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CONVENTIONS FOR CALCULATING U-VALUES, f-VALUES AND Ψ-VALUES FOR METAL CLADDING SYSTEMS USING TWO- AND THREE- DIMENSIONAL THERMAL CALCULATIONS

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THE METAL CLADDING & ROOFING MANUFACTURERS ASSOCATION

The Building Envelope Authority

Contents

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1.0 Summary

This guide provides the information necessary for the calculation of heat loss through plane areas, the U-value, heat loss through thermal bridges, the - value and the lowest internal surface temperature, the f-value, for twin skin or composite panel metal constructions using 2- or 3-dimensional heat flow calculations. It is designed so that users of different software packages can achieve consistent results when starting from the same construction data.

In many construction types, masonry or timber framed for example, because the lowest internal surface temperatures are associated with the thermal bridges, the -value and f-value are calculated together. In twin skin and composite panel metal cladding systems, although there are some details where the lowest surface temperatures are at the thermal bridges, there are many where the f-value is associated with the spacers or panel joints that are part of the plane wall or roof. In these cases, the U-value and the f-value are calculated together. To obtain an accurate U-value it is necessary to take account of spacers, panel joints and profiles; a detailed three dimensional model is therefore necessary. In most cases, however, the -value of a junction may be obtained from a simple two dimensional model, which does not incorporate spacers or profiles.

The following steps are necessary:

1) Decide which features of the construction should be modelled – Section 5. When constructing a model of a structure for calculating U-values, - values or f-values the following features must be considered:

- Include all metal features that cross the insulation.
- Purlins or rails have negligible effect on the U-value of plane walls or roofs, but raise the f-value slightly. If purlins or rails are connected to a severe thermal bridge, such as a gutter base crossing the insulation, they must be included as they increase the severity of the thermal bridge and raise the f-value. It is recommended that they are included.
- Profiled liner and outer sheets should be included in the calculations of the U-value and f-value as they affect the surface area and the effective insulation thickness. If the software used cannot model the sloping sides of the profiles, the heat flow can be approximated very closely by a model with a series of steps, provided the overall dimensions of the profiles are the same.
- Fasteners and other point fixings, which do not cross the insulation layer have a negligible effect on heat flows and can be ignored.
- Air cavities more than 5mm thick, should be included, and allowance made for whether they are ventilated.
- When determining the size of the model, the most accurate results will be obtained by ensuring that the more important thermal bridges are most accurately represented, therefore fixing systems that cross the insulation should be given priority over profiles, and liner profiles, which affect the insulation thickness, should be given priority over outer profiles, which do not.

2) Define the thermal conductivity of each of the materials present – Section 6. Manufacturers data should be used, where possible, otherwise data are available in CIBSE Guide A or BS EN ISO 12524:2000.

3) Allow for features such as air cavities in the structure - Section 6. The standard cavity resistances quoted in BS EN ISO 6946 or CIBSE Guide A should be used.

4) Specify appropriate internal and external surface thermal resistances - Section 8. The standard surface resistances quoted in BS EN ISO 6946 or CIBSE Guide A should be used.

5) Decide which features are part of a plane element and which are part of a thermal bridge – Section 9. It is important to decide which features affect the heat flow through the plane areas and should be assigned to the U-value, and which affect heat flow through the thermal bridge and should be assigned to the -value. Otherwise there is a danger that some features will be included in both and their effect on the heat loss counted twice.

6) Specify and input a two- or three-dimensional grid and position each material present within this grid and subdivide the grid to give accurate results within a reasonable time- Section 10. The best results are achieved by the following procedure

- Define the minimum grid necessary to specify the materials present.
- Divide all the spaces between the grid points into two.
- Identify all areas where the metal components cross insulation and add extra grid points as shown in Figure 22.
- Calculate the resulting heat flow and lowest internal surface temperature.
- Divide all the grid elements into two and recalculate the results.
- If the heat flows calculated from stages d) and e) differ by less than 2% and the minimum surface temperatures by less than 0.1°C, the calculation is complete. If the change is greater, go back to stage c) and investigate adding further grid points in sensitive areas and repeat stages d) and e), until good agreement is reached.

7) Calculate the U-value of the plane elements adjacent to the bridge – Section 11. It is important to distinguish between:

- the U-value of the plane elements, necessary for the calculation of the overall loss from the building, and
- the U-values of those parts of a model used to calculate the -value - see Section 12

In cases where the structure is uniform so that there is no variation in surface temperature along the inside surface, the U-value can be calculated from the inside surface temperature. Otherwise the U-value has to be derived from the heat loss and dimensions of a three dimensional model.

8) Calculate the -value from the heat flows and temperatures output by the software - Section 12. The -value depends on the difference between the heat loss through a thermal bridge, and the heat loss through the adjacent plane areas. It is therefore very sensitive to the U-value used. Therefore, the U-value of the plane elements should never be assumed, but always calculated for each plane element from the output of the model. In many cases reliable -values can be derived from simplified models without profiles or spacer systems.

9) Calculate the f-value - Section 14 – from the temperatures output by the software.

A worked example is included in Section 14 to draw the various ideas together.

The procedures to be used in calculating - and f-values and typical values for a range of details built as recommended on the MCRMA website are provided in the Appendix.

2.0 Introduction

We are all now aware of the need to save energy use in buildings to limit the production of the CO_2 that adds to global warming. That this is very much part of the government agenda is reflected in the successive changes to Part L of the Building Regulations in England and Wales, with similar changes to the equivalent sections in Scotland and Northern Ireland. The latest changes that came into force in 2006[1,2] are also driven by the Energy Performance Directive of the EU.

The introduction of more highly insulated structures that has resulted from this need to save energy has also led to a need for more sophisticated methods for calculating the heat loss and surface temperatures than was previously felt to be adequate. Two changes are particularly important:

- While U-values of the building fabric could previously be calculated by assuming that an element was made up of a series of parallel layers each with uniform thermal resistance, it is now recognised that features such as mortar joints, timber studs or the metal spacers in built up metal cladding contribute significantly to heat loss. More complex calculation methods have been introduced to take account of these.
- It has also been recognised that the joints between the walls, roofs and floors of a building, can add significantly to the fabric heat loss. In these areas, thermal bridges, the higher heat flows that occur because of complex geometries or the use of high conductivity materials, lower internal surface temperatures and can lead to condensation and mould problems.

Calculation of the heat loss through twin skin or composite panel metal construction brings particular difficulties. Simplified methods are possible in some cases, but 2- or 3-dimensional heat flow calculations must be carried out for some U-value and for all thermal bridge calculations. A number of software packages are available but many important decisions, which have a very significant effect on the results, are left to the user.

This guide gives the information needed to carry out these calculations, so that different users of the same package and users of different packages can obtain consistent answers. It has been developed on the basis of a series of calculations, which examined the importance of individual features of the fabric and the validity of a range of approximations.

It should be recognised throughout that the methods discussed in this report will allow designers and manufacturers of metal cladding systems to demonstrate compliance with the Regulations by using standardised calculations that will give consistent answers. In some cases, heat loss through ground floors discussed in section 12.4, for example, the methods may seem unrealistic; however they comply with the standards that underpin the Regulations.

3.0 Heat loss and surface temperatures

3.1 Heat loss

The heat loss from buildings is made of two components:

- ‘fabric loss’ occurs by conduction of heat through the various elements of the building fabric;
- ‘ventilation loss’ occurs when cold outside air replaces the heated indoor air, by a mixture of designed ventilation and undesigned air infiltration.

The fabric loss can be separated into two components:

- through the ‘plane areas’, i.e. the walls, roof, floor, and windows and doors;
- through the joints between the plane areas – the thermal bridges.

3.2 U-values

The loss through the plane areas, which usually represents 80 – 90% of the total fabric loss, is quantified by the U-value of the components – see Section 11. The total heat loss through all the plane elements can then be found by adding the product of the U-value and area of each individual element.

$$\text{Plane area fabric loss} = A \cdot U \ \ \text{W/K} \qquad (1)$$

As described in Section 3 of MCRMA Guide 14[3], methods for calculating U-values have become increasingly sophisticated over the years. Originally, all that was necessary was to assume that a component was made up from a series of parallel layers, add the thermal resistance of each layer and take the reciprocal. More recently the ‘combined method’ has been introduced to take account of features such as mortar joints or timber studs, which distort the heat flow slightly. This method is specified in BS EN ISO 6946[4] and CIBSE Guide A[5] and implemented in the BRE U-value calculator[6]. The correct ways to do this are not always obvious and disputes have arisen over values claimed by different manufacturers/ suppliers. To resolve these issues BRE produced a guide to conventions for U-value calculations[7], which specifies the correct procedures in any construction type.

Site assembled and composite panel walls and roofs are made from profiled metal liner and outer sheets joined by spacer systems or fasteners, which cross the insulation layer in between the sheets. These distort the heat flows so much that the combined method is no longer valid and it is necessary to carry out the detailed 2- or 3-dimensional heat flow calculations, described in Section 3 of MCRMA Guide 14[3], to obtain an accurate U-value. These have been carried out for some construction types and simplified methods published by BRE[8] and the SCI[9], which are included in the BRE Calculator. Despite this guidance, there will still be many instances, where it is necessary for a detailed 2- or 3-dimensional model of a structure to be developed to derive a U-value.

3.3 Thermal bridges

Thermal bridges are regions in a building structure where, because of either the geometry or the materials present, the heat flow from inside to out is higher than in other areas. Besides adding to the heat loss and therefore the energy demand of the building, thermal bridges also cause the temperature of the internal surface to fall, increasing the risk of condensation or mould growth.

Thermal bridges occur at the boundaries between plane elements, such as:

- in corners, where walls meet;
- at eaves, where a wall meets a roof;
- at ridges or valleys, where two roof slopes meet;
- at the junction where walls and floors meet, especially at ground level;
- where different walling systems meet;
- around the edge of doors and windows.

The heat loss at thermal bridges is represented by the linear thermal transmittance or -value in W/mK. This is the extra heat loss through the thermal bridge over and above the heat loss through the adjoining plane elements – see Section 12.

The sum of the products of the length and -values of all the thermal bridges can be added to the loss through the plane areas to give the total fabric loss as

$$A \cdot U + \ l \cdot \text{W/K} \qquad (2)$$

Before 2002, Regulations contained only recommendations that thermal bridges should be minimised in design and construction. The new versions of Approved Document L1 and L2, which came into force in 2002, introduced formal requirements that their effect on heat loss and condensation risk should be quantified. This requirement was met for 'dwellings and similar buildings' by the introduction of a book of 'robust construction details'[10] and for site assembled and composite panel buildings by the MCRMA Guide 14[3]. A BRE Information Paper, IP 17/01[11], provided details of the calculations of the heat loss parameter, the -value, and the condensation risk parameter, the f-value, that are necessary to comply with the Regulations; this IP has now been updated as IP 1/06[16]. These provisions have been retained in the new version of AD L2 that was published in April 2006[1,2]. Because they often involve complex three-dimensional building details, thermal bridge calculations are difficult to carry out without introducing errors and uncertainties.

3.4 Internal surface temperatures

In winter the internal surfaces of external walls and roofs are colder than the internal air temperature, especially in areas of lower thermal insulation. This is especially true at thermal bridges, where the temperature can fall low enough to cause mould growth or condensation. Depending on the internal environment and the materials present, this may be:

- a temporary nuisance in cold weather;
- cause water to drip onto equipment or processes within the building;
- cause mould growth, which can damage internal finishes and has implications for the health of the occupants;

Surface temperature is expressed in terms of the surface temperature factor or f-value, which is a property of the structure and not the assumed internal and external temperatures - see Section 13.

$$f = \frac{T_{si} - T_e}{T_i - T_e} \qquad (3)$$

Where T_{si} is the surface temperature, T_i is the internal air temperature and T_e the external air temperature.

In many construction types, masonry or timber framed for example, because the lowest internal surface temperatures are associated with the thermal bridges, the -value and f-value are calculated together. In twin skin and composite panel metal cladding systems, although there are some details where the lowest surface temperatures are at the thermal bridges, there are many where the f-value is associated with the spacers or panel joints that are part of the plane wall or roof. In these cases, the same 3D model, which incorporates profiles and spacers or panel joints is used to calculate both the U-value and the f-value. In this case a much simpler 2D model can often be used to calculate the -value.

4.0 Multi-dimensional modelling

To obtain an accurate U-value and, in many cases the f-value, it is necessary to take account of spacers, panel joints and profiles; a detailed three dimensional model is therefore usually necessary. In most cases, however, the -value of a junction may be obtained from a simple two dimensional model, which does not incorporate spacers or profiles.

To obtain U-values of plane areas, -values of thermal bridges or the f-value using multi-dimensional heat flow calculations it is necessary to use software packages, which require the user to:

- Decide which features of the construction should be modelled – Section 5
- Define the thermal conductivity of each of the materials present – Section 6
- Allow for features such as air cavities in the structure – Section 7;
- Specify appropriate internal and external surface thermal resistances - Section 8;
- Decide which features are part of a plane element and which are part of a thermal bridge – Section 9;
- Specify and input a two- or three-dimensional grid and position each material present within this grid – Section 10;
- Subdivide the grid to give accurate results within a reasonable time – Section 10;
- Calculate the U-value of the plane elements adjacent to the bridge – Section 11.
- Calculate the -value – Section 12 - and the f-value – Section 13 – from the heat flows and temperatures output by the software.

A worked example is included in Section 14 to draw the various ideas together.

Although there are standards for multi-dimensional heat flow calculations[12,13], these set out very broad guidelines that the calculations and software must follow and do not provide the detailed guidance that is necessary before consistent results can be obtained. This guide sets out to provide that guidance, with particular reference to the considerations that are important in metal cladding.

5.0 Details that should be included in models

Site assembled and composite panel walls and roofs are made from:

- profiled metal liner and outer sheets;
- fixing systems or panel joints, which cross or partially cross, the insulation layer between the sheets;
- purlins and cladding rails, which support the sheets or panels from the inside;
- air cavities where insulation does not fill, for example, spacer rails or profiles
- fasteners which hold it all together.

It is important to consider which of these should be included in a model of the structure to obtain the accurate values of heat flow and inside surface temperature necessary for the calculation of the U-value, -value and f-value.

It is also very important to include representative areas of the fabric to obtain correct estimates of the heat loss.

5.1 Fasteners, brackets etc. that cross the insulation

All metal features that cross, or partially cross, the insulation must be modelled in detail. This includes all through fasteners, spacer systems, such as rail and bracket, zed spacers, aluminium clips and any liner sheets that cross the insulation at corners.

Many spacer systems can have a complex geometry; this need not be represented in full. The important information to include is the width and thickness of the metal elements that cross the insulation. Figure 1 shows an example of an appropriate model of a rail and bracket spacer system. This system will often include fixings that cross the thermal break pad at the base of the bracket. These wil have negligible effect on the U-value, but will reduce the f-value slightly – see A.0.

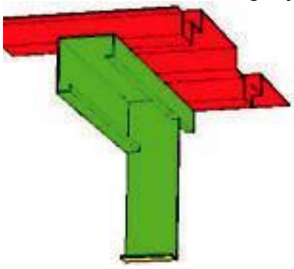


Fig 1: Model of rail and bracket spacer system

5.2 Panel joints

The joints between composite panels can cause significant heat loss and lower internal surface temperatures, especially if there is a continuous metal connection through the joint. Because individual joints vary considerably, it is difficult to develop general rules, they have to be modelled individually. Methods for modelling are discussed in section 11.3.

5.3 Purlins and cladding rails

If purlins or cladding rails are not in close contact with major bridging elements, they need not be included in the model because they have little effect on the heat flow through the structure. For example, Figure 2 shows a cladding rail on a twin skin wall with a rail and bracket spacer system. If the cladding rail is included in the model used to calculate the U-value of the wall, the result is 0.354 W/m^2K. If the cladding rail is omitted, the U-value is 0.353 W/m^2K. As U-values should be reported to two figures, both these are 0.35 W/m^2K.

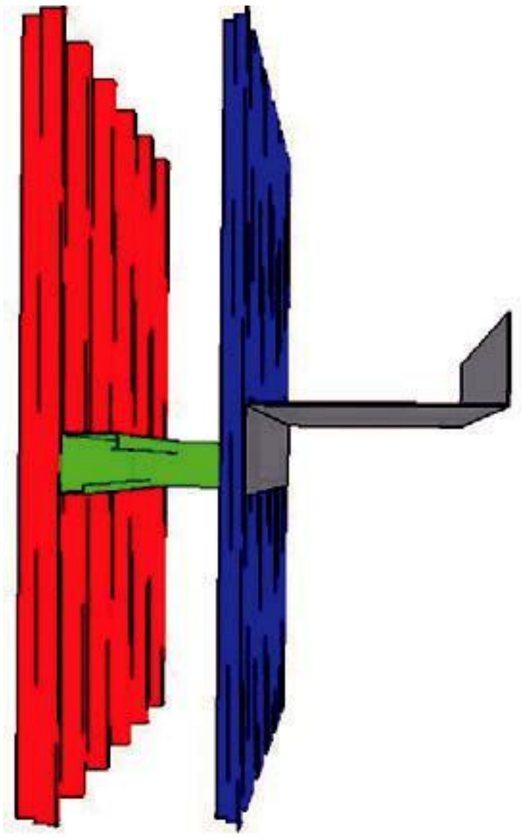


Fig 2: Twin skin metal wall with insulation omitted

Including the rail does make a slightly larger difference to the minimum surface temperature or f-value, because the rail acts to bring heat to the inside surface. In the case shown in Figure 2, including the rail gives a minimum f-value of 0.817, while eliminating it lowers the value to 0.805.

