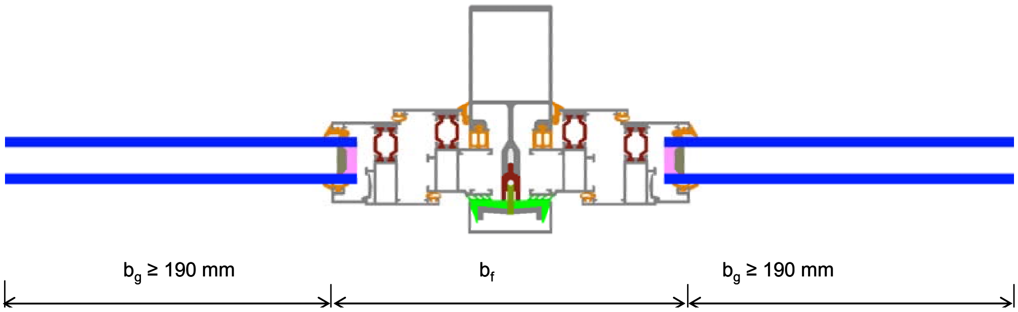

Figure B1 Cross-section of stick system with window inserted at both sides

For a stick system with window inserted, a two dimensional simulation is carried out for the cross-section of profile as shown in Figure B1. The frame U-value is given by:

$$L^{2D} = \frac{Q_2}{(T_i - T_e)}$$

$$U_f = \frac{L^{2D} - \sum U_g b_g}{b_f}$$

Where:

L^{2D}	is the thermal conductance of the cross-section as shown in Figure B1, in W/mK,
U_g	is the centre pane glazing U-value, in W/m^2K,
U_f	is the frame U-value including edge effect, in W/m^2K,
Q_2	is the heat flow rate through the cross-section under typical environmental conditions as described in BS EN ISO 10077-2,
T_i, T_e	are the internal and external environmental temperatures,
b_f	is the width of the frame measured from the solid edges of the frame viewed from inside of the building,
b_g	is the width of the glazing unit measured from the solid edges of the frame viewed from inside of the building, ignoring gaskets.

The overall U-value of a typical zone of curtain wall is then given by:

$$U_{zone} = \frac{\sum U_g A_g + \sum U_p A_p + \sum U_f A_f}{A_{zone}}$$

This method gives an accurate result with the least number of simulations needed. However, it does not separate frame U-value and linear thermal transmittance, and simulations need to be carried out for different glazing or infill panel options.

Method 3– simplified method

This is an approximate method. It can only be used at the early design stage and only gives an indicative overall U-value of a building element. It is described in BS EN ISO 13947. U-values of the framing members are calculated as described in Appendix C but ψ-values are taken as default values that may differ from the exact values that can be calculated using the methods described in Appendix C.

The overall U-value of the building element is calculated according to the formula given in Section 7.10.

Example –Method 1

The zone of calculation can be any extent of curtain walling but in the example below it is taken as one bay in width and one storey in height. Calculation of this U-value allows comparison of different curtain walling systems.

