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GUIDANCE FOR THE DESIGN OF METAL ROOFING AND CLADDING TO COMPLY WITH APPROVED DOCUMENT L2 : 2001

MCRMA Technical Paper No. 14

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The Building Envelope Authority

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Foreword

This publication has been produced by the Metal Cladding and Roofing Manufacturers Association (MCRMA) in collaboration with BRE, to assist the designers, manufacturers and installers of metal walls and roofs to comply with the requirements of Approved Document L2 of the Building Regulations, published in October 2001 to come into force in April 2002.

It describes the content of those parts of the Approved Document relevant to metal cladding and roofing systems and gives guidance as to:

The calculation of U-values

Allowing for thermal bridging at junctions and openings

Infra-red surveys

Air leakage testing

The guidance is designed to be relevant to both twin skin and composite panel systems.

Checklist for compliance with Approved Document L2

Calculation of U-values

1. Approved Document L2 requires that the U-values of metal site assembled and composite panel walls and roofs must be less than or equal to 0.35 W/m^{2}K and 0.25 W/m^{2}K respectively. (The corresponding values in Scottish Technical Standard J are 0.30 W/m^{2}K and 0.25 W/m^{2}K). These values include associated components such as gutters and smoke vents however, rooflights, windows and doors have separate values.
2. Because the method for calculating U-values contained in BS EN ISO 6496 and CIBSE Guide A does not apply to metal roofing and cladding systems, more complex methods must be used.
3. If the construction is one of those covered in BRE IP 5/98, the U-value can be obtained from the graphs or other information in the IP and corrected for air spaces and compression of the insulation by the profiles using the equations in the IP.
4. If the component contains independent linear features that can be represented by a series of two-dimensional models, use a two-dimensional model and combine the results from the different models.
5. If the component contains repeating point thermal bridges, such as clips, develop a three-dimensional model to calculate the heat flows and then the U-value.

Thermal bridging

1. Approved Document L2 requires that the building fabric should be constructed so that there are no significant thermal bridges or gaps in the insulation layer(s) within the various elements of the fabric, at the joints between elements and at the edges of elements such as those around window and door openings. It is also necessary to account for penetration of the insulated envelope by features such as safety harness posts or rafters which project to support a canopy or gutter.

2. It is necessary to consider both the risk of condensation on each individual thermal bridge and the effect of the increased heat loss through thermal bridges on the overall heat from the building.

3. If a detail contains metal components crossing the insulation that would not otherwise be present in a plane element, surface condensation may occur in humid environments. The severity of the bridge, and therefore the risk of condensation, is determined by the f-factor, which is calculated by modelling the structure. If this type of thermal bridge is to be included in a building which is likely to have a humid internal environment, consideration should be given to redesigning the detail.

4. It is also necessary to calculate the contribution of the thermal bridges to the overall heat loss from the building by using the linear thermal transmittance (-value) and then following the procedures specified in BRE IP17/01. If the total heat loss through the thermal bridges is greater than 10% of that through the plane areas, individual details must be modified to reduce the loss through the bridges.

5. The parameters needed to comply with Part L via IP 17/01 (the f-value and the -value) are given in this report for a range of details that should cover most metal clad buildings. Means of improving the thermal performance of each detail are presented. It will be necessary to use a two-dimensional thermal model to calculate the f-value and the -value for all other details.

Infra-red surveys

1. An infra-red survey, carried out by a competent person, can be used to demonstrate that the insulation is reasonably continuous over the whole visible envelope of the building.

2. Given the right conditions, infra-red surveys can provide useful qualitative information about thermal bridges and air infiltration but cannot quantify their effect, nor can they be used to measure the U-value of walls and roofs.

3. Infra-red surveys of the envelope of a building should preferably be done from the inside and ideally require calm, dry, cold and cloudy conditions; there may therefore be a considerable delay before conditions are suitable. The conditions for external surveys are even more restrictive.

4. For a survey to be successful, the building should be heated for at least 12 hours before the survey, there should be no sun and no rain on the external surface.

5. The interpretation of infra-red surveys is subjective requiring experienced staff, especially in the presence of metal components, with emissivities much lower that those of other building materials. This may lead to disputes concerning whether an apparent defect is significant or not.

Air leakage

1. Compliance with the Approved Document can be demonstrated for buildings of floor area < 1000 m^2 by providing evidence that appropriate design details and building techniques have been used and that the work has been carried out in ways that can be expected to achieve conformity.

2. Compliance with the Approved Document can be demonstrated for buildings of any size by demonstrating that the results of air leakage tests are satisfactory.