If a rail or purlin is in contact with a major bridging element it should be included. Figure 3 shows a gutter with the gutter top between the purlin and the liner sheet of the adjacent roof. If no thermal break, as shown in the figure, is included, the gutter top forms a major thermal bridge, with the high -value and low f-value shown in Table 1. In this case including the purlin makes a significant difference to both parameters as shown in the table. If the thermal break is incorporated to minimise
the thermal bridge, including the purlin makes little difference.

	-value	f-value
With no thermal break at gutter top		
With purlin	1.59	0.70
Without purlin	1.34	0.59
With thermal break at gutter top		
With purlin	0.129	0.97
Without purlin	0.127	0.96

Table 1: The effect of including a purlin on the calculated -values and f-values for a gutter with and without a thermal break

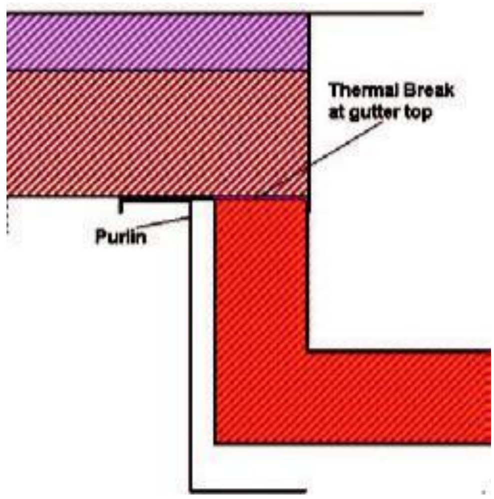


Fig 3: Purlin fixed to gutter top

As rails or purlins are relatively easy to specify it is recommended that they are included in all models.

5.4 Air cavities

Many building fabric elements contain air cavities, which, as discussed in Section 7, have to be treated specially in models. Very small cavities, such as those that may be left between liner profiles and insulation, can be ignored, but any cavity that is larger than 5mm deep should be included. Two common examples, the cavity left when the insulation does not fill the space within a spacer rail and the cavities between the insulation and the outer profiles, are shown in Figure 4.

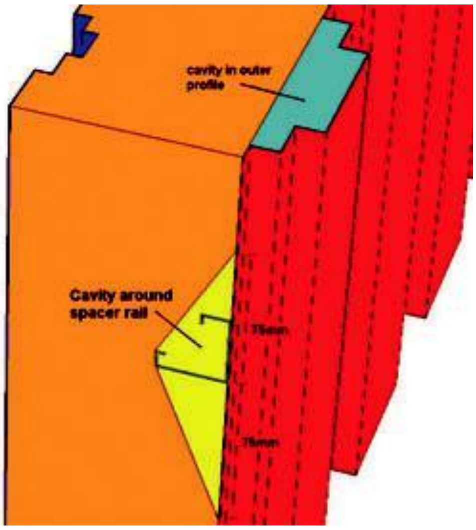


Fig 4: Cavities in the spacer rail and within the profiles of the outer sheet.

Tests by a spacer manufacturer have shown that a spacer rail depresses the insulation for about 75mm on either side of the lowest point of the rail, as shown on Figure 4. This triangular space can be approximated by a series of steps – Figure 5.

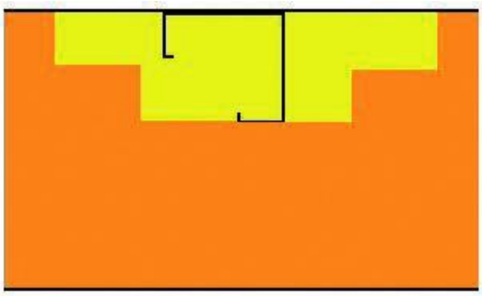


Fig 5: Approximation of the triangular cavity around a spacer rail by a series of steps

Other cavities may occur if insulation is not taken round a corner or in the roof eaves. Some cavities may be ventilated to the outside; this strongly affects their thermal performance and should always be taken into account – see section 7.2.2.

5.5 Profiles

Both the outer and liner sheets in site assembled and composite walls and roofs are often profiled. These affect the heat transfer through the structure:

- The surface area of the outer and liner sheets is larger than it would be without the profiles – this will increase heat transfer.
- The liner profiles locally reduce the insulation thickness – this will increase heat transfer.
- There is an air cavity between the outer profiles and the top of the insulation – this will reduce heat transfer, however as this cavity is usually ventilated to some extent, its effect is reduced.

A typical liner profile, with the parameters that define its shape, is shown in Figure 6.

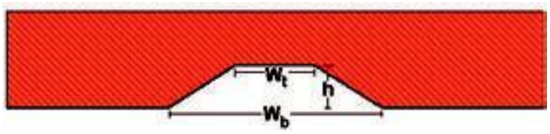


Fig 6: Liner profile with parameters that define its shape

With W_t = 30mm, W_b = 80 mm, h = 18mm, the profiles at 200mm centres, and a total insulation thickness, away from the profiles, of 118 mm, the profile increases the surface area of the liner sheet by 5.8% and reduces the average insulation thickness by 4.2%.

With insulation of thermal conductivity of 0.037 W/mK, the combined effect of these increases the U-value of the construction from 0.300 W/m^2K to 0.323 W/m^2K. The corresponding f-values are 0.970 and 0.969 respectively.

Methods for taking account of the effect of profiles on U-value calculation are included in the guidance documents covering zed-spacers[8] and rail and bracket fixing systems[9] and the BRE U-value calculator[6].

If a model of the construction is being developed to calculate the U-value and its f-value, the liner and outer profiles should be included.

While some software can take account of the sloping lines at the profile edges, other packages (TRISCO for example) work only on rectangular shapes. To use these it is necessary to approximate the profile as a series of steps as shown in Figure 7.

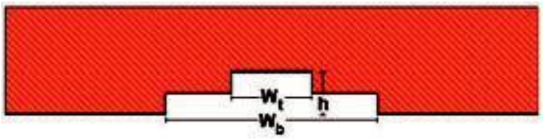


Fig 7: Liner with profile with slopes approximated as a series of steps

This approximation can be done in more or less complex ways, with increasing numbers of steps, or adjusting the height and width of the steps to match the areas taken up by the real and stepped profiles or the increased surface areas. However a very good approximation of the heat flow results from the two steps as shown in Figure 7, with the sizes matched as shown in the two figures.

With the values for the wall used above, the full sloped profile gives U= 0.3238 W/m^{2}K and the stepped profile gives U = 0.3245 W/m^{2}K, which agree very well within the necessary accuracy. The f-values are even closer, being 0.96915 for the sloped profile and 0.96908 for the stepped profile.

5.6 Fasteners

Fasteners which do not cross the insulation layer have a negligible effect on heat flows and can be ignored in models for U-value, -value or f-value calculations. Fasteners which cross a thermal break pad alone, will have a negligible effect on the U-value or -value but may reduce the f-value slightly.

5.7 Metal cladding meeting other systems

Some details contain elements where a metal cladding system meets a separate component from a different supplier. Common examples are the sill where a metal wall meets either a masonry wall or a concrete floor slab (Figure 8), or at a window opening, where the window frame and glazing are provided by the glazing contractor.

As the heat loss and surface temperatures through this type of detail depend on both the elements present, it will not be possible for the cladding designer to calculate the f-value or -value without knowledge of the other element. To avoid this difficulty the performance of the cladding detail may be calculated by assuming that there is no heat flow between the cladding and the other element. This is done by imposing an adiabatic boundary condition at the join between the two elements – see Figure 8. This is done by defining a boundary condition as usual within the software, but putting the surface heat transfer coefficient, h, to zero.

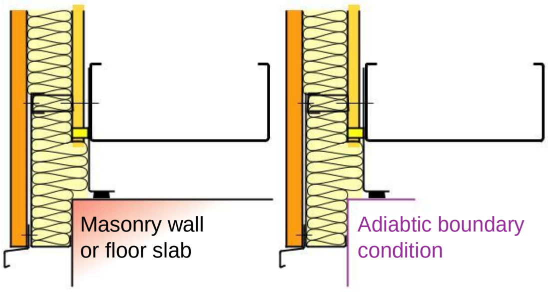


Fig 8: Use of an adiabatic boundary condition at a sill on a masonry wall or floor slab

This technique will give a reasonable estimate of the heat loss and surface temperatures in the case of window surrounds, but is unrealistic when used to model a sill meeting a masonry wall or floor slab. For example, Table 2 shows the f-value and -value calculated for the detail shown in Figure 8, with a) the adiabatic boundary shown in the figure, b) a masonry wall with an adiabatic boundary where the cladding joins it, and, c) the cladding and masonry wall together. In this case the thicker wall insulation above the point where the systems meet, leads to a negative -value when the adiabatic boundary condition is used. The sum of the -values from a) and b) is 0.17 W/mK, half that when the two are combined in c). The f-value of the combined cladding and wall is well below that of the cladding alone and well above that for the wall alone.

d) shows the values for a floor slab alone with an adiabatic boundary corresponding to the position of the cladding and e) the values with the floor slab and cladding combined. The sum of the -values from a) and d) is 0.86 W/mK, about 75% that when the two are combined in c). The f-values are very different in the three cases – a) d) and e).

Modelling the cladding with an adiabatic boundary alone will severely underestimate the effect of this important thermal bridge. It is not at present possible to obtain a reasonable result by combining values derived from separate models containing adiabatic boundaries. It will therefore be necessary to model the cladding and wall or floor slab together.

	f-value	-value – W/mK
a) Cladding with adiabatic boundary	0.94	-0.02
b) Masonry wall with adiabatic boundary	0.50	0.19
c) Cladding and masonry wall	0.71	0.33
d) Concrete floor slab with adiabatic boundary	0.53	0.88
e) Concrete floor slab with cladding	0.61	1.10

Table 2: f-value and -value calculated for the detail shown in Figure 8 for an adiabatic boundary condition and with the inclusion of a masonry wall and ground floor slab with an adiabatic boundary condition and in combination with the cladding.

When the -value of a junction between cladding and a ground floor slab is being calculated, special techniques specified in BS EN ISO 13370[17] must be used to calculate the ground floor U value – see section 12.4.

5.8 Point thermal bridges

Most thermal bridges are linear features where two plane elements of a building meet; however, in some cases, steel elements penetrate the insulation only at discrete points. Typical examples are harness attachment points, which penetrate a roof or beams attached to the structural steelwork within the building, which pass through the insulated cladding to support, for example a canopy or an eaves gutter.

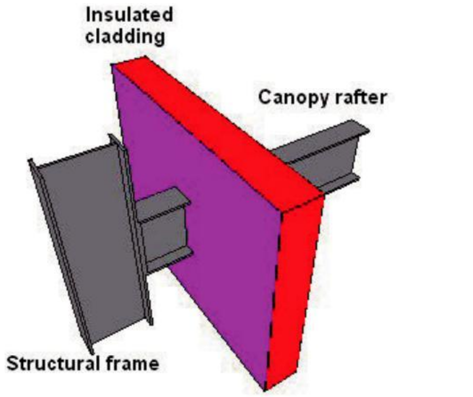


Fig 9: Canopy rafter forming a point thermal bridge

These can add to the heat loss from the building, and more significantly, lower the surface temperature low enough to promote condensation within the building.

5.9 Parapets and overhangs

There are two methods of construction for parapets and overhanging verges and eaves, which are generally similar in both twin skin and composite panel constructions, as shown in Figure 10

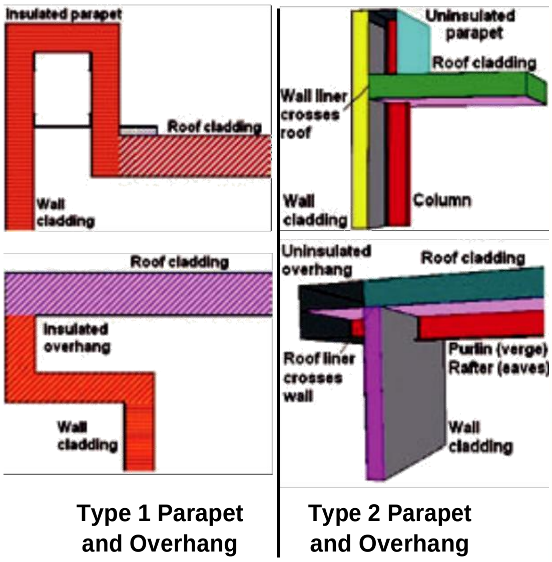


Fig 10: The two types of parapets and overhangs

In Type 1, the parapet or overhang is insulated so that it adds to the heated internal volume of the building and adds to the surface area from which heat will be lost. This increased surface area raises the -value significantly and the -value

will increase as the height of the parapet or length of the overhang increases. On the other hand, the line of the insulation is continuous and is not crossed by any metal components so there are no local severe thermal bridges and the f-value remains high.

Type 1 parapets and overhangs may also be analysed by finding the areas and U-values of the additional plane areas and the -values and f-values of the corners between them. This approach will give the same f-values as the approach described above, but much lower -values, if the corners are designed and constructed appropriately. However, both techniques will give the same overall heat loss, i.e. AU + L , for the building.

In Type 2, the parapet or overhang is not insulated, and the line of the insulation follows the normal eaves or verge, with no increase in the heated volume or surface area. However there are two sources of thermal bridging:

- the insulation line is penetrated by beams or purlins or columns, which are typically at 6 to 8m centres in the case of beams and typically at an average spacing of 1.5m centres in the case of purlins.
- in details with parapets, the wall liner crosses the roof insulation and details with overhangs, the roof liner crosses the wall insulation.

Both of these cause severe local thermal bridging, which can lower the f-value in the area of the penetration low enough to lead to a risk of condensation, and raise the -value. The f-value and -value are effectively independent of the height of the parapet and length of the overhang.

In this case, therefore, the normal correlation between high -value and low f-value breaks down, as Type1 constructions have both high -values and f-values while in Type 2 both are lower.

5.10 Size of the model

It is very important that any models, which are to be used to calculate the U-value or -value of a structure, include a representative section of the building. For example, if a model is to be used to find the U-value of a roof or wall containing spacer rails at 1800mm centres and brackets along the rails at 600mm centres, the model must be as shown in Figure 11. A smaller model will overestimate the heat loss through the rail and bracket therefore the U-value; conversely a larger model will underestimate the U-value.

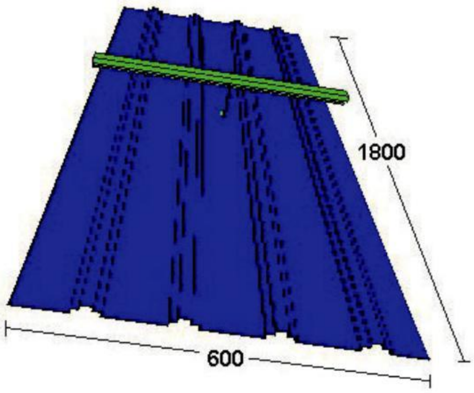


Fig 11: Model of a twin skin roof with rail and bracket fixing systems at 1800mm and 600mm centres respectively (with outer sheet and insulation removed)

Strictly, representative sections of liner and outer profiles should also be included, as shown in Figure 12.

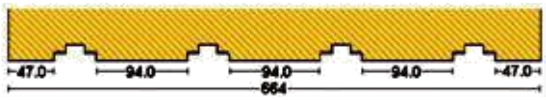


Fig 12: Representative section of liner profile

However if liner and outer profiles are at different centres, as shown in Figure 13, this becomes practically impossible. To represent both profiles completely, the model would have to be the lowest common multiple of the two centres wide. So that if, for example, the liner profiles were at 210mm centres and the outer at 190mm centres, the model would have to be 3990mm wide.

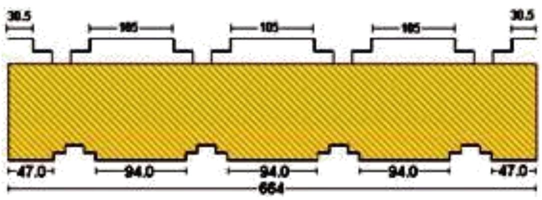


Fig 13: Liner and outer profiles at different centres

6.0 Material thermal conductivities

The situation becomes more complex when spacer systems such as rails and brackets have to be taken into account. With brackets at 600mm centres, as the major thermal bridges in the system it is more important to size the model to represent them fully, as shown in Figure 14.

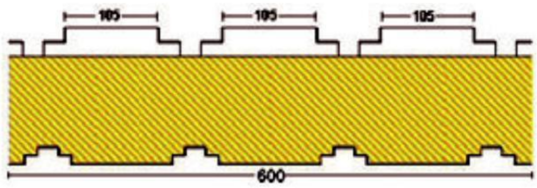


Fig 14: Model constrained by brackets at 600mm centres

The most accurate results will be obtained by ensuring that the more important thermal bridges are most accurately represented, therefore fixing systems that cross the insulation should be given priority over profiles, and liner profiles, which affect the insulation thickness, should be given priority over outer profiles, which do not.

All heat transfer calculations rely on the use of accurate values of the thermal conductivity of all the materials present. The two most important general sources of information are BS EN 12524:2000[14] and CIBSE Guide A[5], however manufacturers literature also provide information on specific products. The values used in calculations should always be listed with the results.