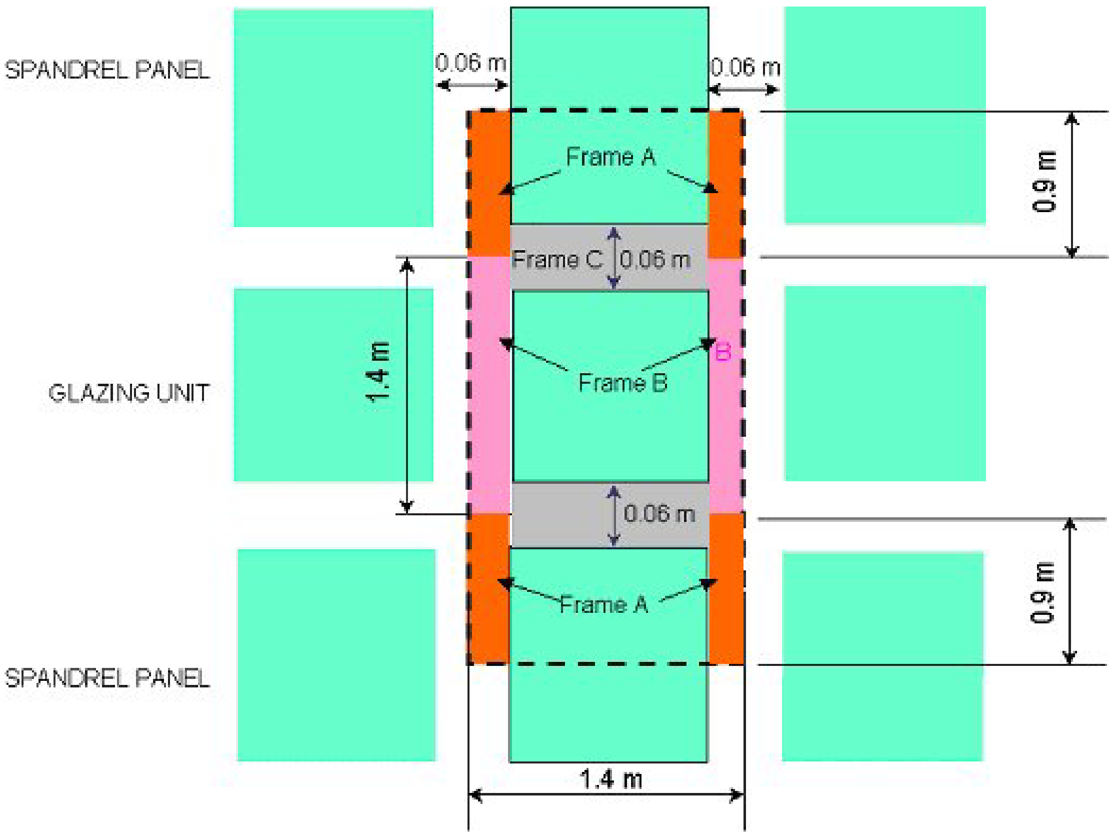

Figure B2 Elevation of a typical curtain wall zone

Element	Height m	Length m	Area m^2	Total area m^2	U-value W/m^2K	AxU W/K	Ψ W/mK	P m	PxΨ W/K
Glass	1.340	1.340	1.796	1.796	1.400	2.514			
Spandrel	0.870	1.340	1.166	2.332	0.288	0.672			
Frame A	0.900	0.030	0.027	0.108	5.390	0.582	0.110	4x0.870	0.383
Frame B	1.400	0.030	0.042	0.084	6.330	0.532	0.110	2x1.340	0.295
Frame C	1.340	0.060	0.080	0.161	5.680	0.914	0.110	4x1.340	0.590
Total				4.481		5.214			1.268

In the table above the total heat transfer through the zone of wall is calculated due to U-values and ψ-values to give a zone U-value:

$$U_{Zone} = \frac{\sum AU + \sum P\psi}{\sum A} = \frac{5.214 + 1.268}{4.481} = 1.447 W/m^2K$$

Addition of an opening light

If the glazed opening in the example above is replaced by an opening light with a U-value of 2.0 W/m^2K then the U-value of the zone is calculated as follows:

Element	Height m	Length m	Area m^2	Total area m^2	U-value W/m^2K	AxU W/K	Ψ W/mK	P m	PxΨ W/K
Opening light	1.340	1.340	1.796	1.796	2.000	3.592			
Spandrel	0.870	1.340	1.166	2.332	0.288	0.672			
Frame A	0.900	0.030	0.027	0.108	5.390	0.582	0.110	4x0.870	0.383
Frame B	1.400	0.030	0.042	0.084	6.330	0.532	0.090	2x1.340	0.241
Frame C	1.340	0.060	0.080	0.161	5.680	0.914	0.220 0.11	2x1.340 2x1.340	0.590 0.295
Total				4.481		6.292		1.389	1.509

Giving:

$$U_{Zone} = \frac{\sum AU + P\boldsymbol{\psi}}{\sum A} = \frac{6.292 + 1.509}{4.481} = 1.74 W/m^2K$$

APPENDIX C CALCULATING PROPERTIES OF FRAMING MEMBERS

Geometrical model

Cut-off planes in the geometrical model should be adiabatic (i.e. zero heat flow).

For glass the adiabatic boundary should be a plane perpendicular to the surfaces of the glazing with a distance no less than 190 mm from the solid edge of the frame.

For the infill panel the adiabatic boundary should be a plane perpendicular to the surfaces of the infill panel with a distance no less than 1000 mm from the solid edge of the frame or at the symmetry plane of the profile.

For the frame, the adiabatic boundary, in general, should be the boundary of the frame connecting to other building elements.

In particular for a window with an insert frame the adiabatic boundary should be along the surface of the part of the insert clamped into the curtain walling system frame as shown in Figure C1.

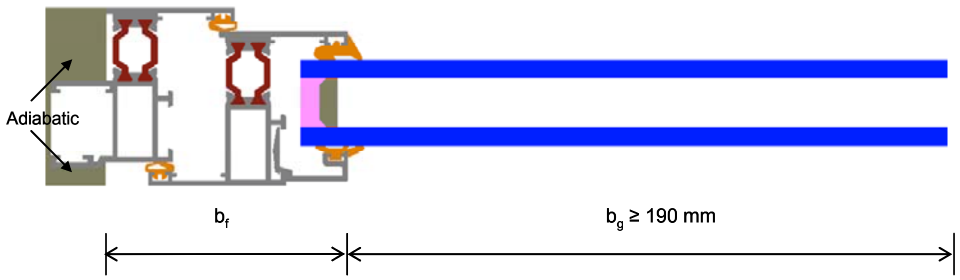

Figure C1 Frame adiabatic boundary of window with insert frame

Boundary conditions

The boundary conditions should be as defined in BS EN ISO 10077-2.