3. Pressurisation testing of whole buildings gives a good estimate of their energy loss from air infiltration in practice.

4. The contribution of individual areas of the building envelope to the overall leakage can be identified and quantified by the use of smoke tubes, infra-red surveys and reductive sealing.

5. The leakage through individual cladding systems and the effect of sealing joints etc. can be measured in laboratory tests. The effect of other components installed into the envelope, such as doors, windows, smoke vents etc.

Introduction

should be quoted by the manufacturer. The results from these tests can be scaled up to estimate the leakage contribution of the cladding to the leakage of a full scale building, provided the cladding has been properly installed.

6. Small scale tests have shown that **installed** metal cladding will already comply with the new air leakage requirements and that additional sealing of internal side laps and vertical and horizontal perimeter joints will substantially further reduce the air leakage through the cladding systems of buildings to a very low level. The MCRMA therefore recommends that side and end laps/joints and all perimeter joints should be effectively sealed, not only to reduce the air leakage but also to provide vapour control. Attention has to be paid to the leakage through all associated elements within the envelope.

7. However well designed a system is; it will fail and require expensive retesting, possibly delaying the completion of a contract by many weeks, if it has not been well installed. It is therefore essential that installation is carried out by experienced contractors, is well supervised and follows the cladding manufacturer's guidance.

As part of the government's programme to reduce the effects of global warming by limiting greenhouse gas emissions from buildings, transport and industry, the 1995 version of Approved Document L *Conservation of fuel and power* [1], which applies until April 2002 has been extensively revised. After consultation with industry and research bodies, an initial revised version of the Approved Document was published for consultation in June 2000. After the replies from the consultation had been considered a revised document was published as an 'interim draft', in April 2001. After minor revisions and editorial changes this version was published in October 2001 and will come into force in April 2002. The published Approved Document is available in two volumes; L1, covering domestic buildings, and L2, covering buildings other than dwellings. This guide covers the provisions of L2[2].

Approved Document L2 applies to only England and Wales, Scottish Technical Standard J *Conservation of fuel and power* has been revised in parallel and will come into force at the same time. The revisions are generally the same as in Approved Document L2, with some significant differences:

- The elemental U-value for walls is required to be 0.30 W/m^{2}K, compared to 0.35 W/m^{2}K in England and Wales.
- The category 'roofs with integral insulation' with a required U-value of 0.25 W/m^{2}K, that would apply to both site assembled and composite panel roofs in England and Wales does not appear in the Scottish Standard. Roofs up to a 10° slope will be assessed as flat roofs requiring 0.25 W/m^{2}K, but it is possible that steeper roofs could be assessed as a pitched roof with insulation between the rafters requiring 0.20 W/m^{2}K.
- The BRE IP 17/01 that covers thermal bridging is not referenced in the Scottish Standard, there is instead many more references to the BRE Report *Thermal insulation: avoiding risks.*
- There is no requirement for post-completion

thermal imaging surveys or pressurisation testing in Scotland.

The new Approved Document includes a wide range of new requirements, including improved efficiency of heating, mechanical ventilation and air conditioning systems, improved control of heating, hot water supply and lighting. However, the most important changes with significant potential impacts on the metal cladding and roofing industry are:

- The U-values required for walls and roofs are significantly lower and more rigorous methods of calculating U-values have been introduced.
- It is required that more attention is given to thermal bridging at, for example, junctions and openings.
- It is required that more attention is given to limiting air leakage through the building envelope.
- Post construction thermal imaging and air infiltration testing may be required to demonstrate compliance with the Regulations.

A guide to 'robust construction details' for 'domestic type constructions'[3] that meet the requirements of the Regulations, and do not lead to problems of condensation and mould or air infiltration, has been published in association with the Approved Documents (although it is relevant mainly to Approved Document L1, it also applies to, for example, schools or small office buildings covered by L2 but built with 'domestic style' details). This present document provides guidance to assist building designers and manufacturers and installers of metal cladding and roofing systems and associated components to meet the requirements of the new Approved Document L2 relevant to the building fabric (i.e. it does not cover issues such as heating, hot water supply and lighting that are covered in Approved Document L2). The Approved Document makes reference to this MCRMA/BRE guide as a means of demonstrating compliance with the Regulations. Scottish Technical Standard J does not reference either the 'domestic' robust details or the current document.

2.1 Requirements of the Approved Document

The essential requirement of Approved Document L2 is summarised in the opening sentence of clause 1.1 - all text in italics below is a direct quote from the Approved Document.