Table 3 gives values for the more important materials used in metal faced wall and roof construction.

Material	Conductivity W/mK
Metals	
Steel	60*
Stainless steel	17
Aluminium	160
Copper	380
Other materials	
Timber	0.14
PVC	0.17
Polyester resin	0.20
Polycarbonate	0.20
Polythene thermal break	0.35
Insulants	
Glass fibre	0.040
Mineral wool	0.037
Expanded polystyrene	0.035
Urethane	0.022

Table 3: Thermal conductivities of typical materials

* Some standards, including BS EN 12524[14], and the BRE U-values Conventions[7] quote a conventional value of 50 W/mK for the conductivity of steel. The available information suggests that 60 W/mK is a more appropriate value for metal cladding systems. That value was used in the preparation of MCRMA Technical Note 14[3] and has been assumed in this guide.

7.0 Effective thermal conductivity of air cavities

Heat transmission through air cavities within a structure is by a complex mixture of convection and radiation and depends on the dimensions and orientation of the cavity, the emissivity of the surfaces and the degree to which the cavity is ventilated to the outside. The emissivity of a surface is the property that determines how much infra-red radiation it emits at any given temperature. The emissivity of almost all materials in buildings is between 0.9 and 1.0. Only those materials with a polished metal surface, such as aluminium foil, have lower emissivities, close to 0.1. If either or both of the surfaces of a cavity have an emissivity less than 0.2, the radiative component of heat transfer across the cavity will be reduced and so the thermal resistance of the cavity will be higher, i.e. its effective thermal conductivity will be less.

It should be assumed that the emissivity of all materials is high unless there is evidence to the contrary.

7.1 Use of CEN values

One software package, TRISCO, includes the option of implementing the calculation rules included in BS EN ISO 10077-2:2003[15]. This procedure calculates the effective thermal conductivity of the cavity depending on its orientation, dimensions, surface emissivity, the temperature difference across it and whether it is an 'internal' unventilated cavity or whether it is 'external' and partially ventilated. It is necessary to select the appropriate option within TRISCO using the coordinate system shown in Figure 15. For example CEN Xz_I is an internal cavity with heat flow parallel to X and width parallel to Z, while CEN Yx_E is an external cavity with heat flow parallel to Y and width parallel to X.

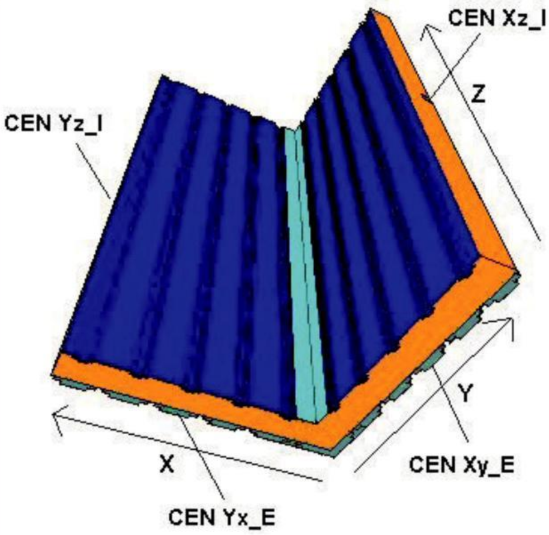


Fig 15: Coordinate system used to calculate 'CEN' cavities in TRISCO

There are a number of disadvantages to this system:

- The equations in BS EN ISO 10077-2 are designed for the cavities in PVC or metal window frames, which play a very significant role in the thermal performance of the frame. It is not clear whether they are applicable to the much larger cavities in metal cladding constructions.
- It is very easy to make a mistake with the coordinate system; this can lead to major errors in the conductivities. In the example shown in Figure 15, the conductivity of CEN Xz_I is 0.15 W/mK while CEN Yx_I = 3.06 W/mK.
- The BS EN ISO 10077-2 equations may not be implemented in software packages other than TRISCO, or even if they are implemented, they are so complex that they might lead to different cavity conductivity values.
- Because the calculated cavity conductivity depends on the temperature difference across the cavity, which depends on the cavity conductivity, it is necessary to repeat the whole calculation of the heat flows through the structure up to five times before the correct value is obtained. This significantly adds to the calculation time.

Using the 'CEN cavity' system therefore makes calculations more complex and introduces a degree of uncertainty that may make it more difficult to compare results found by different people. Use of the standard cavity resistances specified in BS EN ISO 6946 and CIBSE Guide A will overcome these difficulties.

7.2 Standard cavity resistances

7.2.1 Unventilated cavities

BS EN ISO 6946 and CIBSE Guide A quote standard values for the thermal resistance of unventilated cavities as a function of the thickness of the cavity and the direction of heat flow; these are shown for cavities with high emissivity surfaces in Table 4.

	Direction of heat flow		
Thickness of air layer mm	**Upwards**	**Horizontal**	**Downwards**
0	0	0	0
5	0.11	0.11	0.11
7	0.13	0.13	0.13
10	0.15	0.15	0.15
15	0.16	0.17	0.17
25	0.16	0.18	0.19
50	0.16	0.18	0.21
100	0.16	0.18	0.22
300	0.16	0.18	0.23

Table 4:Thermal resistance (in $m^2 \cdot K/W$) of unventilated air layers : high emissivity surfaces

TRISCO, and other software packages, requires the input of the thermal conductivity, , of a layer. Given a cavity of thickness d metres, it is necessary to calculate the thermal conductivity that would give the resistance shown in Table 4 using:

$$= d/R \quad W/mK \qquad (4)$$

Where R is the resistance from Table 4.

	Direction of heat flow		
Thickness of air layer mm	**Upwards**	**Horizontal**	**Downwards**
5	0.045	0.045	0.045
7	0.054	0.054	0.054
10	0.067	0.067	0.067
15	0.094	0.088	0.088
25	0.156	0.139	0.132
50	0.313	0.278	0.238
100	0.625	0.556	0.455
300	1.875	1.667	1.304

Table 5: Thermal conductivity in W/mK of unventilated air cavities with high emissivity surfaces to achieve the thermal resistance values shown in Table 4

The values in Table 5 are directly proportional to the thickness of the layer, d in metres, and can be expressed as:

Upwards heat flow: $= 0.00511 + 6.227 \cdot d$ W/mK (5)

Horizontal heat flow: $= 0.00858 + 5.518 \cdot d$ W/mK (6)

Downwards heat flow: $= 0.0247 + 4.268 \cdot d$ W/mK (7)

For example, the equivalent thermal conductivity for a 32 mm deep cavity in a roof rib, will be 0.204 W/mK

7.2.2 Ventilated cavities

If a cavity is affected by air flow from the outside of the building its thermal properties will be modified. BS EN ISO 6946 distinguishes a number of cases.

Minimal ventilation

If there is no insulation between a cavity and the external environment and small openings to the external environment, it can be considered as an unventilated air layer, if these openings are not arranged so as to permit air flow through the layer and they do not exceed:

500 mm^2 per m length for vertical air layers;
500 mm^2 per m^2 of surface area for horizontal air layers.

8.0 Surface heat transfer

Slightly ventilated cavity

A slightly ventilated cavity is one in which there is provision for limited air flow through it from the external environment by openings within the following ranges:

> >500 mm^2 but δ 1,500 mm^2 per m length for vertical air layers;
> >500 mm^2 but δ 1,500 mm^2 per m^2 of surface area for horizontal air layers.

The thermal resistance of a slightly ventilated cavity is half of the corresponding value in Table 4 and thermal conductivity twice that given in Table 5 or equations (5) to (7)

Well ventilated cavity

A well ventilated cavity is one for which the openings between the air layer and the external environment exceed:

> 1,500 mm^2 per m length for vertical air layers;
> 1,500 mm^2 per m^2 of surface area for horizontal air layers.

The total thermal resistance of a building component containing a well-ventilated cavity should be obtained by disregarding the thermal resistance of the cavity and all other layers between the cavity and the external environment, and including an external surface resistance corresponding to still air (i.e. equal to the internal surface resistance of the same component).

The most important ventilated cavities in metal faced construction are those between the outer profiles and the insulation. If these have typical vented fillers at eaves and ridge, they can be considered as slightly ventilated cavities and the thermal conductivities adjusted as specified above. If no fillers are included they should be treated as well ventilated cavities.

Heat transfer between the air in a building or outside and the surfaces of the building is a very complex process, depending on a combination of radiation from surrounding materials and convection from air movement over the surface.

For practical calculations to be possible, a series of standard coefficients have been developed, which at the inside surface depend on the direction of heat flow. These values, R_{si} and R_{se}, which are quoted as surface thermal resistances in BS EN ISO 6946[4] and CIBSE Guide A[5], are shown in Table 6, together with their reciprocals, h_{si} and h_{se}, the surface heat transfer coefficients, which are required as inputs to software.

	Direction of heat flow		
	Upwards (roof)	**Horizontal (wall)***	**Downwards (floor)**
Inside surface			
R_{si} m^{2}K/W	0.10	0.13	0.17
h_{si} W/m^{2}K	10.0	7.7	5.9
Outside surface			
R_{se} m^{2}K/W	0.04	0.04	0.04
h_{se} W/m^{2}K	25.0	25.0	25.0

Table 6: Standard surface resistances and heat transfer coefficients

*The values under "horizontal" apply to heat flow directions ± 30° from the horizontal plane, i.e. if a roof slope is greater than 60°, the wall values should be used, otherwise the roof-values are used.

The appropriate values from Table 6 should always be used in calculations.

9.0 Assignment of features to plane elements and to thermal bridges

As described in Section 3, the fabric heat loss can be divided into that through the plane elements, represented by the U-value and that through the thermal bridges, which are generally the joints between the plane areas, represented by the -value. In any construction the lowest internal surface temperature and therefore the f-value may be associated with either one of the plane elements or with the thermal bridge.

When a structure is being analysed it is important to decide which features affect the heat flow through the plane areas and should be assigned to the U-value, and which affect heat flow through the thermal bridge and should be assigned to the -value. Otherwise there is a danger that some features will be included in both and their effect on the heat loss counted twice.

For example, Figure 16 shows a section of a corner between two walls with rail and bracket spacers. The brackets which cross the insulation act as thermal bridges and should be included in any calculation of the heat loss. If they are a normal part of the wall structure, they must therefore be included in the calculation of the wall U-value and not included in the calculation of the -value. Alternatively, if there are extra brackets in the corner for structural or other reasons, they must be included in the -value calculation. See Section 12 for details of the calculation method.

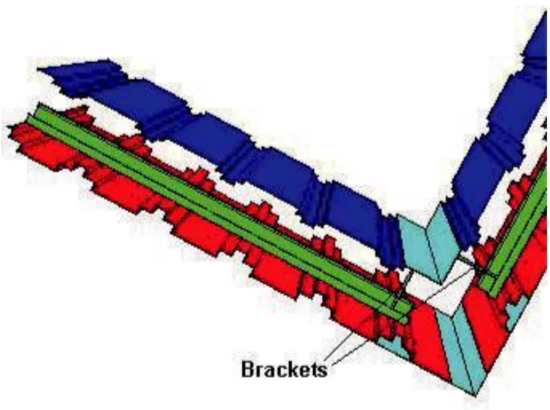


Fig 16: Corner between two walls with insulation removed to show the rail and bracket fixing system

10.0 Defining the grid points

Once the details of the structure to be modelled have been finalised, the first task in developing a structure for thermal calculations in any of the software packages is to set up a two or three dimensional grid of points, within a three dimensional coordinate system, which defines the relative positions of the materials making up the detail.

In principle, the three co-ordinates of the system, X,Y and Z, can be oriented in any direction relative to the structure, however, to avoid confusion it is best to adopt a consistent convention, where X and Y represent the two horizontal co-ordinates and Z the vertical as shown, for a corner between two walls, in Figure 17.

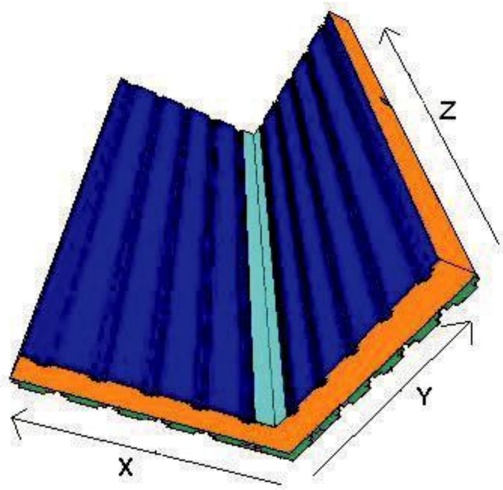


Fig 17: Recommended X,Y, Z directions for a corner between two walls

Initially a ‘minimum grid’ in which the points define only the corners of the materials is constructed. This is shown for a simple two dimensional structure with a steel fixing joining two sheets of steel with insulation between in Figure 18, in which the points where the black lines cross define the grid. The heat flows and temperatures can be calculated using this minimum grid, and because this calculation will be fast, it is worth doing this and inspecting the result to check that the structure and boundary conditions have been correctly defined. However, the results from this minimum grid will not be correct, especially in structures with thin metal components crossing insulation. The minimum grid should therefore be subdivided. This can be done easily in most software packages by automatically inserting new grid points to split all the intervals between the original grid points into two as shown in Figure 19.

This process can be successively repeated to subdivide the grid by 2, 4, 8, 16 etc. However, in a three dimensional model the number of grid points rises as the cube of the number of subdivisions, so that if the minimum grid has, for example 2,000 points, successive subdivisions will produce 16,000, 128,000, 1,024,000 and 8,192,000 points, which is difficult even for a fast computer with large memory.

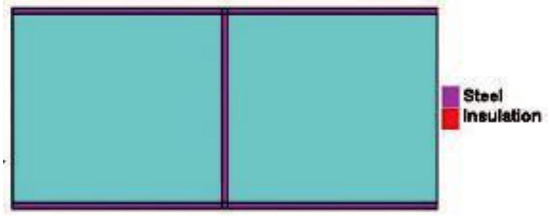


Fig 18: Two dimensional model of steel crossing insulation – minimum grid

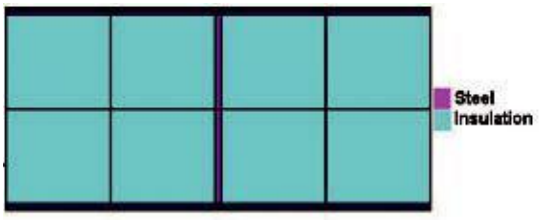


Fig 19: Two dimensional model of steel crossing insulation – minimum grid divided by two

The benefits of subdividing the grid can be seen in Figure 20 , which shows the heat flow and minimum surface temperature calculated through a corner including the inner and outer profiles and a rail and bracket spacer system, see Figure 16. As the minimum grid, with about 17,000 points is successively subdivided by two, without consideration of the materials present, the heat flow and temperature both fall by about 10 percent, when the grid has been divided 16 times to give about 1.7 million points.

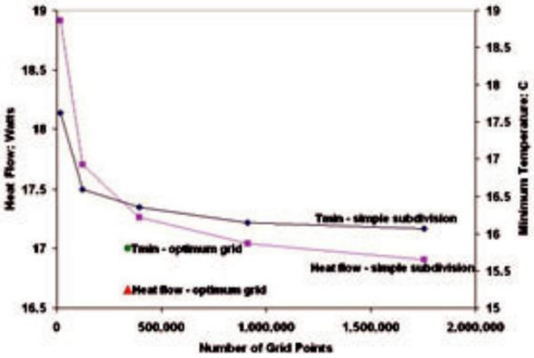


Fig 20: Calculated heat flow and minimum internal temperature in a corner model which is successively subdivided

As mentioned above, the process of successively subdividing the model is easy, but inefficient. A more satisfactory solution is to identify the important heat flow paths and concentrate the grid points near them as shown in Figure 21.

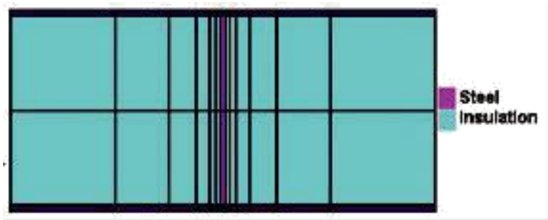


Fig 21 -Two dimensional model of steel crossing insulation – optimum grid

It is especially important to concentrate grid points near boundaries between materials with very different thermal conductivities, for example where steel passes through insulation as shown in Figure 21. TRISCO, and other software packages, includes the facility to include an 'expansion factor' in the grid subdivision process. When this is used to divide, for example, a 20mm section into five smaller sections, it does not simply produce equal 4mm sections, but sections which could be 1, 1.7, 3.0, 5.2 and 9 mm wide.

The minimum grid (17,000 points) on the model of the corner shown in Figure 16 was divided by two (122,000) and then the area around each bracket, shown in horizontal cross section in Figure 22, was subdivided in detail as described above giving 336,000 points. The calculated values of

11.0 Calculation of U-values from 2- and 3-D models

heat flow and minimum internal temperature for this “optimum grid”, shown on Figure 20, are lower than the values calculated with 1.7 million grid points with simple subdivision.