For a heat flow simulation, the boundary conditions are:

External environmental temperature	T_e	0.00	°C
Internal environmental temperature	T_i	20.00	°C
External surface resistance	R_{se}	0.04	m²K/W
Internal surface resistance	R_{si}	0.13	m²K/W
Sheltered internal surface resistance	R_{si}	0.20	m²K/W

Determination of frame U-value

The frame U-value is defined as the thermal conductance of the frame calculated according to the simulation result of the profile cross section shown in Figure C2. To assess the frame U-value (excluding the edge effect), an insulation panel with λ=0.035 W/m^{2}K is used to replace the glazing unit in use.

The heat flow rate per metre, Q_1, from the internal environment to the external environment, is obtained from a simulation of the cross-section shown in Figure C2:

$$L_f^{2D} = \frac{Q_1}{(T_i - T_e)}$$

Where:

L_f^{2D} is the thermal conductance of the profile cross-section shown in Figure C2, in W/mK.

The frame U-value is given by:

$$U_f = \frac{L_f^{2D} - \sum U_p b_p}{b_f}$$

Where:

U_f	is the frame U-value excluding edge effect, in W/m^{2}K;
U_p	is the centre pane U-value of the insulation panel, in W/m^{2}K;
b_p	is the projected width of the insulation panel from the solid edge of the frame, in m;
b_f	is the projected width of the frame profiles excluding gaskets, in m.

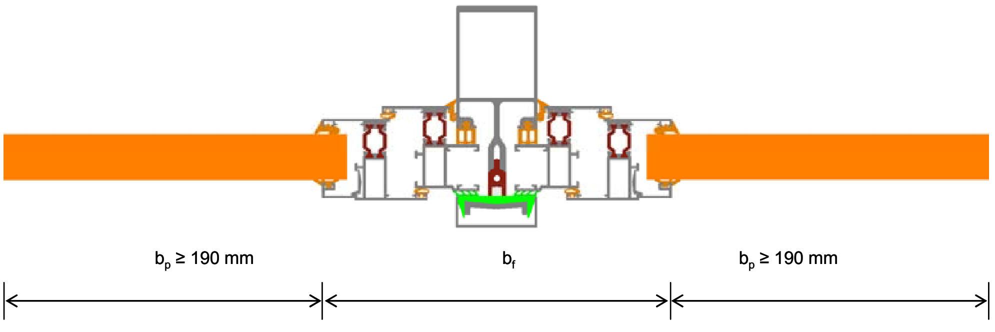

Figure C2 Profile cross-section with insulation panel

Linear thermal transmittance

To assess the linear thermal transmittance, ψ, at the edge of the glazing or infill panel, the glazing unit or the infill panel, where it is appropriate, is used for the two dimensional simulation. For the case with a glazing unit in use, see Figure C3.

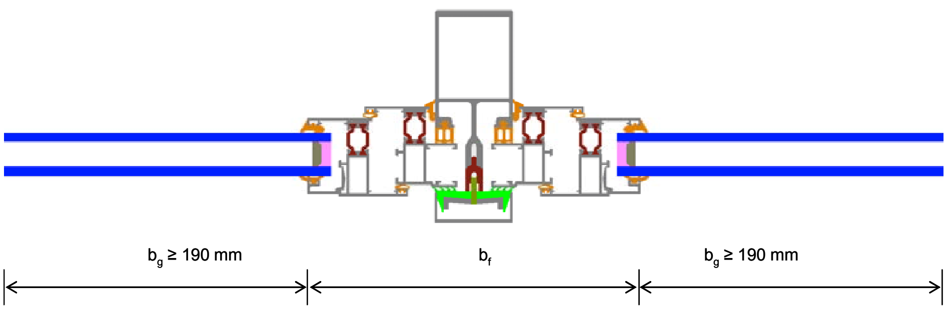

Figure C3 Profile cross-section with glazing

The heat flow rate per metre, Q_2, from the internal environment to the external environment is obtained from a simulation of the cross-section shown in Figure C3:

$$L_{\psi}^{2D} = \frac{Q_2}{(T_i - T_e)}$$

The linear thermal transmittance at the edge of the glazing is given by

$$\psi = \frac{L_{\Psi}^{2D} - \sum U_g b_g - \sum U_f b_f}{l_{edge}}$$

Where:

L_{ψ}^{2D} is the thermal conductance of the profile section shown above, in W/mK;
ψ is the linear thermal transmittance at the junction between the edge of the glazing and the frame, in W/mK;
U_g is the central pane glass U-value, in W/m^{2}K;
b_g is the width of the glass from the solid edge of the frame (excluding gaskets), in m;
l_{edge} is the length of the junction between the edge of the glazing and the frame perpendicular to the cross-section plane, in m.

- For symmetrical configurations, l_{edge} = 2 m, when there are glazing units at both sides of the frame;
- For non-symmetrical configurations, l_{edge} = 1 m, leading to a total ψ-value for both edges (equivalent to the joint ψ-value in BS EN 13947).