1.1 In order to achieve energy efficiency in practice, the building and its services systems should be appropriately designed (Section 1) and constructed (Section 2).

There are three methods of demonstrating compliance with the standard, all of which involve consideration of the design and construction of the building fabric and the design and operation of the services.

1.6 Three methods are given for demonstrating that reasonable provision has been made for the conservation of fuel and power. These different methods offer increasing design flexibility in return for greater demands in terms of the extent of calculation required. However the overall aim is to achieve the same standard in terms of carbon emissions. The methods are:

a) an Elemental Method (paragraphs 1.7 – 1.68). This method considers the performance of each aspect of the building individually. To comply with the provisions of Part L, a minimum level of performance should be achieved in each of the elements. Some flexibility is provided for trading off between different elements of the construction and between insulation standards and heating system performance.

b) a Whole Building Method (paragraphs 1.69 – 1.73). This method considers the performance of the whole building. For office buildings, the heating, ventilation, air conditioning and lighting systems should be capable of being operated such that they will not emit no more carbon than a benchmark based on the ECON 19 data. Alternative methods are also provided for schools and hospitals.

c) a Carbon Emissions Calculation Method (paragraphs 1.74 – 1.76). This method also considers the performance of the whole building, *but can be applied to any building type. To comply with the provisions of Part L, the annual carbon emissions from the building should be no greater than that from a notional building that meets the compliance criteria of the Elemental Method. The carbon emissions from the pro-posed building and the notional building need to be estimated using an appropriate calculation tool.*

Many of the issues covered by the Approved Document are the concern of the architect or services installer and manager of the building. There are three issues, covered in this guide, that are of special relevance to the building designers, and the designers, manufacturers and installers of metal cladding and roofing systems. These are:

energy efficient design of the complete building fabric;
limiting the effect of thermal bridging, e.g. at junctions, openings and penetrations;
limiting air leakage through the building envelope.

2.2 Energy efficient design of the building fabric

1.7 To show compliance following the Elemental Method, the building envelope has to provide certain minimum levels of insulation…

1.8 The requirement will be met if the thermal performances of the construction elements are no worse than those listed in Table 1

As well as lowering the required values, the Approved Document requires more rigorous methods for calculating U-values, which take full account of heat loss through repeating thermal bridges, such as spacers etc.

0.15 U-values should be calculated using the methods given in :

- for walls and roofs: BS EN ISO 6946.

The details of the BS EN ISO 6946[4] method are given in Appendix B of Approved Document L2 however, it is made clear that this method does not apply to metal systems.

Appendix B: Calculation of U-values using the Combined Method

B4 The procedure in this appendix does not apply to elements containing metal connecting paths, for which the reader is directed to BRE IP 5/98 for metal cladding, CAB and CWCT guidance for curtain walls, and to BS EN ISO 10211-1 and –2 for other cases

Section 3 describes how to calculate appropriate U-values using a number of analysis tools.

Table 1: Standard U-values of construction elements

Exposed element	*U-value – W/m²K*
Pitched roof with insulation between rafters	*0.20*
Pitched roof with insulation between joists	*0.16*
*Flat roof or roof with integral insulation**	*0.25*
Walls, including basement walls	*0.35⁺*
Floors, including ground floors and basement floors	*0.25*
Windows, roof windows and personnel doors, (area weighted average for the whole building), glazing in metal frames	*2.2*
Windows, roof windows and personnel doors, (area weighted average for the whole building), glazing in wood or PVC frames	*2.0*
Rooflights	*2.2*
Vehicle access and similar large doors	*0.7*

* Built-up metal or composite panel roofs are regarded as having integral insulation; this category is not included in Scottish Technical Standard J.

⁺ This value is 0.30 W/m²K in Scottish Technical Standard J.

2.3 Maximum areas of windows, doors and rooflights

1.12 Provision should be made to limit the rate of heat loss through glazed elements of the building. One way of complying would be to limit the total area of windows, doors and rooflights so that they do not exceed the values given in Table 2 - unless compensated for in some way.

Table 2: Maximum area of openings unless compensating measures are taken

Building Type	*Windows and doors as % of the area of exposed wall*	*Rooflights as % of area of roof*
Industrial and storage buildings	*15*	*20*

Trade off between construction elements

1.14 In order to provide greater design flexibility, the U-values of construction elements and the areas of windows, doors and rooflights may vary from the values given in Table 1 and Table 2 provided that suitable compensating measures are taken. If glazing areas are reduced from those given in Table 2, special care needs to be given to confirm that levels of daylight are adequate. Guidance on designing for daylight is contained in CIBSE LG10.