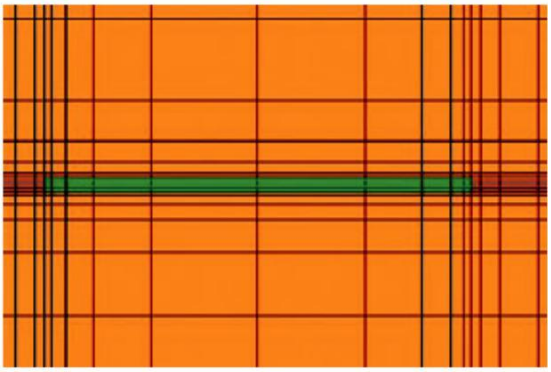


Fig 22: Horizontal cross section through a bracket (green) crossing insulation (orange) showing an ‘optimum’ grid in two dimensions concentrated about the metal/insulation interface

The best results are achieved by the following procedure:

1) Define the minimum grid necessary to specify the materials present.
2) Divide all the spaces between the grid points into two.
3) Identify all areas where the metal components cross insulation and add extra grid points as shown in Figure 22.
4) Calculate the resulting heat flow and lowest internal surface temperature.
5) Divide all the grid elements into two and recalculate the results.
6) If the heat flows calculated from stages 4) and 5) differ by less than 2% and the minimum surface temperatures by less than 0.1°C, the calculation is complete. If the change is greater, go back to stage 3) and investigate adding further grid points in sensitive areas and repeat stages 4) and 5), until good agreement is reached.

As noted in Section 9, it is very important to distinguish clearly between those features of the structure that are part of the plane elements adjacent to the thermal bridge and included in the calculation of its U-value, and those that are an intrinsic part of the thermal bridge.

It is also important to distinguish between:

- the U-value of the plane elements, necessary for the calculation of the overall loss from the building, and
- the U-values of those parts of a model used to calculate the -value - see Section 12

11.1 2-D models

If a structure can be represented purely in two dimensions with no features which cross or reduce the insulation and no profiles, so that the internal and external surface temperatures do not vary along its length, the U-value can be found from:

$$U = \frac{T_i - T_{si}}{T_i - T_e} \times h_i \qquad (8)$$

Where: T_i is the internal air temperature in °C T_e is the external air temperature in °C

T_{si} is the internal surface temperature at the edge of the model in °C

h_i is the internal surface heat transfer coefficient for that element in the model in W/m^2K

It is important to note that this equation cannot be used to calculate the U-value in a three-dimensional model or if outer and/or liner profiles are included – See Section 11.2.

11.2 3-D models

If details such as profiles or rail and bracket systems are included in the model, these will affect the temperature distribution over the internal surface. There will be no single T_{si} value that can be used to calculate the U-value as described in Section 11.1. It is therefore necessary to calculate the U-value with a full 3-D model, such as that shown in Figure 23.

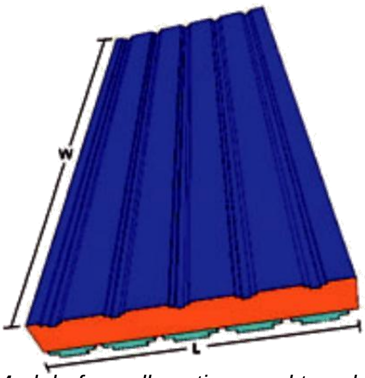


Fig 23: Model of a wall section used to calculate the U-value

The wall U-value is then calculated from the heat flow through the model, Q, using:

$$U = \frac{Q}{(T_i - T_e) \cdot L \cdot W} \qquad (9)$$

Where: Q is the calculated heat loss through the model, in W; L and W are the dimensions shown in Figure 23 in metres.

11.3 The effect of joints in composite panels

The joints between composite panels are so varied that it has not been possible to develop simplified rules for calculating the additional heat loss through them. It is therefore necessary to calculate the thermal performance in each case. Many panel joints are complex containing fine detail, which cannot be easily represented on a rectangular grid, but which plays an important part in the heat transfer – Figure 24. This can be modelled in detail with appropriate software to calculate the heat loss. A simplified model can then be constructed with a single material crossing the insulation and the conductivity of this material adjusted to give the same heat flow.

Fig 24: Detailed cross section of a composite panel joint and the simplified model to give the equivalent heat flow

11.4 Point thermal bridges

The effect of point thermal bridges, such as canopy rafters passing through a wall (see Figure 9), on the heat loss can be found by developing a model of the wall or roof including the point thermal bridge. The wall or roof area included in the model should extend at least a metre away from the thermal bridge in all directions. The 'point thermal transmittance' (pronounced 'chi') in W/K is then given by:

$$= \frac{Q}{T} - A \cdot U \text{ W/K} \qquad (10)$$

Where Q is the heat loss through the model in W

T is the temperature difference across the model in °C

A is the area of the wall or roof in the model in m^2

U is the U-value of the wall or roof, derived from the model, in W/m^2K

The total heat loss from the building from each type of point bridge is then found by multiplying the - value by the number of bridges of that type.

12.0 Linear thermal transmission - -value

Heat loss through linear thermal bridges is expressed in terms of the linear thermal transmittance or -value (pronounced 'psi'). This is the extra heat loss through the thermal bridge over and above the heat loss through the adjoining plane elements. For example, Figure 25 shows a corner in which the liner of one composite wall panel bridges the insulation of the other; this could apply equally well to a twin skin system in which the liner of one wall bridged the insulation of the other.

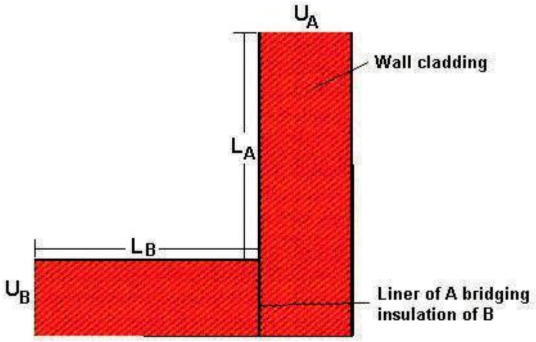


Fig 25: 2-D model of corner

The model is extended at least 1 metre in the third dimension and the -value calculated from:

$$= \frac{Q}{T_i - T_e} - U_A \cdot L_A - U_B \cdot L_B \text{ W/mK} \quad (11)$$

Where Q is the heat flow through the model in W/m T_i and T_e are the inside and outside temperatures in °C

U_A and U_B are the U-values of A and B in W/m^2K

L_A and L_B are the lengths of cladding A and B out from the inside corner in m

Because the calculation of the -value depends on the difference between the heat flow term and the U-value terms, it is very sensitive to the U-value used. Therefore, the U-value of the plane elements should never be assumed, but always calculated for each plane element from the output of the model.

It is essential that the U-values used in Equation (11), are those that apply to the plane areas in the model of the thermal bridge; these may be slightly different from those calculated from a representative model of the plane area. Even though this difference might be small it may be sufficient to change the -value significantly.

12.1 Two dimensional models without profiles

Strictly speaking, -values apply to two dimensional structures, where there is no variation in the third dimension, as in Figure 25, which includes insulation with flat metal liner and outer sheets on either side; no profiles or fixings are included. As shown in Section 12.2, it is possible to calculate a -value from a three-dimensional model, but the process is more complex and more care needs to be taken.

In a 2-D case, the U-value of the walls can be calculated from the internal surface temperatures from the model of the thermal bridge, provided they are taken far enough from the corner. For example Figure 26 shows the lines of constant temperature (isotherms) calculated through the detail shown in Figure 25.

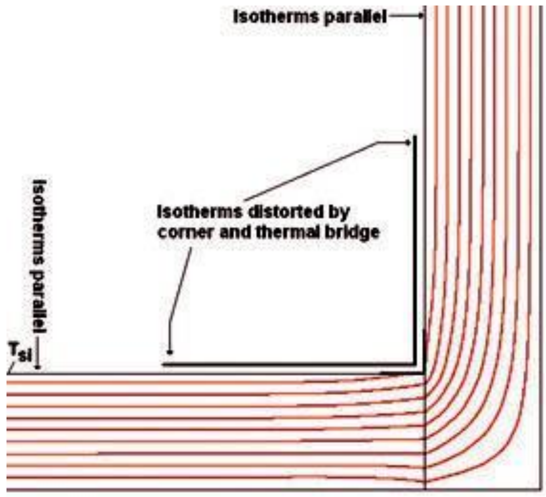


Fig 26 – Isotherms calculated from the detail shown in Fig 25

In the region of the corner and the thermal bridge, the isotherms are distorted and not parallel to the inner and outer sheets. However, if the model is extended sufficiently far from the corner, in both directions, the isotherms will become parallel, as shown in Figure 26. When this has been done correctly, extending the model further will not change the calculated internal surface temperature, T_{si}, at the edge of the model – see Figure 26.

In practice, one metre from the corner will usually be sufficient, however this should be checked by confirming that the T_{si} at the edge of the model changes by less than 0.01°C when the model is extended by a further 100mm away from the corner.

Most software packages will output the temperatures at all the corners of the materials, including at the edges; T_{si} can usually be determined from this provided the corner is correctly identified on the output. Alternatively, a very small 'marker material' with the same thermal conductivity as the liner sheet can be incorporated into the liner sheet at the edges away from the corner. This should be a cube with sides less than 50 percent of the thickness of the liner. The software will output the maximum and minimum temperatures of this material, which should be almost identical; the maximum temperature should be taken as T_{si}.

Because the U-value equation depends on the ratios of the temperature differences, it is very sensitive to the temperature values. Figure 27 shows the marked effect of varying the T_{si} value on the calculated U-value and -value. Use of incorrect T_{si} values can lead to a negative -value, which can only occur in details where the area of the external surface is less than the internal surface, such as an internal corner.

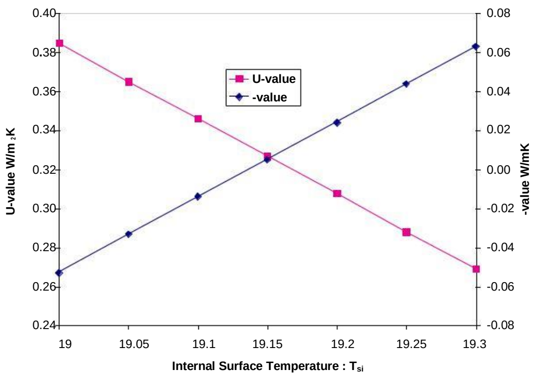


Fig 27: U-value and -value calculated from T_{si} value

12.2 Three dimensional models and models with profiles

If it is necessary to include details such as inner and outer profiles and spacers, such as a rail and bracket system, in the model – see Section 5 for a discussion of the features that should be included – a three-dimensional model, as that shown in Figure 28 must be constructed.

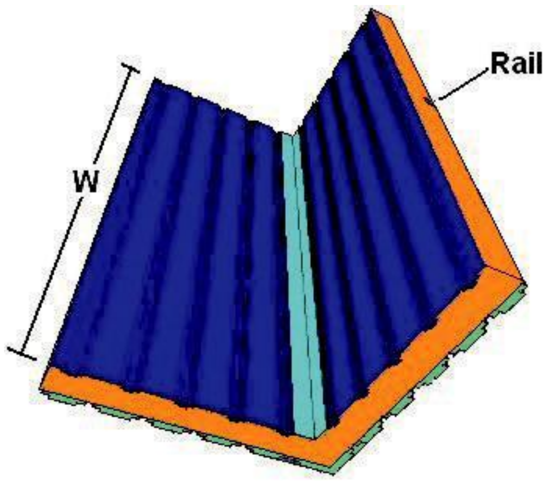


Fig 28: Three-dimensional model of corner including profiles and rail and bracket system

This alters the calculation of the -value in two ways.

1) The width of the model (W in Figure 28) may be different from the 1 metre assumed in Section 12.1, to represent, for example the heat flow through a construction with spacers at 1800mm centres. In this case the width, W, in metres must be included in the equation for the -value:

$$= \frac{Q}{(T_i - T_e)\cdot W} - U_A \cdot L_A - U_B \cdot L_B \quad (12)$$

2) the U-value of the walls must be calculated from a 3-D model as described in section 11.2; in this case the wall model should:
   a) contain all the features that would be present in the wall away from the corner,
   b) contain none of the features that are part of the corner, and
   c) use the same grid system for specifying the materials as is used in the full corner model.

Point c) is especially important because the calculated -value depends strongly on the calculated U-value, and the calculated heat flow, and therefore the U-value, depends on the grid system used in the model – see Section 10.

It is therefore strongly advised that the full corner model should be constructed first, then the wall model developed by deleting one of the walls and any features representative of the corner, without changing the grid system. If the corner and wall models are developed and gridded separately, the calculated -values will not be reliable.

12.3 Detail needed to calculate -values

Figure 29 shows a full model of a corner with the profiles of the liner and outer sheets and a rail and bracket spacer system fully represented. This can be greatly simplified as shown in Figure 30, so that the model contains only flat liner and outer sheets with no spacer system.

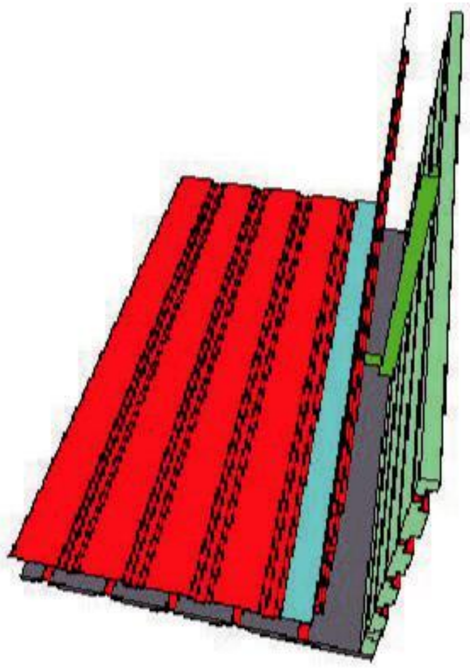


Fig 29: Full model of corner, with profiles and spacer system (insulation removed)

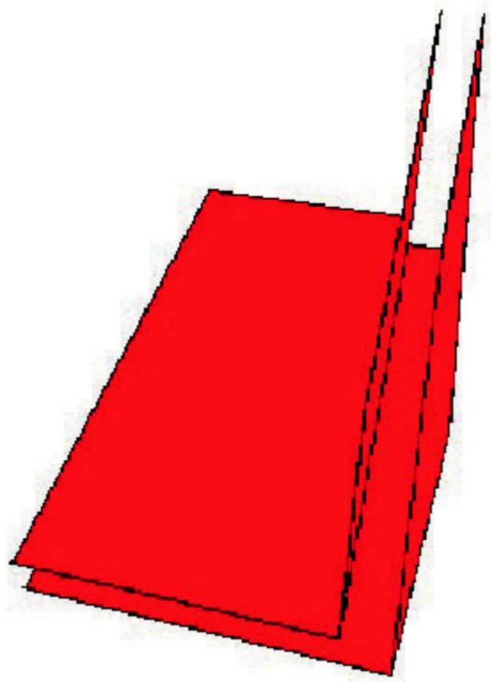


Fig 30: Simplified model of corner with no profiles and spacers

Table 7 shows the calculated heat loss through the full corner (Q_{3D}) and the wall model (Q_{2D}), the wall U-value and the resulting -values, from the full model and from models with progressive simplifications. This shows that, although the heat loss and wall U-value fall by almost 12%, when the model is greatly simplified, the change in -value is very small.

Table 8 shows the effect of dividing the calculation grid from the minimum grid, simply by 2 and by 4 and then by 2 with extra points around the thermal bridge, to give the case shown in row A of Table 7.

Although moving from the minimum grid to the 'optimum' grid reduces the heat flow through the full model and the wall U-value by almost 12 percent, the effect on the -value is very small.

These two examples show that, while a full model with attention to the appropriate number of grid points is necessary to calculate the U-value, the -value may be calculated from a much simpler model.

	Rail & Bracket	Profiles	Q_{3D}: W	Q_{2D}: W	U_{wall}: W/m^{2}K	: W/mK
A	Yes	Yes	16.656	7.919	0.356	0.027
B	No	Yes	15.451	7.348	0.331	0.025
C	Yes	No	15.804	7.533	0.339	0.025
D	No	No	14.692	6.975	0.314	0.025

Table 7: Thermal parameters calculated from the corner model shown in Fig 28, with a series of simplifications.

Grid	No of grid points	Q_{3D}: W	Q_{2D}: W	U_{wall}: W/m^{2}K	: W/mK
Minimum	17616	18.916	9.073	0.409	0.025
Divided by 2	122661	17.698	8.471	0.382	0.025
Divided by 4	911589	17.042	8.137	0.367	0.025
Divided by 2 with extra points at thermal bridge	359817	16.656	7.919	0.356	0.027

Table 8:Thermal parameters calculated from the corner model shown in Fig 28, as the grid is subdivided.

12.4 -values of junctions including ground floors

To calculate the -value of the junction between metal cladding and a ground floor slab, it is necessary to calculate a model of the junction, similar to that shown in Figure 31. To represent the heat flows realistically the length of the floor in the model (L_{floor}), must be half the width of the building, and the model must include ground extending out from the building (X) and down (Y) 2.5 times the width of the building. For example, for a large building 100m across, L_{floor} must be 50 m and X and Y 250 m

It is obviously unrealistic to assume that the ground is uniform for these large distances down and out from a building. However, this is an idealised calculation procedure which will allow different users to obtain consistent answers for the same building.