Assessment for linear thermal transmittance of window insert

A construction detail is often a combination of different building elements. The heat transfer through the interface needs to be taken into account while assessing the overall heat transfer through the construction detail.

For example, the heat transfer through a stick system framing with window insert can be divided into five parts:

$$Q = Q_g + Q_g^{edge} + Q_{wi} + Q_{wi}^{edge} + Q_f^{cw}$$

Where:

Q_g is the one-dimensional heat transfer through glazing;
Q_g^{edge} is the two-dimensional heat transfer due to the interaction between the window frame and the glazing;
Q_{wi} is the two-dimensional heat transfer through the window frame with window insert;
Q_{wi}^{edge} is the two-dimensional heat transfer due to the interaction between the stick system framing and the window insert;
Q_f^{cw} is the two-dimensional heat transfer through the stick system framing.

A numerical methodology has been established to assess the linear thermal transmittance at the junctions between the window insert and stick curtain wall frame, ψ_{wi}. The same principle applies to stick system with infill panel, rainscreen and unitised wall.

Stick system with window insert at both sides

Figure C4 shows the cross-section of a stick system mullion with windows at both sides. The linear thermal transmittance at the junction between the window insert and the mullion is given by:

$$\Psi_{wi} = \frac{L^{2D} - \sum U_p b_p - U_{cw} b_{cw} - 2 \times U_{wi} b_{wi}}{2}$$

$$Q = L^{2D}(T_i - T_e)$$

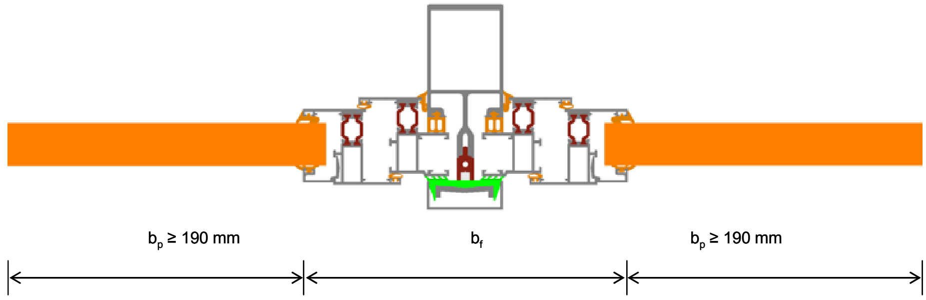

Figure C4 Cross-section of stick system mullion with window at both sides and insulation panel

Where:

- Q is the rate of heat transfer through the cross section shown in Figure C4;
- U_p is the centre panel U-value of the insulation panel, in W/m^2K;
- U_{cw} is the frame U-value of the stick system mullion, in W/m^2K;
- U_{wi} is the frame U-value of the window with the visible part of the window insert, in W/m^2K;
- b_p is the total width of the insulation panel from the solid edge of the frame in m;
- b_{cw} is the projected width of the stick system mullion, in m;
- b_{wi} is the projected width of the window with the visible part of the window insert, in m.

Stick system with window insert at one side

Figure C5 shows the cross-section of a stick system mullion with window at one side. The linear thermal transmittance at the junction between the window insert and the mullion is given by:

$$L^{2D} = \frac{Q}{(T_i - T_e)}$$

$$\Psi_{wi} = L^{2D} - \sum U_p b_p - U_{cw} b_{cw} - U_{wi} b_{wi}$$

Where:

Q is the rate of heat transfer through the cross-section shown in Figure C5.

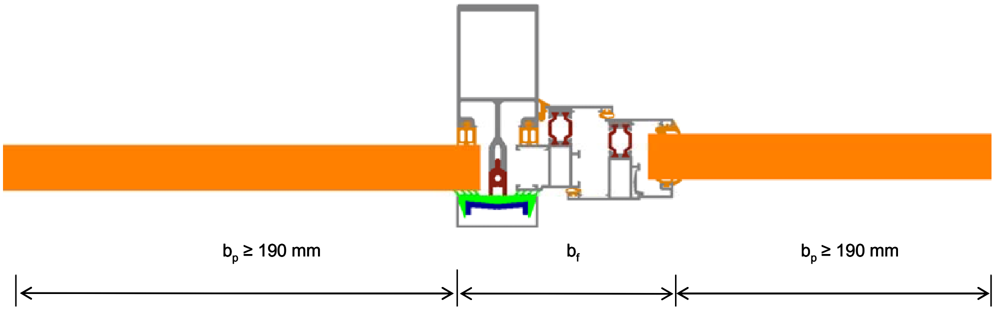

Figure C5 Cross-section of stick system mullion with window at one side and insulation panel

Frame U-value of window with window insert

For the purpose of assessing the linear thermal transmittance at the junction between the window insert and the mullion, the frame U-value of the window with window insert is defined as:

$$L_{wi}^{2D} = \frac{Q_{wi}}{(T_i - T_e)}$$

$$U_{wi} = \frac{L_{wi}^{2D} - U_p b_p}{b_{wi}}$$

Where:

Q_{wi} is the heat transfer through the cross-section shown in Figure C6.