The -value is then given by:

$$= \frac{Q}{T_i - T_e} - U_{clad} \cdot L_{clad} - U_{floor} \cdot L_{floor} \text{ W/mK} \qquad (13)$$

Where Q is the heat loss from the model in W T_i and T_e are the inside and outside temperatures

U_{clad} and U_{floor} are the U-values of the cladding and floor in W/m^{2}K

L_{clad} and L_{floor} are the lengths of the cladding and floor in m

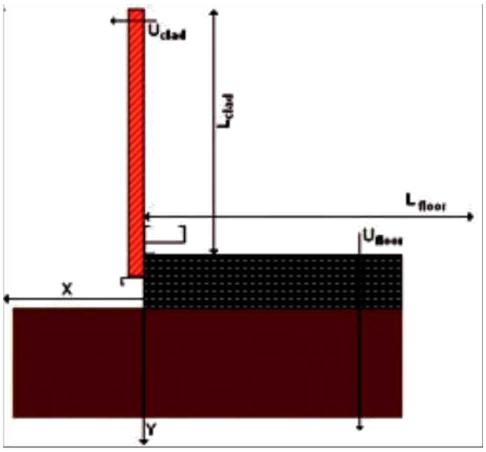


Fig 31: Dimensions of the model necessary to calculate the -value of a junction between metal cladding and a ground floor slab

Heat loss from ground floors is a complex process and depends as much on the size of the building, expressed as the ratio of the perimeter to the area, P/A, as on the nature of the floor. The ground floor U-value U_{floor} can be calculated using the methods defined in BS EN ISO 13370[17], which are implemented in the BRE U-value calculator[6]. When using this it is essential to input the P/A ratio of the model used to calculate the heat flow; i.e. with a model 1 metre wide, with L_{floor} = 50m, P = 1 and A = 50m^2.

13.0 Minimum internal surface temperature or f-value

The calculated internal surface temperature, T_{si}, will depend on both the internal and external temperatures and the structure of the detail that is being modelled. To separate the effect of the structure from that of the temperatures the surface temperature factor is calculated:

$$f = \frac{T_{si} - T_e}{T_i - T_e} \qquad (14)$$

Where T_i is the internal air temperature and T_e the external air temperature.

For a well insulated wall T_{si} will be close to T_i so that f will be close to 1. In a severe thermal bridge T_{si} will fall so that f may be 0.5 or less. Once the f-value has been calculated using one combination of inside, outside and surface temperatures, it may be used to calculate the surface temperature for any other combination of inside and outside temperatures from:

$$T_{si} = T_e + f \cdot (T_i - T_e) \qquad (15)$$

For example, if, for T_i = 20°C and T_e = 0°C, T_{si} = 14°C, f = 0.7.
Then, if T_i = 18°C and T_e = 2°C, T_{si} will be 13.2°C

It should be noted that the calculation of the f-value assumes that the internal and external temperatures are constant and that the building fabric is not warming or cooling.

BRE IP 1/06[16] gives values of the minimum f-value that should be achieved to minimise the risk of either mould growth or surface condensation in buildings with different occupancies – see Table 9.

The calculation of the surface temperatures and therefore the f-value depends critically on the value of the surface heat transfer coefficient assumed. This is less important in well insulated areas where the thermal resistance of the wall is much higher than the surface resistance. However at thermal bridges, where the effective thermal resistance of the wall is lower choosing the wrong surface resistance will make a very significant difference. This is illustrated in Table 10, which shows the f-factor calculated with three surface resistances, for three thermal bridge severities. It is assumed in each case that the horizontal heat flow case is correct.

Mould growth	f_{min}
Dwellings; residential buildings; schools	0.75
Swimming pool (including a dwelling with an indoor pool)	0.90
Surface condensation	
Storage buildings	0.30
Offices, retail premises	0.50
Sports halls, kitchens, canteens: buildings with un-flued gas heaters	0.80
Buildings with high humidity, such as swimming pools, laundries, breweries	0.90

Table 9: Minimum f- value to avoid either mould growth or surface condensation in buildings with different occupancies

Direction of heat flow	R_{si}	**No thermal bridge**	**Slight thermal bridge**	**Severe thermal bridge**
Upwards	0.10	0.95	0.81	0.65
Horizontal	0.13	0.94	0.75	0.55
Downwards	0.17	0.92	0.68	0.41

Table 10: Calculated f-values for three different thermal bridge intensities with different R_{si} values

The location of the lowest internal surface temperature and therefore the lowest f-value, will depend on the nature of the structure being analysed. In the case of the corner shown in Figure 32 the lowest temperatures are associated with the rail and bracket fixing system, which in this case happen to be close to the corner.

14.0 Worked Example

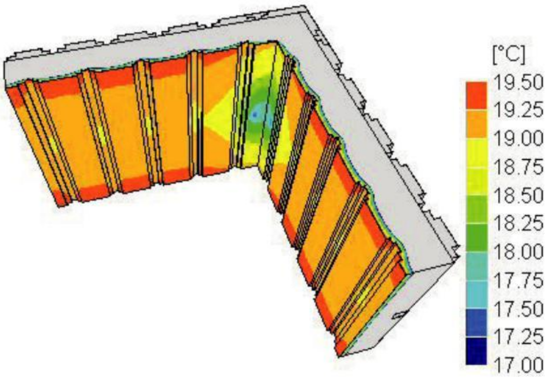


Fig 32: Calculated temperatures on the internal surface of a model of a corner which includes profiles and a rail and bracket fixing system

If it can be assumed that the brackets are a part of the wall and not part of the corner, the f-value should be derived from the wall model that is necessary to calculate the U-value.

The ideas discussed in the sections above are illustrated below using the corner between two twin-skin metal walls with a rail and bracket spacer system, shown in Figure 33.

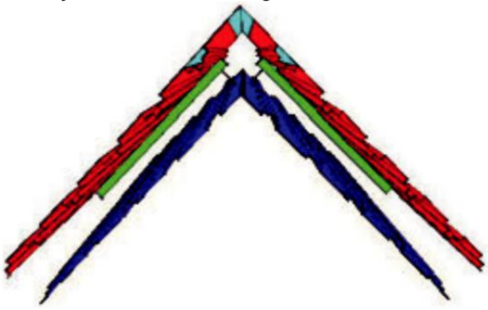


Fig 33: Outline view of corner with insulation removed for clarity

The rails are of 1.25mm steel at 1500 mm centres and the brackets are of 1.5mm steel at 600mm centres. There is 120mm of mineral wool, with conductivity 0.037W/mK, between the sheets and 3mm thermal break pads, with conductivity 0.35 W/mK, between the brackets and the liner sheet. The internal and external temperatures assumed are 20˚C and 0˚C respectively.

The following steps are necessary to find the U-value, -value or f-value:

14.1 Details to be included in the model

a) Spacers – Section 5.1
The rail and bracket system must be included in the calculation of the U-value and f-value as this crosses the insulation

b) Cladding rails - Section 5.3
As these only touch the bracket in a small area, they will have a negligible effect upon the heat flow, and so do not need to be included.

c) Air cavities – Section 5.4
There are air cavities in the spacer rail and inside the outer profiles.

d) Profiles – Section 5.5
The liner and outer profiles should be included in the calculation of the U-value and the f-value, either with realistic sloping sides, if the software can handle them, or with steps as described in section 5.5.

e) Fasteners - Section 5.6
It is assumed that there are no significant fasteners or point fixings that should be included.

f) Size of the model - Section 5.10
As the rails are at 1.5m centres and the brackets at 600mm centres, these must be the dimensions of the model to calculate the U-values.

14.2 Material thermal conductivities

See Table 2 in Section 6

Steel	60	W/mk
Mineral wool	0.037	W/mK
Thermal break	0.35	W/mK

14.3 Cavity thermal conductivities

There are two types of cavity in this detail – see Figure 34

a) Unventilated cavities through the rail of the spacer system - see Section 7.2.1
These are 38mm deep, with horizontal heat flow, therefore the conductivity given by equation (6) is:
$= 0.00858 + 0.005518 \times 38 = 0.218$ W/mK

b) Slightly ventilated cavities through the outer profiles - see Section 7.2.2, These are 30mm deep, with horizontal heat flow, therefore the conductivity is twice the value given by equation (6):
$= 2\times(0.00858+0.005518\times30)= 0.328$W/mK

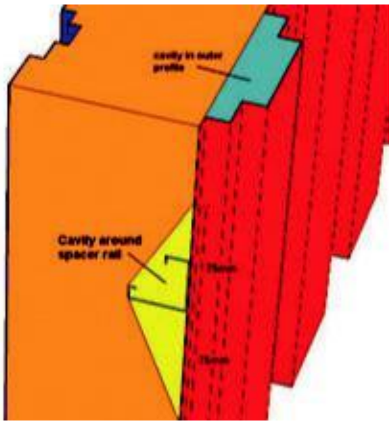


Fig 34: Unventilated cavity within the spacer rail and slightly ventilated cavity within the outer profiles

14.4 Specify the surface heat transfer coefficients

The standard values are taken from Table 5 in Section 8.

Internal – horizontal heat flow – h_{si} = 7.7 W/m^{2}K External – h_{se} = 25.0 W/m^{2}K

14.5 Decide which features are part of the thermal bridge

In this case the rail and bracket spacer system is assumed to be part of the wall and there are no extra brackets at the corner. The only extra features unique to the corner are the inner and outer trims, shown in pale blue on Figure 35. This also forms extra slightly ventilated cavities in the outer profiles as shown in the figure.

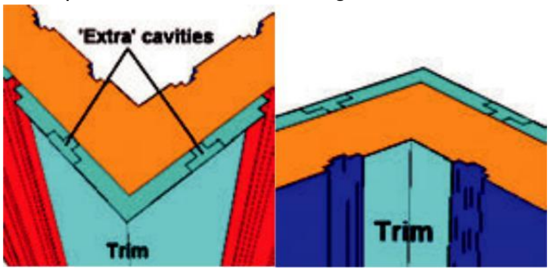


Fig 35: Extra features at the corner

14.6 Calculation of the wall U-value

A model of the wall with the longitudinal and cross sections shown in Figure 36 and Figure 37, is constructed. Note from Figure 37, that the profiles are not fully represented because priority has been given to the brackets, which are at 600mm centres – see Section 5.5.

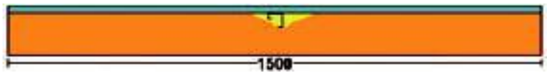


Fig 36: Longitudinal section of model to calculate wall U-value

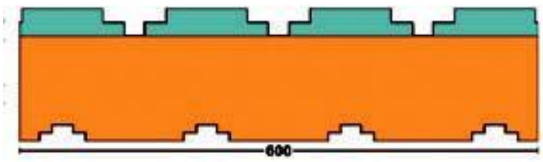


Fig 37: Cross section of model to calculate wall U-value

Table 11 shows the value of the heat loss, Q, the minimum internal surface temperature $T_{si,min,}$ and the U-value calculated from the heat loss, temperature difference and the dimensions of the model, for various grid details.

	Heat loss: Q Watts	$T_{si,min}$	U-value W/m^2K
1) Minimum grid	7.108	18.002	0.395
2) Grid divided by two	6.709	17.456	0.373
3) Grid divided by four	6.483	17.060	0.360
4) as 2) with extra points round the bracket	6.337	16.539	0.352
5) as 4) divided by 2	6.306	16.531	0.350

Table 11: Summary of heat loss and surface temperature data for different grid spacings

Taking the minimum grid, dividing it by two and adding further gridpoints around the bracket that crosses the insulation, see Figure 22, produces heat loss and minimum temperature values that fall by only 0.4% and 0.008°C, when the grid is further subdivided by two. The U-value of this wall is therefore 0.35 W/m^2K.

14.7 Calculation of the f-value of the wall

As shown in Table 11 the minimum internal surface temperature on the model of the wall used to calculate the U-value is 16.54°C. The f-value is therefore 0.83.

14.8 Calculation of the -value

a) **Using a full model**

Figure 38 shows the dimensions of the cross section of the model to calculate the -value. The model is 1500mm long in the third dimension, to represent the effect of the spacer rails. By dividing the minimum grid by two and adding further gridpoints around both the brackets that cross the insulation, the heat loss, Q, is equal to 17.529 W and the minimum inside surface temperature is 17.067°C.

Cutting down one side of the model shown in Figure 38, gives the model of one wall shown in Figure 39, which, in this case, has dimensions 830 by 1500mm.

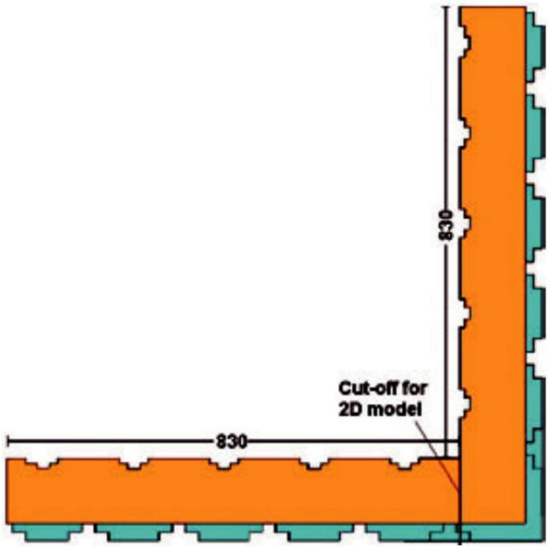


Fig 38: Dimensions of model to calculate the -value

Fig 39: Cross section of wall model cut down from full corner model

The heat loss through this is 8.440W, therefore the U-value is:

$$8.440/(20 \times 1.5 \times 0.83) = 0.339 \text{ W/m}^2\text{K}$$

Note this is not the same as the wall U-value calculated above (0.352 W/m^2K) because of the different dimensions of the models.

Assuming the two walls making up the corner are identical, Equation (12) from Section 12.2 then gives the -value as

$$\frac{17.529}{20 \times 1.5} - 2 \times 0.83 \times 0.339 = 0.022 \text{ W/mK}$$

If the wall U-value calculated above (0.365 W/m^2K) was used instead, this would give a value of 0.00 W/mK. Although it could be argued that both these values are small, the correct one will give a substantial contribution from the corner (a long thermal bridge) to the ·l value component of the total heat loss. The differences will also be more important in the case of a severe thermal bridge.

b) **Using a simplified model**
The model can be simplified by removing the spacers and profiles to leave only the outer and liner sheets filled with 120mm insulation shown in Figure 40. When this simplification is carried out, it is important to define a 'datum point' or origin of coordinates from which all dimensions are measured; in this case, as shown in the figure, the appropriate point is the internal corner.

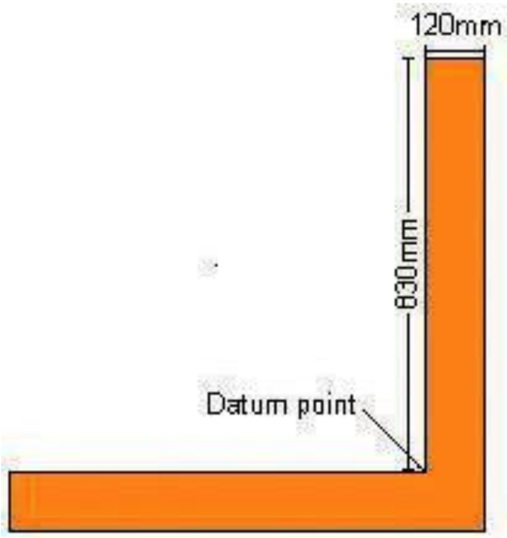


Fig 40: Cross section of simplified model

The heat loss through the simplified model (which is assumed to be 1 m long in the third dimension) is 10.123 W.

The internal surface temperature of the wall at the edges of the model away from the corner is 19.239°C. Equation (8) in section 11.1, gives the U-value as 0.293 W/m^{2}K.

As shown in the figure, the length of each of the walls is 0.830 m, therefore the -value is

$$\frac{10.123}{20 \times 1.0} - 2 \times 0.830 \times 0.293 = 0.020 \text{ W/mK}$$

14.9 Calculation of the f-value at the corner

The f-value is calculated from the minimum internal surface temperature found from the full model of the corner using equation (14) from Section 13.

$$f = \frac{16.804 - 0}{20 - 0} = 0.84$$

This is very close to the value found from the U-value calculation in section 14.7, i.e. 0.82.

The minimum surface temperature calculated from the simplified model described in section 14.8 is 18.97, giving an f-value of 0.95.

In this example therefore, the lowest f-value is associated with the profiles and bracket in the plane wall and not with the corner.

15.0 Appendix: Details

Introduction

The sections below discuss for the twin skin and composite panel details on the MCRMA website:

- The possible significance of that detail as a thermal bridge
- The possible causes of thermal bridging that will raise the -value and lower the f-value at that detail. The likely thermal bridges are classified as:

  mild 0.05 f 0.90
  moderate 0.25 f 0.75
  severe 0.25 f 0.75

- The important features of the detail that should be included in the model.
- The areas of the detail where care is needed when defining the grid.
- Any special factors that need to be taken into consideration.
- The -value and f-value that should be achieved using the details shown on the MCRMA website, and the values that are likely to result when different details are followed.

In most cases the twin-skin and composite panel details are effectively the same, any differences between the two types have been noted, where they occur

Because the lowest surface temperatures can be associated with the spacers or joints in walls or roof, rather than the junctions, the f-values associated with U-values are discussed in section A.0. The following details are then covered

A.0 f-values associated with plane areas
A.1 Ridge
A.2 Hip
A.3 Valley gutter
A.4 Hip valley
A.5 Eaves
A.6 Overhanging eaves
A.7 Roof verge
A.8 Overhanging verge
A.9 Parapet eaves
A.10 Parapet verge
A.11 Corner
A.12 Drip sill
A.13 Window/door jamb, lintel and sill
A.14 Point thermal bridges

The -values and f-values quoted for the details A.1 - A.14 have been found assuming:

1) No profiles, spacers or joints are included in walls and roofs, which have the insulation thickness and conductivity shown below:

		Insulation thickness : mm	Insulation conductivity : W/mK
Twin skin	Wall	125	0.04
	Roof	180	0.04
Composite panel	Wall	70	0.02
	Roof	80	0.02

These values have been chosen to give the U-values required by Regulations, when the effect of profiles, spacers and joints are included.

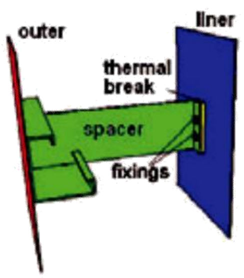
2) The conductivity of steel was assumed to be 60 W/mK.

A.0 The effect of fixings within plane areas on the f-value

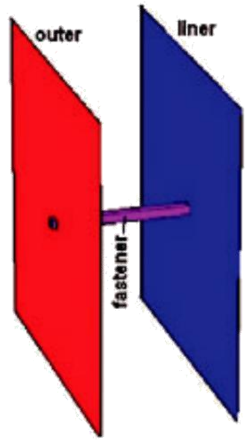
In most construction types, masonry or timber framed walling, for example, the lowest internal surface temperature and therefore the f-value is associated with the thermal bridges at the junctions. The f-value and -value are therefore calculated together. This is not necessarily true for metal cladding systems where the lowest surface temperatures may be associated with the fixing, spacer or joint systems in the wall or roof. In this case it may therefore be necessary to calculate the f value with the U-value. Three details are of importance: spacer systems in twin-skin construction, and joints and fixings in composite panels. Joints in composite panels vary so much that each system has to be assessed individually; however it is possible to summarise the effect of the other two details on the f-value. When individual details are being assessed, the lower of either:

- the f-value associated with the detail, discussed in the sections below, or
- the f-value associated with plane areas, shown here,

should be quoted.



Spacer system in twin skin wall (insulation removed)



Fastener in composite panel wall (insulation removed)

Spacer in twin skin cladding

The detail, shown above, is a 'worst case' assuming that the spacer is connecting the minimum separation of the inner and outer profiles. There is a 3mm thick thermal break with conductivity 0.35 W/mK between the bracket and the liner sheet and the rail and bracket steel thicknesses are 1.25mm and 1.5mm respectively.

With no fixings crossing the thermal break:

With 125 mm of insulation in a wall **f = 0.82**

With 180 mm of insulation in a roof **f = 0.88**

With 5mm diameter steel fixings crossing the thermal break:

With 125 mm of insulation in a wall **f = 0.76**

With 180 mm of insulation in a roof **f = 0.84**

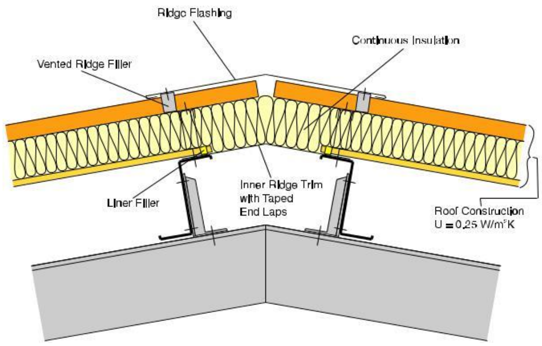
Fastener in a composite panel

The detail, shown above, assumes that there is a 5.5mm diameter steel or stainless steel fastener passing between the two sheets. This gives the following f-values:

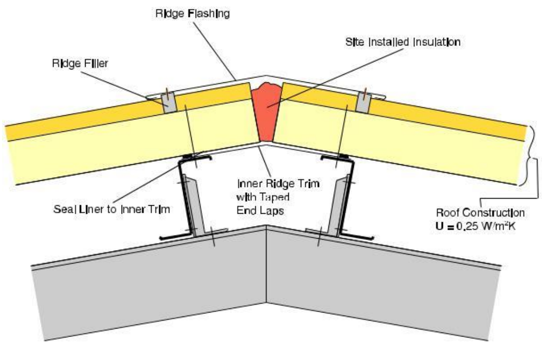
	Wall (70mm of insulation)	**Roof (80mm of insulation)**
Steel	0.74	0.77
Stainless steel	0.84	0.87

A.1 Ridge

The long ridge lengths in most metal clad buildings makes this a potentially important bridge, however, when the ridge is constructed as shown below the low -value and high f-value minimise the impact.



Twin skin



Composite panel

Possible thermal bridges:

- Angle in structure - very mild
- Insulation not continuous across ridge - moderate
- Extra spacers at the ridge not accounted for in plane surface U-values - moderate

Detail necessary to model

Two sloping roofs meeting can be modelled properly only with software that can deal with non rectangular structures. If the insulation is continuous and there are no extra spacers at the ridge, it is not necessary to model this detail; the values quoted below can be assumed.

If the insulation is not continuous over the ridge or if there are extra spacers at the ridge, the detail can be modelled as a corner – see section A.11.

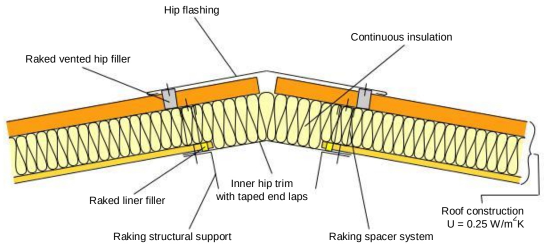
The -value and f-value

Provided the insulation is complete across the ridge and there are no extra fixings that have not been taken into account in the U-value of the roof surface, the only thermal bridge occurs because of the larger area on the outside surface compared to the inside. The -value and f-value will vary slightly with the roof slope, however they can be assumed to be:

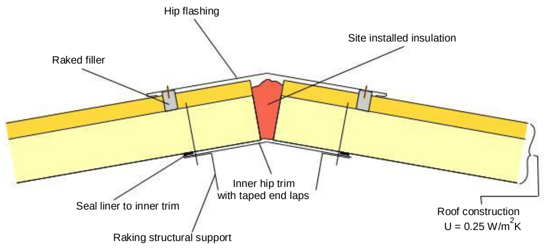
= 0.01 W/mK   f = 0.95

A.2 Hip

The relatively short length in many buildings and good thermal performance, when this detail is built properly, means it has little impact on energy use or condensation risk.



Twin skin



Composite panel

Possible thermal bridges:

- Angle in structure - very mild
- Insulation not continuous across hip - moderate
- Extra spacers at the hip not accounted for in plane surface U-values - moderate

Detail necessary to model

Two sloping roofs meeting can be modelled properly only with software that can deal with non rectangular structures. If the insulation is continuous and there are no extra spacers at the hip, it is not necessary to model this detail; the values quoted below can be assumed.

If the insulation is not continuous over the hip or if there are extra spacers at the hip, the detail can be modelled as a corner – see section A.11.

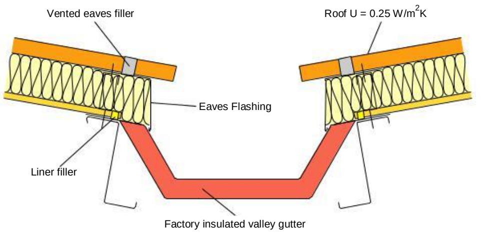
The -value and f-value

Provided the insulation is complete across the ridge and there are no extra fixings that have not been taken into account in the U-value of the roof surface, the only thermal bridge occurs because of the larger area on the outside surface compared to the inside. The -value and f-value will vary slightly with the roof slope, however they can be assumed to be:

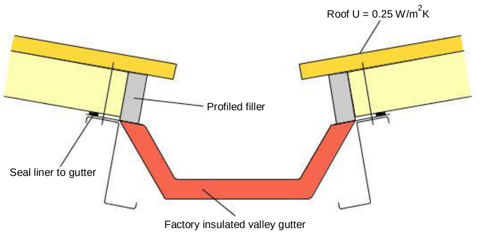
= 0.01 W/mK   f = 0.95

A.3 Valley gutter

The long gutter lengths in many buildings and risk of high -values and low f-values means this detail can have a very significant impact on the fabric heat loss and condensation risk. If appropriate, consideration should be given to improved design of the detail.



Twin skin



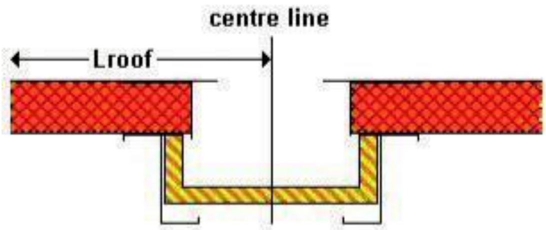
Composite panel

Possible thermal bridges:

- Increased surface area - mild
- Extra spacers at the gutter not accounted for in plane surface U-values – moderate
- Metal gutter top crossing insulation - very severe

Detail necessary to model

When software that can handle only rectangular structures is used, is necessary to approximate the structure as shown below:



When making this approximation it is important to ensure that, a) the insulation thickness in the gutter, b) the width of the penetration into the cladding and c) the length of the gutter liner sheet, are the same as the real gutter.

As the gutter is symmetrical the model can include only half the gutter, up to the centre line as shown, with the roof length shown used for the calculation of the -value. This calculated value should then be doubled to give the total -value for the gutter.

With this detail, purlins in contact with the gutter top will add significantly to the heat flows and should therefore be included in the model.

Defining the grid

The grid should be detailed around the area where the gutter top crosses the insulation.

The -value and f-value

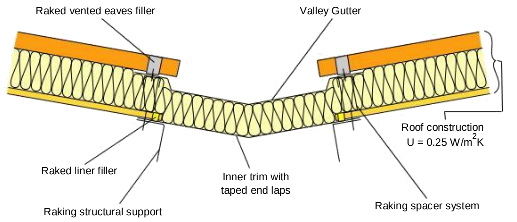
Because this is a significant thermal bridge, it is necessary to calculate the -value and f-value in individual cases. The values summarised below assume that the gutter insulation is 40mm thick, with a conductivity of 0.22 W/mK. The gutter outer sheet is 1.6mm thick and the conductivity of the thermal break where the gutter head crosses the insulation is 0.2 W/mK. The values for twin-skin and composite panel roofs are very similar.

	Width of opening in the cladding: mm	-value W/mK	f-value
No thermal break at gutter head	300	1.95	0.64
Thermal break at gutter head and roof liner set back in line with purlin web	300	0.31	0.95
No thermal break at gutter head	600	2.04	0.63
Thermal break at gutter head and roof liner set back in line with purlin web	600	0.39	0.95

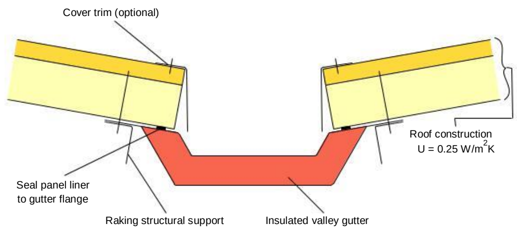
Typical thermal properties of valley gutters

A.4 Hip valley

This detail is of little importance in twin skin construction because of its good thermal performance. However in composite panel roofs there is a danger of significant heat loss and condensation risk unless the valley is designed well.



Twin skin



Composite panel

Possible thermal bridges:

- Twin skin: Slightly reduced insulation thickness at gutter – very mild
- Composite panel: Metal gutter top and roof liner crossing insulation - very severe

Detail necessary to model

Two sloping roofs meeting can be modelled properly only with software that can deal with non rectangular structures.

With twin skin, if the insulation is continuous and there are no extra spacers at the valley, it is not necessary to model this detail; the values quoted below can be assumed. If the insulation is not continuous over the hip or if there are extra spacers at the hip, the detail can be modelled as a corner – see section A.11.

In composite panel structures this detail should be treated as a valley gutter see Section A.3.

The -value and f-value

Twin skin

Provided the insulation is complete across the valley and there are no extra fixings that have not been taken into account in the U-value of the roof surface, the only thermal bridge occurs because of the slightly reduced insulation at the gutter. If the reduction in insulation thickness is less than 20mm, there is no need to model this detail and the -value and f-value can be assumed to be:

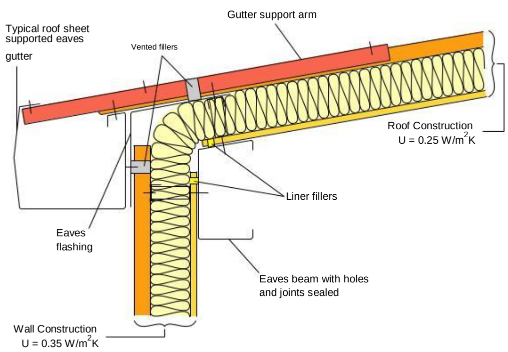
= 0.01 W/mK f = 0.95

Composite panel

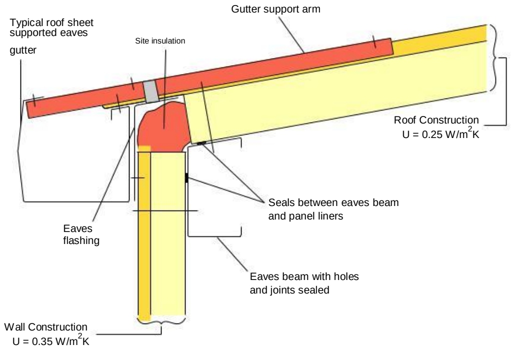
The detail should be modelled, however the values in Section A.3 are typical

A.5 Eaves

The long length of this detail in many buildings makes it a potentially serious bridge, but provided that the insulation is carried over between the wall and roof and neither of the liner sheets touch the outer sheets, the -value will be low and the f-value high.



Twin skin



Composite panel

Possible thermal bridges:

- Corner in structure - mild
- Insulation not continuous between roof and wall - moderate
- Extra fixings in corner not accounted for in plane surface U-values - moderate
- Liner crossing insulation – severe if liner crosses insulation completely to touch outer sheet

Detail necessary to model

Unless there are very complex extra fixing details at the eaves, this can be reliably modelled in 2D, without including profiles or spacers.

A sloping roof meeting a vertical wall can be modelled properly only with software that can deal with non rectangular structures. The eaves can be assumed to be a 90° corner for other software that deals only with rectangles, although this is strictly correct only for a dead flat roof. For roof slopes up to 15° the error is negligible; for steeper slopes, assuming a 90° corner will slightly overestimate the -value and underestimate the f-value.

The extent to which the liner of the roof or wall crosses the insulation of the other component, and especially whether the liner touches the outer sheet, is the most important potential thermal bridge and should be represented fully.

The model should be extended at least a metre away from the eaves in both directions.

Defining the grid

The grid should be detailed around any area where the liner crosses the insulation.

The -value and f-value

If the roof cladding liner is taken back to the wall liner, and the air gap filled with insulation, there is no need to model this detail and the -value and f-value can be assumed to be:

= 0.02 WmK, f = 0.95

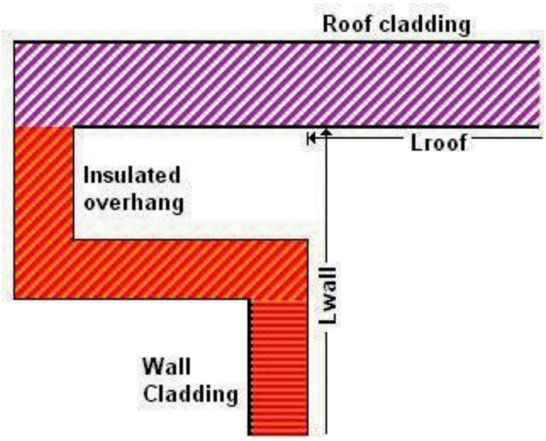
If one of the liners fully crosses the insulation to touch the outer sheet, the detail should be modelled. Typical values will be:

Twin skin **= 0.16 WmK, f = 0.84**

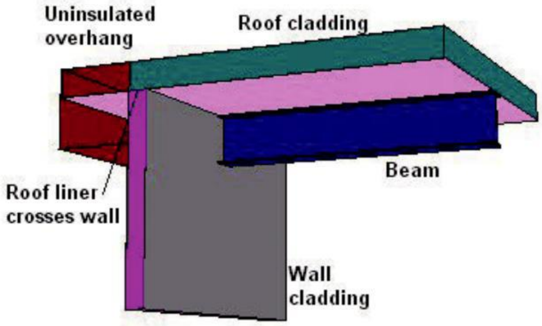
Composite panel **= 0.23 WmK, f = 0.79**

A.6 Overhanging eaves

As noted in Section 5.9, in both twin skin and composite panel constructions, there can be two types of overhanging eaves, Type 1 in which the overhang is insulated and Type 2 in which it is not, but the insulation line is penetrated by steel sections at regular intervals and by the roof liner sheet. In Type1 the -value will be high and increase with the overhang length however the f-value will also be high. In Type 2, the -value is lower and independent of overhang length, but the f-value may be very low where the beams penetrate the insulation.