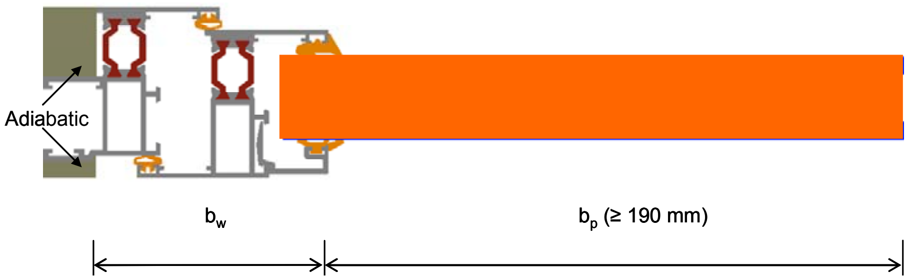

Figure C6 Cross-section of window with window insert and insulation panel

APPENDIX D CALCULATING U-VALUES OF RAINSCREEN OVERCLADDING

The U-value for a rainscreen may be calculated using either two-dimensional or three-dimensional analysis. Two-dimensional analysis is simpler but three-dimensional analysis may be used to obtain more accurate, and lower, U-values.

In a two-dimensional model it is assumed that the frame is continuous and any discontinuous components such as brackets or fixings are modelled as 'smeared' components with equivalent thermal conductivity. This is based on the principle that the heat loss through the smeared component is the same as the one through the discontinuous components.

In a three-dimensional model the brackets and fixings are modelled correctly as discrete components. A χ-value is calculated for the isolated thermal bridge formed by the bracket and its fixings.

A one-dimensional U-value of the insulation and support wall is required. This should be calculated using the method given in BS EN ISO 6946.

Geometrical model

Cut-off planes of the geometric model should be adiabatic (i.e. zero lateral heat flow).

The vertical adiabatic boundaries should be planes perpendicular to the surfaces of the wall with a distance no less than 1000 mm from the extreme edge of the frame (including brackets) or at the mid points between frame centrelines if they are less than 2000 mm apart and the configuration is symmetric.

For three dimensional models the horizontal adiabatic boundaries should be planes perpendicular to the surfaces of the wall with a distance no less than 1000 mm from the extreme edge of the bracket being modelled or at the mid points between bracket centres.

The rainscreen panels and the air cavity behind them are omitted from the calculations, as the air temperature in the cavity is the same as the external environmental temperature.

Boundary conditions

The boundary conditions used should be those defined in BS EN ISO 10211.

For heat flow simulation, the boundary conditions are:

External environmental temperature	T_e	0.00	°C
Internal environmental temperature	T_i	20.00	°C
External surface resistance	R_{se}	0.13	m²K/W
Internal surface resistance	R_{si}	0.13	m²K/W
Shielded internal surface resistance	R_{si}	0.20	m²K/W

Note that because the rainscreen panels and the air cavity behind them have been omitted from the model the external surface of the model is not the true external surface but the warmside of the air cavity behind the rainscreen panels. The cavity surfaces are more sheltered than the outer surface and have a higher surface resistance, as defined in BS EN 6946:1997.

Determination of two-dimensional frame U-value

In this model the discrete components are modelled as continuous prismatic sections with modified thermal conductivities. This technique is known as 'smearing' the components. The modified thermal conductivity of a 'smeared component' is:

$$\lambda' = \frac{\lambda A}{A'}$$

Where:

λ'	is the equivalent thermal conductivity of the 'smeared' components;
λ	is the true thermal conductivity of the discontinuous components;
A'	is the section area of the smeared component, measured in the plane of the wall;
A	is the total section area of the discontinuous components, measured in the plane of the wall.

In many cases the relative lengths of the smeared and discontinuous components can be substituted for their relative section areas.

Thus for a 4 mm thick steel bracket of height 100 mm at 1200 mm centres fixed with 6 mm diameter steel fixings the values are:

λ_{steel} = 50.00 W/mK
$\lambda'_{bracket}$ = 4.17 W/mK
λ'_{fixing} = 1.57 W/mK

The geometrical model shown in Figure D1 has depth 1000 mm with all components prismatic and equivalent values of conductivity, λ', used to 'smear' components.

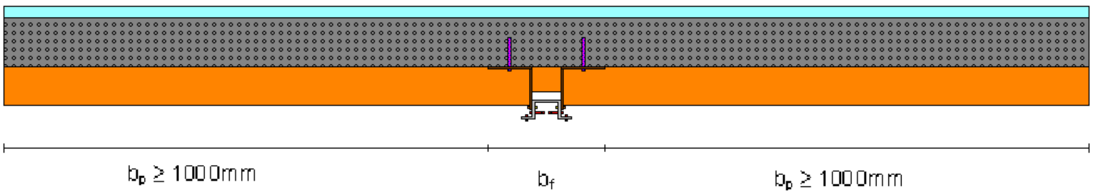

Figure D1 Profile of rainscreen

The heat flow rate, Q_1, from the internal environment to the external environment through the section shown in Figure D1 is obtained from a 2-D simulation and:

$$L^{2D'} = \frac{Q_1}{(T_i - T_e)}$$

Where:

$L^{2D'}$ is the thermal conductance of the profile section shown in Figure D1, in W/mK.