Type 1



Type 2

Possible thermal bridges:

- In Type 1 increased surface area caused by overhang - severe
- In Type 2 penetration of beam and roof liner sheet through insulation – locally severe

Detail necessary to model

Unless there are very complex extra fixing details at the overhang, Type 1 eaves can be reliably modelled in 2D, without including profiles or spacers. Type 2 eaves have to be modelled in 3D to include the beam penetration and the width of the model must equal the beam centres to obtain the appropriate heat loss for calculation of the -value.

The model should be extended at least a metre away from the eaves down the wall and across the roof.

Defining the grid

If the insulation is continuous and not crossed by any metal liners etc, Type 1 eaves are very simple to model, with no areas where grid definition is particularly important. In Type 2 eaves it is essential that the grid is detailed around the penetration of the beam through the insulation and where the roof liner crosses the wall insulation.

The -value and f-value

Because this is a significant thermal bridge with properties that will depend on the detailing the -value and f-value should be calculated in each case. When calculating the -value in Type 1 eaves the roof length should be taken from the points shown above. The dimensions of the Type 2 eaves should be taken as for an ordinary eaves, but with the width along the wall included to represent the rafter centres.

Typical values are shown in the tables below. For Type 1 eaves the -value is directly proportional to the length of the overhang. For Type 2 eaves the -value is independent of the overhang length but is affected by the presence of the rafter and the roof liner. Reducing the rafter centres increases the -value slightly.

Type 1 Overhanging eaves

	Length of overhang: m	f_{min}	-value: W/mK
Twin skin	0.5	0.93	0.25
	1.5	0.93	0.76
Composite panel	0.5	0.95	0.24
	1.5	0.95	0.75

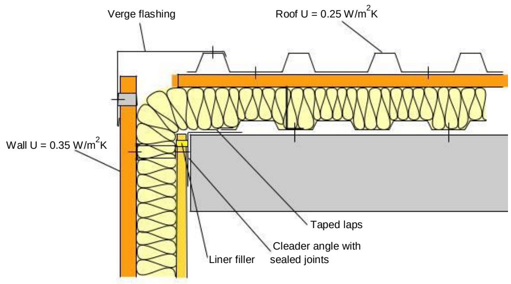
There are linear relationships between the lengths and -values in the table, given by:
Twin skin:
= 0.01 + 0.51 × Overhang Length in m Composite panel:
= 0.02 + 0.51 × Overhang Length in m

Type 2 Overhanging eaves

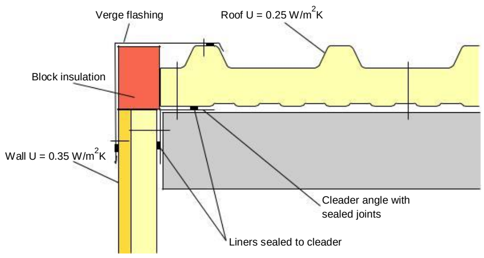
	Rafter centres: m	f-value	-value: W/mK
Twin skin	6.0	0.58	0.18
	8.0	0.58	0.14
Composite panel	6.0	0.50	0.20
	8.0	0.50	0.15

A.7 Roof verge

The long length of this detail in many buildings makes it a potentially serious bridge, but provided that the insulation is carried over between the wall and roof and neither of the liner sheets touch the outer sheets, the -value will be low and the f-value high.



Twin skin



Composite panel

Possible thermal bridges:

- Corner in structure - mild
- Insulation not continuous between roof and wall - moderate
- Extra fixings in corner not accounted for in plane surface U-values - moderate
- Liner crossing insulation – severe if liner crosses insulation completely to touch outer sheet

Detail necessary to model

Unless there are very complex extra fixing details at the verge, this can be reliably modelled in 2D, without including profiles or spacers.

The extent to which the liner of the roof or wall crosses the insulation of the other component, and especially whether the liner touches the outer sheet, is the most important potential thermal bridge and should be represented fully.

The model should be extended at least a metre away from the verge in both directions.

Defining the grid

The grid should be detailed around any area where the liner crosses the insulation.

The -value and f-value

If the roof cladding liner is taken back to the wall liner, and the air gap filled with insulation, there is no need to model this detail and the -value and f-value can be assumed to be:

= 0.02 WmK, f = 0.95

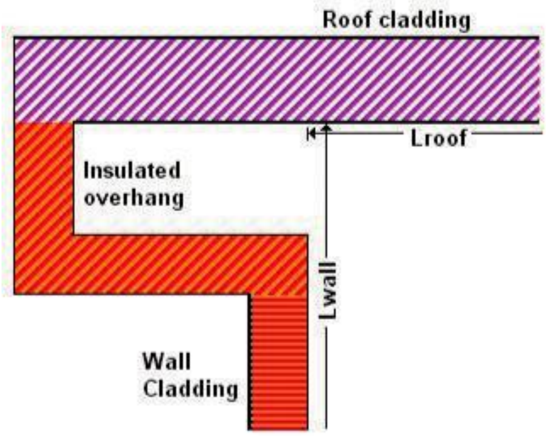
If one of the liners fully crosses the insulation to touch the outer sheet, the detail should be modelled. Typical values will be:

Twin skin **= 0.16 WmK, f = 0.84**

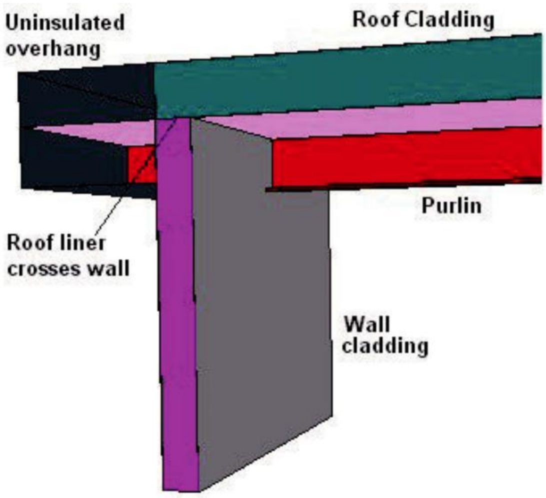
Composite panel **= 0.23 WmK, f = 0.79**

A.8 Overhanging verge

As noted in Section 5.9, in both twin skin and composite panel constructions, there can be two types of overhanging verge, Type 1 in which the overhang is insulated and Type 2 in which it is not, but the insulation line is penetrated by steel purlins at regular intervals and the liner sheet of the roof cladding crosses the wall insulation. In Type 1 the -value will be high and increase with the overhang length however the f-value will also be high. In Type 2, the -value is independent of overhang length, and the f-value may be very low where the roof liner and purlins penetrate the insulation.



Type 1 Overhanging verge



Type 2 Overhanging verge

Possible thermal bridges:

- In Type 1 increased surface area caused by overhang - severe
- In Type 2 penetration of purlin and roof liner through insulation – severe

Detail necessary to model

Unless there are very complex extra fixing details at the overhang, a Type 1 verge can be reliably modelled in 2D, without including profiles or spacers. Type 2 verges have to be modelled in 3D to include the purlin penetration and the width of the model must equal the purlin centres to obtain the appropriate heat loss for calculation of the -value.

The model should be extended at least a metre away from the verge down the wall and across the roof.

Defining the grid

If the insulation is continuous and not crossed by any metal liners etc, Type 1 verges are very simple to model, with no areas where grid definition is particularly important. In Type 2 verges it is essential that the grid is detailed around the penetration of the purlin and the roof liner through the insulation.

The -value and f-value

Because this is a significant thermal bridge with properties that will depend on the detailing the

-value and f-value should be calculated in each case. When calculating the -value in Type 1 verges the roof and wall lengths should be taken from the point shown in the diagram above. The dimensions of the Type 2 verge should be taken as for an ordinary verge, but with the width along the wall included to represent the purlin centres.

Typical values are shown in the tables below. For Type 1 verges the -value is directly proportional to the length of the overhang. For Type 2 verges the -value is independent of the overhang length but is affected by the presence of the purlin and the roof liner crossing the wall insulation. Reducing the purlin centres increases the -value slightly.

Type 1 Overhanging verges

	Length of overhang: m	f_{min}	-value: W/mK
Twin skin	0.5	0.93	0.25
	1.5	0.93	0.76
Composite panel	0.5	0.95	0.24
	1.5	0.95	0.75

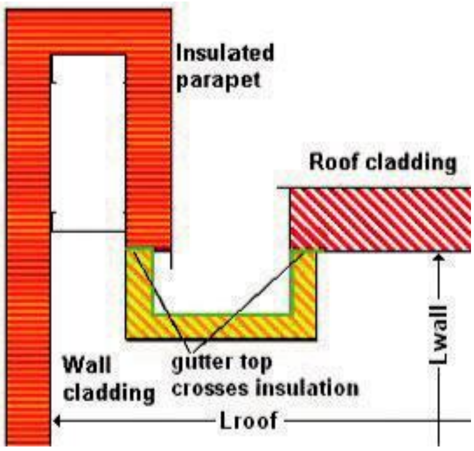
There are linear relationships between the lengths and -values in the table, given by:
Twin skin:
= 0.01 + 0.51 × Overhang Length in m
Composite panel:
= 0.02 + 0.51 × Overhang Length in m

Type 2 Overhanging verges

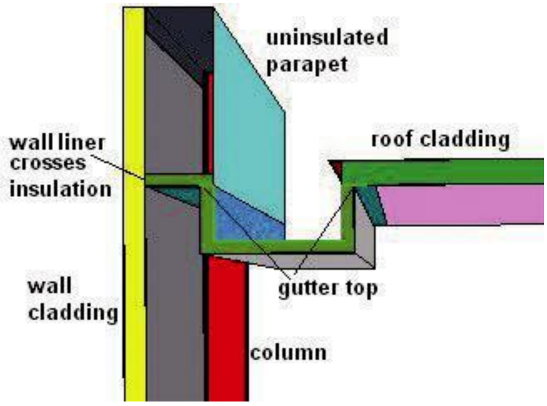
	Rafter centres: m	f-value	-value: W/mK
Twin skin	1.5	0.68	0.36
	2.5	0.68	0.31
Composite panel	1.5	0.58	0.49
	2.5	0.58	0.43

A.9 Parapet gutter

As noted in Section 5.9, in both twin skin and composite panel constructions, there can be two types of parapet eaves, Type 1 in which the parapet is insulated and Type 2 in which it is not, but the insulation line penetrated by steel columns at regular intervals and the liner of the wall cladding cuts across the roof insulation. In both cases it is common for the metal gutter top to cross the roof insulation, which forms the most severe thermal bridge. With a thermal break at the gutter head, in Type 1 eaves the -value will be high and increase with the parapet height however the f-value will also be high; in Type 2, the -value is lower and independent of parapet height, but the f-value may be very low where the columns and wall liner penetrate the insulation.



Type 1 Parapet eaves



Type 2 Parapet eaves

Possible thermal bridges:

- In Type 1 increased surface area caused by the parapet - severe
- In Type 2 penetration of column through insulation – locally severe
- In Type 2 wall liner crossing the insulation – severe
- In both types the gutter top crossing the roof insulation - severe

Detail necessary to model

Unless there are very complex extra fixing details at the parapet and eaves, Type 1 eaves can be reliably modelled in 2D, without including profiles or spacers. Type 2 eaves have to be modelled in 3D to include the column penetration and the width of the model must equal the column centres to obtain the appropriate heat loss for calculation of the -value.

Defining the grid

If the insulation is continuous and not crossed by any metal liners etc, the only area necessary to model in detail in Type 1 is the gutter head crossing the roof insulation. In Type 2 it is essential that the grid is detailed around the penetration of the column through the insulation and the area where the wall liner crosses the roof insulation as well as the gutter head.

The -value and f-value

Because this is a significant thermal bridge with properties that will depend on the detailing the -value and f-value should be calculated in each case. When calculating the -value in Type 1 eaves the roof length should be taken from the points shown on the diagram above. The dimensions of the Type 2 eaves should be taken as for an ordinary eaves, but with the width along the wall included to represent the column centres.

Typical values are shown in the tables below. These assume that the gutter is 400mm wide and the gutter insulation is 40mm thick with a conductivity of 0.022 W/mK. For Type 1 the -value is directly proportional to the height of the parapet. For Type 2 the -value is independent of the parapet height but is affected by the presence of the column.

Type 1 Eaves

Twin skin - with metal gutter top crossing the insulation

Height of parapet: m	f_{min}	-value: W/mK
0.5	0.48	1.93
1.5	0.48	2.54

There are linear relationships between the lengths and -values in the table, given by:
= 1.63 + 0.61 × Height of parapet in m

Twin skin - With gutter top replaced by a thermal break with k = 0.2 W/mK

Height of parapet: m	f_{min}	-value: W/mK
0.5	0.91	0.79
1.5	0.91	1.39

There are linear relationships between the lengths and -values in the table, given by:
= 0.49 + 0.60 × Height of parapet in m

Composite panel - with metal gutter top crossing the insulation

Height of parapet: m	f_{min}	-value: W/mK
0.5	0.52	1.93
1.5	0.52	2.48

There are linear relationships between the lengths and -values in the table, given by:
= 1.66 + 0.55 × Height of parapet in m

Composite panel - With gutter top replaced by a thermal break with k = 0.2 W/mK

Height of parapet: mm	f_{min}	-value: W/mK
0.5	0.94	0.64
1.5	0.94	1.18

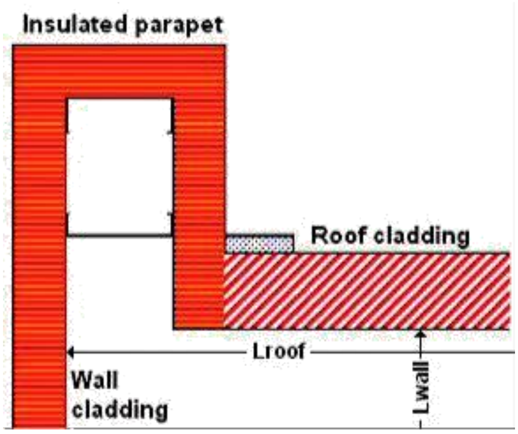
There are linear relationships between the lengths and -values in the table, given by:
= 0.37 + 0.54 × Height of parapet in m

Type 2 eaves

	Column centres: m	$'_{min}$	-value: W/mK
Twin skin			
No thermal break at gutter head	6.0	0.51	1.49
	8.0	0.51	1.47
With thermal break at gutter head	6.0	0.57	0.61
	8.0	0.57	0.60
Composite panel			
No thermal break at gutter head	6.0	0.44	2.10
	8.0	0.44	2.09
With thermal break at gutter head	6.0	0.44	0.75
	8.0	0.44	0.73

A.10 Parapet verge

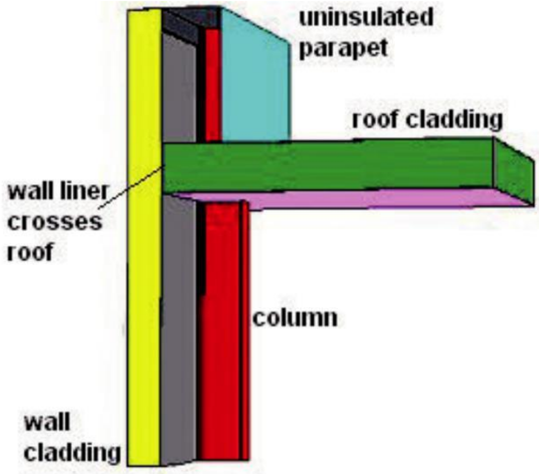
As noted in Section 5.9, in both twin skin and composite panel constructions, there can be two types of parapet verge, Type 1 in which the parapet is insulated and Type 2 in which it is not, but the insulation line penetrated by steel columns at regular intervals. In Type 1 the -value will be high and increase with the parapet height however the f-value will also be high. In Type 2, the -value is lower and independent of parapet height, but the f-value may be very low where the columns penetrate the insulation.



Type 1 parapet verge

Possible thermal bridges:

- In Type 1 increased surface area caused by parapet - severe
- In Type 2 penetration of column through insulation and the wall liner crossing roof insulation –severe



Type 2 parapet verge

Detail necessary to model

Unless there are very complex extra fixing details at the parapet and eaves, a Type 1 verge can be reliably modelled in 2D, without including profiles or spacers. Type 2 verges have to be modelled in 3D to include the column penetration and the width of the model must equal the column centres to obtain the appropriate heat loss for calculation of the -value.

The model should be extended at least a metre away from the verge down the wall and across the roof.

Defining the grid

If the insulation is continuous and not crossed by any metal liners etc, Type 1 is very simple to model, with no areas where grid definition is particularly important. In Type 2 eaves it is essential that the grid is detailed around the penetration of the column through the insulation and the area where the wall liner crosses the roof insulation.

The -value and f-value

Because this is a significant thermal bridge with properties that will depend on the detailing the -value and f-value should be calculated in each case. When calculating the -value in Type 1 verges, the roof and wall lengths should be taken from the points shown on the diagram. The dimensions of Type 2 verges should be taken as for an ordinary verge, but with the width along the wall included to represent the column centres.

Typical values are shown in the tables below. For Type 1 verges the -value is directly proportional to the height of the parapet. For Type 2 verges the -value is independent of the parapet height but is affected by the presence of the column.