The frame U-value is given by:

$$U'_f = \frac{L^{2D'} - U_p b_p}{b_f}$$

Where:

U'_f is the frame U-value including smeared brackets and edge effect, in W/m^2K;
U_p is the 1-D U-value of the insulation and support wall, in W/m^2K;
b_p is the total projected width of the insulation and supporting wall from the solid edge of the frame (including the brackets), in m;
b_f is the projected width of the frame (including brackets), in m.

Determination of rainscreen U-value from 2-D simulation

The U-value of a section of rainscreen is calculated from:

$$U_{RS} = \frac{A_p U_p + A_f U'_f}{A_{rs}}$$

Where:

A_{rs} is the area of a repeating section of rainscreen

Determination of rainscreen U-value from 3-D simulation

In order to accurately calculate the effect of the brackets and fixings a 3-dimensional simulation should be carried out that includes a correct geometrical representation of all components of the rainscreen (see Figure D2).

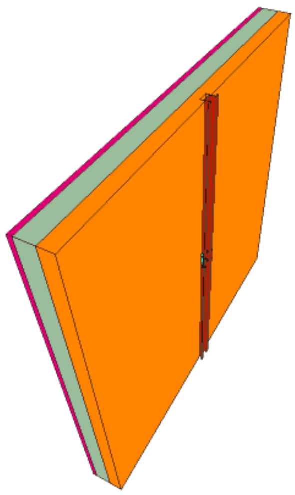

Figure D2 3-dimensional simulation of rainscreen

The heat flow rate, Q_2, from the internal environment to the external environment through the section is obtained from the simulation shown in Figure D2 and:

$$L^{3D} = \frac{Q_2}{(T_i - T_e)}$$

Where:

L^{3D} is the thermal conductance of the profile section shown in Figure D2, in W/K.

Now if the boundaries are midway between frames and midway vertically between brackets the U-value of a zone of rainscreen is simply:

$$U_{rs} = \frac{L^{3D}}{A_{rs}}$$

Where:

A_{rs} is the area of the wall as simulated, in m^2.

Alternatively a χ-value may be calculated for the bracket and its fixings so that U-values can be calculated for different frame spacing and/or bracket spacing.

Determination of point thermal transmittance, χ

In order to calculate the point thermal transmittance a two-dimensional simulation is carried out with the brackets removed, see Figure D3. The overall width should be the same as for the three-dimensional simulation with a depth of 1000 mm.

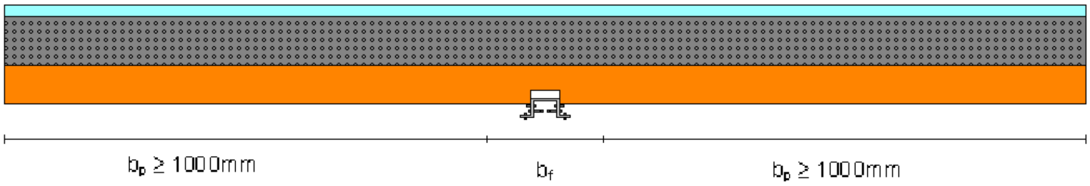

Figure D3 Rainscreen without brackets

The heat flow rate, Q_3, from the internal environment to the external environment through the section shown in Figure D3 is obtained from a 2-D simulation. The point thermal transmittance, χ, is:

$$\chi = \frac{(Q_2 - H \times Q_3)}{(T_i - T_e)}$$

$$L^{2D} = \frac{Q_3}{(T_i - T_e)}$$

Where:

H is the overall height of the three-dimensional model, in m.

L^{2D} is the thermal conductance of the profile section without brackets as shown in Figure D3, in W/mK.

The frame U-value is given by:

$$U_f = \frac{L^{2D} - U_p b_p}{b_f}$$

Where:

U_f is the frame U-value including edge effect, but excluding the effect of 3-D thermal bridging, in W/m^2K;
U_p is the 1-D U-value of the insulation and support wall, in W/m^2K;
b_p is the total projected width of the insulation and wall from the extreme edges of the frame (including brackets), in m;

b_f is the projected width of the frame, between the edges of the brackets, in m.

The U-value of a zone of rainscreen is calculated as follows:

$$U_{rs} = \frac{\sum A_p U_p + \sum A_f U_f + n\chi}{A_{rs}}$$

Where n is the number of brackets in the zone.

APPENDIX E CALCULATING U-VALUES TO INPUT TO BUILDING ENERGY MODELS

Comparison

When comparing the U-value of a zone of non-traditional wall with an equivalent zone of traditional wall it is important to recognise the presence of linear thermal bridges in both types of construction.

The U-value of a traditional wall should be calculated using the weighted U-value calculation. There will be linear thermal bridges at the interfaces between windows and wall that should be included in the calculation. A simplified method of calculation is often used where the ψ-values of the linear thermal bridges are not calculated but assumed to be a fixed proportion of the U-value of the zone. The notional building of ADL-2A assumes that the linear thermal bridges are present in the building envelope. These may be treated as separate linear thermal bridges with default ψ-values or as an overall increase in U-value represented by a factor α_{tb}. The additional heat loss is typically fifteen percent for which the factor α_{tb} is 0.15. The U-value of a traditional wall should therefore be calculated as:

$$U_{zone} = (1+\alpha_{tb}) \times \left[\frac{\sum_{zone} A_{window} U_{window} + \sum_{zone} A_{wall} U_{wall}}{\sum_{zone} A_{window} + \sum_{zone} A_{wall}} \right]$$

or

$$U_{zone} = \frac{\sum_{zone} A_{window} U_{window} + \sum_{zone} A_{wall} U_{wall} + \sum_{zone} \psi L}{\sum_{zone} A_{window} + \sum_{zone} A_{wall}}$$

The U-value of a non-traditional wall may be calculated as described elsewhere in this guide. Note that the calculation will include all linear and localised thermal bridges within the envelope zone. Additional factors may need to be applied to the linear thermal transmittance at the interface between cladding types/zones.

Linear thermal transmittance

Clause 5.7 of ADL-2A requires the designer to demonstrate that reasonable provisions have been taken to ensure continuity of insulation. In order to ensure that the modelled performance of junctions/interfaces is realistic, the calculated linear thermal transmittance may require an adjustment. This is set out in section 3.4 of this document.

There are two situations where the linear thermal transmittance is calculated, and their treatment is different. These situations may be defined as standard details and bespoke details.

Standard details

A standard detail is one which is integral to a system, such as a window or curtain wall frame. The linear thermal transmittances can be anticipated, such as that between the frame and the glazing, or due to a window insert in a curtain wall frame, as shown in Figure 1.

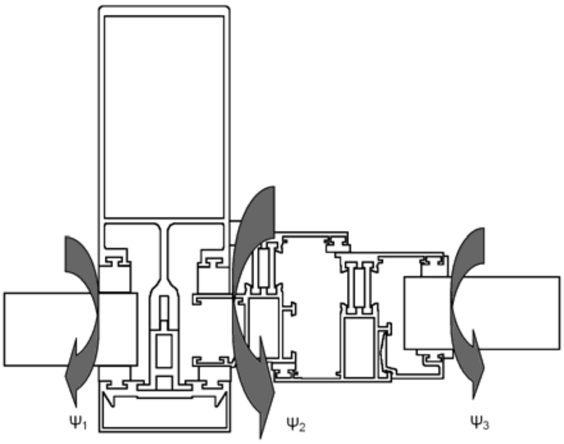

Figure 1 Typical linear thermal transmittances within a standard detail

Calculation methods are given in Appendix C of this document. These details are not dependant on workmanship. Due to their standard and repeatable nature there is no need to add any additional factors to the linear thermal transmittances calculated.

Bespoke details

Bespoke details are those which are unique to a particular project, such as the design of the interface between a zone of curtain walling and rainscreen system or a window and a wall system, as shown in Figure 2.

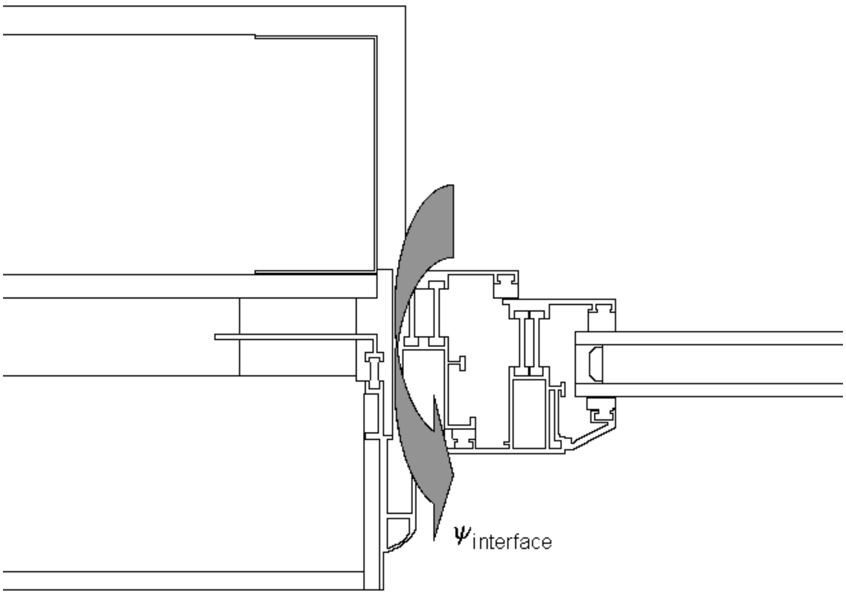

Figure 2 Interface between a window and a wall system

Due to the nature of most projects these details are often modified on site to overcome problems of fit and coordination, and as such the performance may differ from that which was calculated at the design stage. Therefore for such situations it is necessary to adjust the calculated ψ value, according to the robustness of the design, as set out in ADL-2A.