Type 1 parapet verges

	Length of overhang: m	f_{min}	-value: W/mK
Twin skin	0.5	0.95	0.34
	1.5	0.95	0.95
Composite panel	0.5	0.96	0.28
	1.5	0.96	0.83

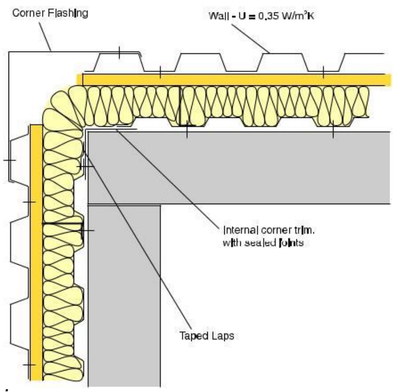
There are linear relationships between the lengths and -values in the table, given by:
Twin Skin:
= 0.04 + 0.61 × Height of parapet in m
Composite Panel:
= 0.01 + 0.55 × Height of parapet in m

Type 2 parapet verges

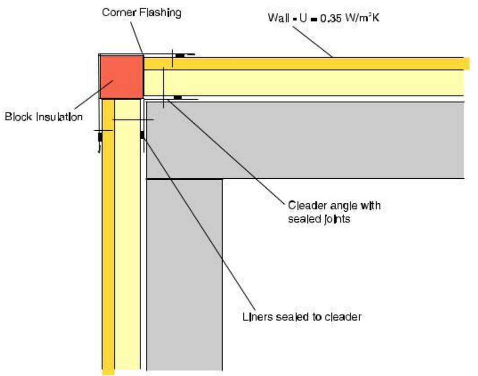
	Column centres: m	f_{min}	-value: W/mK
Twin skin	6.0	0.70	0.18
	8.0	0.70	0.16
Composite panel	6.0	0.62	0.26
	8.0	0.62	0.24

A.11 Corner

The long length of this detail in some buildings makes is a potentially serious bridge, but provided that the insulation is carried over between the walls and neither of the liner sheets touch the outer sheets, the -value will be low and the f-value high.



Twin skin



Composite panel

Possible thermal bridges:

- Corner in structure – mild
- Insulation not continuous across the corner – moderate
- Extra fixings in corner not accounted for in wall U-values – moderate
- Liner crossing insulation – severe if liner crosses insulation completely to touch outer sheet

Detail necessary to model

Unless there are very complex extra fixing details in the corner, this can be reliably modelled in 2D, without including profiles or spacers. The extent to which the liner of either of the walls crosses the insulation of the other wall, and especially whether the liner touches the outer sheet, is the most important potential thermal bridge and should be represented fully. The model should be extended at least a metre away from the corner in both directions.

Defining the grid

The grid should be detailed around any area where the liner crosses the insulation.

The -value and f-value

If neither wall liners crosses the insulation, and the air gap filled with insulation, there is no need to model this detail and the -value and f-value can be assumed to be:

= 0.02 W/mK, f = 0.95

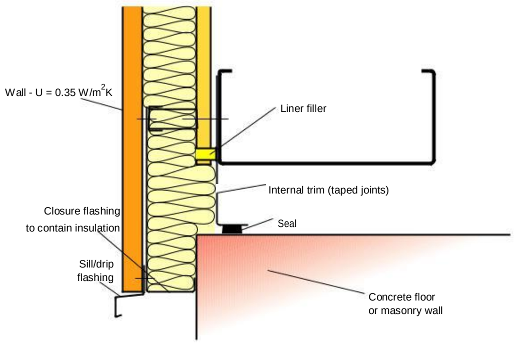
If one of the liners fully crosses the insulation to touch the outer sheet, the detail should be modelled. Typical values will be:
Twin skin **= 0.16 W/mK, f = 0.84**
Composite panel **= 0.23 W/mK, f = 0.79**

Internal corners

Some buildings with more complex plans have internal corners, i.e. corners that are convex from the inside. If the insulation is complete and there or no extra spacers at the corner, these will have a small negative -value, (-0.025 W/mK is typical), which can be used to offset other -values. Because the internal surface temperature at the corner is higher than on the adjacent plane areas, the f-value is not relevant.

A.12 Drip sill

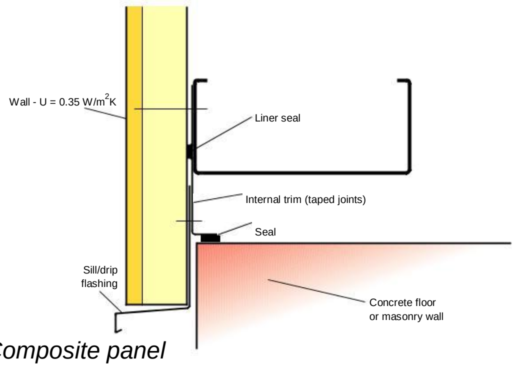
The intensity of the thermal bridge depends on the interaction of the detailing of the cladding and the masonry wall or floor slab to which it is fixed. This means that information about the wall or floor slab is essential before this -value and f-value can be calculated. As it often extends the full length of the building perimeter and the -value can be high, this thermal bridge can make a major contribution to the fabric heat loss.



Twin skin

Possible thermal bridges:

- Cladding insulation stopping at the head of the wall or floor slab
- Flashing at base of cladding crossing insulation



Composite panel

Detail necessary to model

Unless there are extra spacers adjacent to the join with the wall or floor slab, this can be modelled in two dimensions without the need to include profiles or spacers. Details of the masonry wall or floor slab must be included and close attention should be paid to the position of any insulation in that element. Section 12.4 describes how to calculate the - value of junctions including ground floor slabs.

Defining the grid

As the potential heat loss route in twin skin sills is through the masonry wall or floor slab, definition of the grid is straightforward. The flashing at the base of composite panels needs to be modelled in detail. If a ground floor slab is included the model must be extended to half the building width inside and to 2.5 times out and down into the ground - see Section 11.4.

Calculating the -value and f-value

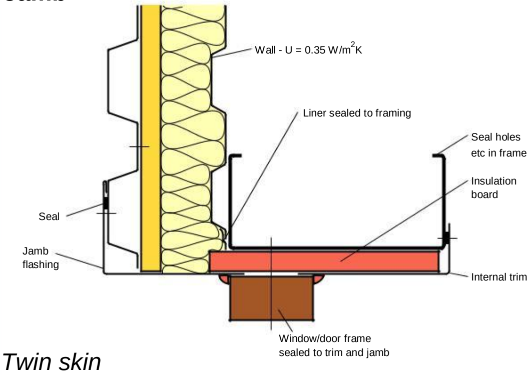
The -value and f-value of this important thermal bridge must be calculated using the dimensions shown in Figure 31 in Section 12.4.

The table below shows the f-value and -value for twin skin and composite panel sills, with a 250mm masonry wall, with an insulated cavity and with a 250mm thick concrete floor slab.

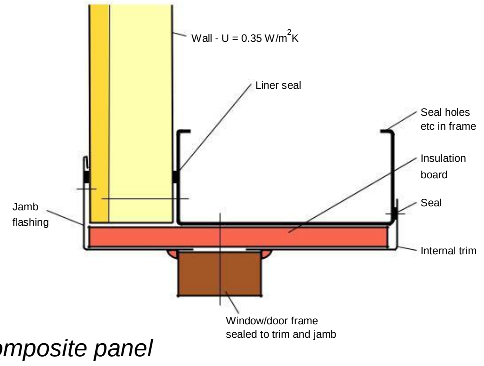
	Twin skin		Composite panel	
Masonry wall	**f-value**	**-value: W/mK**	**f-value**	**-value: W/mK**
k = 0.11 W/mk	0.83	0.12	0.75	0.47
k = 0.50 W/mk	0.73	0.23	0.74	0.57
k = 1.00 W/mk	0.71	0.28	0.72	0.62
Floor slab				
k = 1.00 W/mk	0.71	0.75	0.70	0.99
k = 1.50 W/mk	0.66	0.89	0.67	1.12
k = 2.30 W/mk	0.61	1.10	0.63	1.32

A.13 Window/door jamb, head and sill

Jamb

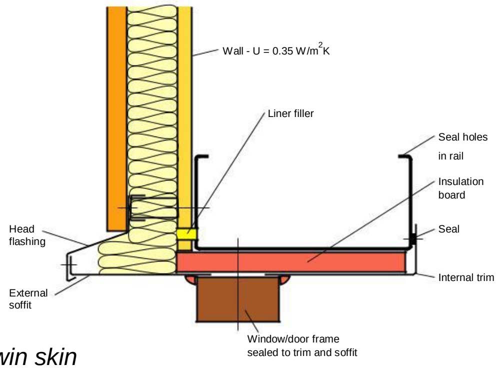


Twin skin

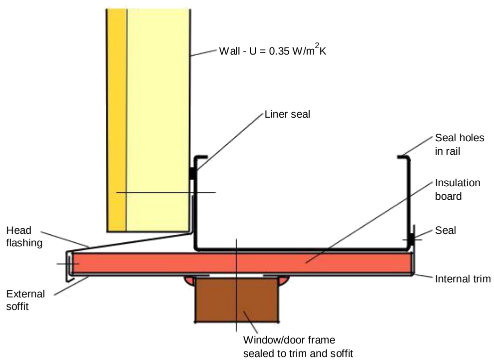


Composite panel

Head

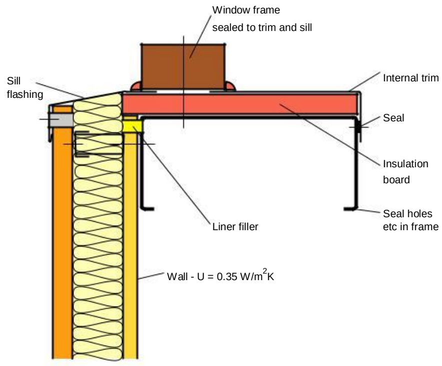


Twin skin

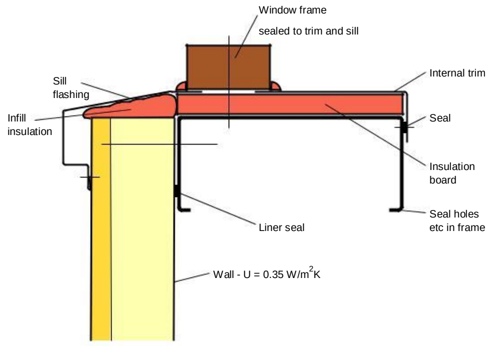


Composite panel

Sill



Twin skin



Composite panel

As these three details are essentially the same on metal cladding they have been treated together.

Possible thermal bridges:

- Metal trim meets behind the window/door frame (i.e. the gap shown in the twin skin jamb figure is not present) – severe
- Insulation board not included between the window/door frame and the steelwork - severe

Detail necessary to model

Unless there are extra spacers near the window opening the cladding can be modelled in two dimensions without profiles or spacers. If the window frame is known this can be included in the model with the glass represented by an adiabatic boundary condition (see Section 5.7). If the frame is not known this is represented as adiabatic boundary.

Defining the grid

The grid should be detailed where any metal trim crosses the insulation.

Calculating the -value and f-value

The length of cladding taken into the -value calculation should be taken up to the edge of the adiabatic boundary condition at the frame or the glass.

-value and f-value

The values that will result if the details are built as shown in the diagrams above are

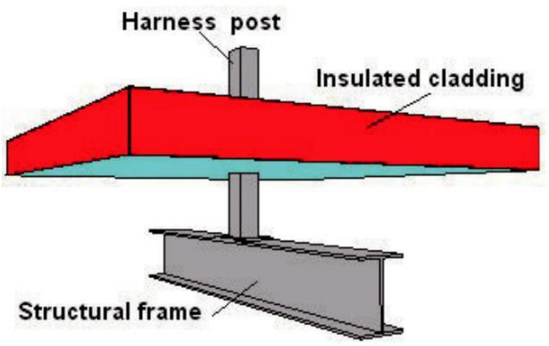
	Twin skin		Composite panel	
	f-value	-value: W/mK	f-value	-value: W/mK
Jamb	0.95	0.05	0.96	0.03
Lintel	0.95	0.05	0.58	0.70
Sill	0.95	0.05	0.96	0.03

A.14 Point thermal bridges

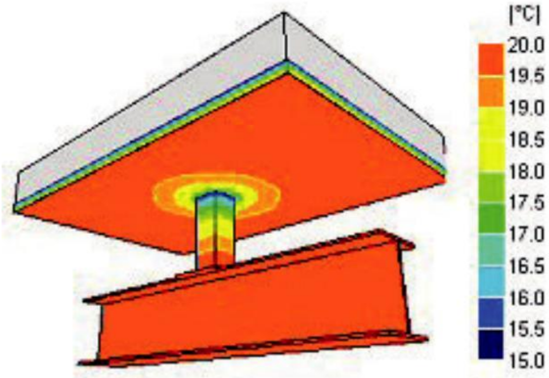
Some features of industrial buildings in which steel elements penetrate the insulation, exist at only discrete points, and are not linear features like the other details discussed in this Appendix. Although their analysis is not a requirement of Approved Document L, it should be recognised that they can be sources of extra heat loss from the builing and, more importantly, can locally lower the internal surface temperature low enough to cause severe surface condensation, especially in high humidity buildings. These features are much more variable than the other details discussed above and the examples below are included for illustration only, individual calculations should be done whenever any of these features are included in a high humidity building. Two examples are shown in the figures below:

a) a hollow steel post, with 2 mm thick walls, which is attached to the structural steel inside the building and passes through the roof;
b) a rafter, which is attached to the structural steelwork within the building and passes though the insulated cladding to support, for example a canopy or eaves gutter.

For each example, the f-value and the extra heat loss in W/K, caused by each is quoted; the total heat loss is found by multiplying this by the number of these features in the building. See section 11.4.



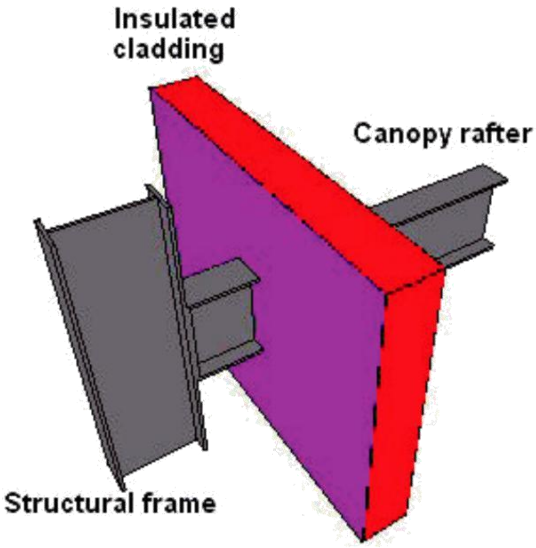
Post



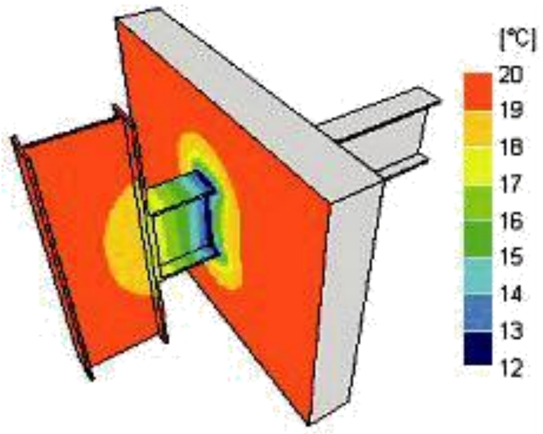
Internal surface temperature

f-value = 0.77, Heat loss = 0.17 W/K

References



Canopy rafter



Internal surface temperature

f-value = 0.62, Heat loss = 0.69 W/K

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7. BR443 Conventions for U-value calculations, 2006 Edition, BRE 2006
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13. BS EN ISO 10211-2:2001 Thermal bridges in building construction – Calculation of heat flows and surface temperatures – Part 2: Linear thermal bridges [1]

14. BS EN 12524:2000 Building materials and products – Hygrothermal properties – Tabulated design values [2]

15. BS EN ISO 10077-2:2003 Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 2: Numerical method for frames

16. BRE IP 1/06, Assessing the effects of thermal bridging at junctions and around openings, BRE 2006

17. BS EN ISO 13370:1998 Thermal performance of buildings – Heat transfer via the ground – Calculation methods

[1] These two standards are being combined into single standard that will be published in late 2006: BS EN ISO 10211:2006 Thermal bridges in building construction - Calculation of heat flows and surface temperatures

[2] The data in EN 12524 is being incorporated into a new version of ISO 10456: 'Building materials and products. Procedures for determining declared and design thermal values' that will be published in 2007 when EN12524 will be withdrawn.

MCRMA technical papers

No 1 Recommended good practice for daylighting in metal clad buildings

No 2 Curved sheeting manual

No 3 Secret fix roofing design guide

No 4 Fire and external steel-clad walls: guidance notes to the revised Building Regulations, 1992 (*out of print*)

No 5 Metal wall systems design guide

No 6 Profiled metal roofing design guide

No 7 Fire design of steel-clad external walls for building: construction, performance standards and design

No 8 Acoustic design guide for metal roof and wall cladding

No 9 Composite roof and wall cladding panel design guide

No 10 Profiled metal cladding for roof and walls: guidance notes on revised Building Regulations 1995 parts L & F (*out of print*)

No 11 Flashings for metal roof and walls: design, detailing and installation guide

No 12 Fasteners for metal roof and wall cladding: design detailing and installation guide

No 13 Composite slabs and beams using steel decking: best practice for design and construction

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No 15 New Applications: composite construction

No 16 Guidance for the effective sealing of end lap details in metal roofing constructions.

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The diagrams of typical constructions in this publication are illustrative only.

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