Envelope zone

A schematic of the calculation method for a zone of building envelope consisting of an area of curtain walling and the interface to a different system construction is shown in Figure 3.

The overall U-value for the zone below would be:

$$U_{zone} = \frac{U_{CW}A_{CW} + \psi_{interface}l_{interface}}{A_T}$$

where:

U_{zone} is the overall U-value of the zone, in W/m^{2}K,
U_{CW} is the U-value of the curtain wall, including the linear thermal transmittances between components within the system, in W/m^{2}K,
A_{CW} is the area of the curtain wall, in m^2,
$\Psi_{interface}$ is the linear thermal transmittance of the interface between the curtain wall and the adjacent construction, increased according to Clause 5.7 of ADL-2A as appropriate, in W/mK,
$l_{interface}$ is the length of the interface, in m,
A_T is the total area of the zone, in m^2.

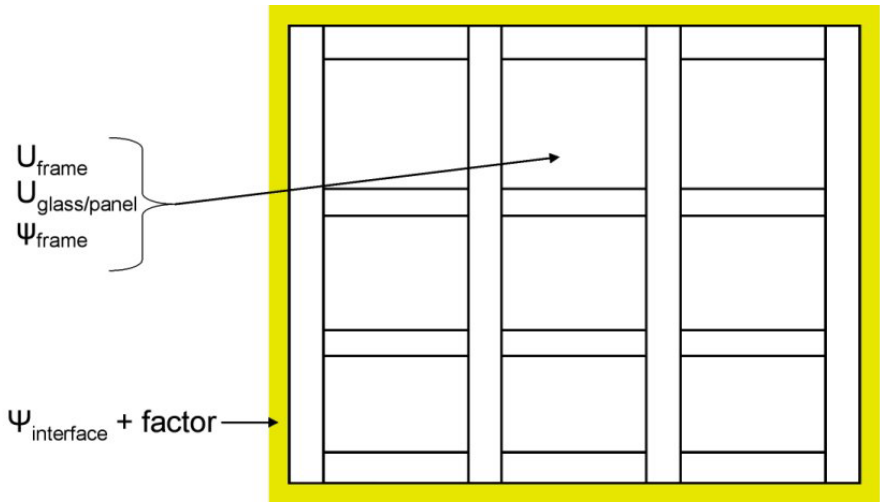

Figure 3 Schematic of the calculation method for an envelope zone

Input to building energy models

Building energy models such as SBEM require walls to be input as if they are traditional walls comprising windows and opaque wall. It is important that non-traditional walls are correctly represented when using such models.

The correct area of glass has to be input as the models will calculate total solar energy transfer and transmission of daylight. However the U-values of windows and walls do not need to be the correct values provided the overall U-value of any zone is correct. The following procedure may be applied:

The building energy model will assume either a framing fraction (F_f) or a transmission factor (T_f) for the windows and factor the window area to obtain an area of glass. The framing fraction is the area of window represented by the glazing frame and the normal default value is fifteen or twenty per cent (which is high for a curtain wall). The transmission factor is the fraction of light transmitted through the window and includes the obstruction of the glazing frame as well as additional shading devices. Either the framing fraction should be given the value zero, or the transmission factor should be calculated only taking account of additional shading devices. Where default values are used the window area should be taken as:

$$A_{windows} = \frac{A_{glass}}{1 - F_f} \quad \text{or,} \quad A_{windows} = \frac{A_{glass}}{T_f}$$

The U-value of the windows may be assumed to be a nominal U_{window} = 2.0 W/m^{2}K and the nominal thermal transmittance through the windows calculated as:

$$Q_{windows} = A_{windows} \times U_{window}$$

The nominal U-value of the wall (opaque parts) can now be calculated to give a correct U-value for the zone as a whole. However, most software will make a correction for linear thermal bridges by calculating linear thermal bridges using ψ-values or applying a factor (α_{tb}) to the simple U-value calculation.

The inclusion of additional thermal bridges in the building energy model by using ψ-values should be nullified by setting the ψ-values to zero in the building energy model and using α_{tb} = 0 in the equations below.

The appropriate U-value of the opaque parts of the envelope may then be calculated from:

$$A_{zone} U_{zone} = (1 + \alpha_{tb})[A_{windows} U_{windows} + A_{opaque} U_{opaque}]$$

$$U_{opaque} = \frac{[A_{zone} U_{zone} / (1 + \alpha_{tb}) - A_{windows} U_{windows}]}{A_{opaque}}$$

$$A_{opaque} = A_{zone} - A_{windows}$$

Where U_{zone} is the zone U-value as described elsewhere in this guide.