1.15 Compliance with provisions of Part L would be achieved if:

a) the rate of heat loss from the proposed building does not exceed that from a notional building of the same size and shape that meets the criteria set out in Table 1 and 2; and

b) the U-value of any part of an element is no worse than the values given in the following Table 3.

Table 3: Poorest U-value acceptable when trading off between elements

Element	*Poorest acceptable U-value (W/m^2K)*
Parts of roof [1]	*0.35*
Parts of exposed wall or floor[1]	*0.70*

Notes: [1] *Whilst parts of these elements may (within the limits given in this table) have poorer U-values than those given in Table 1, it will not normally be practical to make sufficient allowances elsewhere in the design for the whole element to be built to these standards.*

1.16 As further constraints on these methods however,

a) if the U-value of the floor in the proposed building is better than the performance given in Table 1 with no added insulation, the better performance standard is to be adopted for the notional building; and

b) if the area of openings in the proposed building is less than the values shown in Table 2, the average U-value of the roof, wall or floor cannot exceed the appropriate value in Table 1 by more than 0.02 W/m^2K.

c) no more than half the allowable rooflight area can be converted into an increased area of windows and doors.

2.4 Thermal bridging at junctions and around openings

The Approved Document requires that

1.9 The building fabric should be constructed so that there are no significant thermal bridges or gaps in the insulation layer(s) within the various elements of the fabric, at the joints between elements and at the edges of elements such as those around window and door openings.

1.10 One way of demonstrating compliance would be to utilise details and practice that have been independently demonstrated as being satisfactory. For domestic style construction a selection of such satisfactory details is given in the robust construction details publication.

1.11 An alternative way of meeting the requirements would be to demonstrate by calculation or by adopting robust design practices that the performance of the building fabric is at least as good as it would be by following paragraph 1.10. BRE IP 17/01 and the MCRMA Technical Paper No 14 illustrate how this can be done.

See section 2.5 for discussion of BRE IP 17/01[5].

Section 2 of the Approved Document contains requirements for demonstrating the thermal quality of the completed building.

2.1 To avoid excessive thermal bridging, appropriate design details and fixings should be used (see paragraph 1.9). Responsibility for achieving compliance with the requirements of Part L rests with persons carrying out the work. In the case of new buildings, that "person" will usually be,

e.g. a developer or main contractor who has carried

out the work subject to Part L, directly or by engaging a subcontractor. The person responsible for achieving compliance should (if suitably qualified) provide a certificate or declaration that the provisions meet the requirements of Part L2(a)
(i.e. limiting the losses and gains through the
fabric *they should*of*obtain*thebuilding)*acertificate*
or declaration to that effect from a suitably qualified person. Such certificates or declarations would state:

a) that appropriate design details and building techniques have been used and that the work has been carried out in ways that can be expected to achieve reasonable conformity with the specifications that have been approved for the purposes of compliance with Part L2; or

b) that infra-red thermography inspections have shown that the insulation is reasonably continuous over the whole visible envelope. BRE Report 176 gives guidance on the use of thermography for building surveys.

Section 4 discusses methods of meeting this requirement and section 5 discusses methods of carrying out infra-red surveys.

2.5 BRE IP 17/01

BRE IP 17/01[5] gives the requirements for limiting the risk of surface condensation or mould growth at non-repeating thermal bridges and describes how to assess their thermal performance and how to incorporate the additional heat loss with that through the remaining building fabric. The guidance is intended for thermal bridges that are not as recommended in the guide to 'domestic' robust construction details and forms the basis of the treatment of the details in this BRE/MCRMA guide. For these details, it requires:

a) the calculation of the minimum temperature factor, f_{min}, on the inside surface of the thermal bridge and imposes limits on this depending on the use of building and whether condensation or mould growth is likely to be a problem;

b) the calculation of the transmission heat loss coefficient or -value (pronounced 'psi value') associated with the thermal bridge and imposes limits on the total heat loss through all the thermal bridges in the building as a proportion of the heat loss through the unbridged fabric (i.e. the heat loss that takes account of the U-values of the plane areas).

Methods of calculating f_{min} and and demonstrating compliance with the Regulations are discussed in sections 4.2 and 4.3 respectively. A range of metal cladding and roofing details, that should cover most buildings currently being designed and constructed are shown in the Appendix, together with appropriate f_{min} and
-values.

2.6 Building air leakage

The Approved Document requires that:

1.17 Buildings should be reasonably airtight to avoid unnecessary space heating and cooling demand and to enable the effective performance of ventilation systems.

1.19 A way of meeting the requirement would be to incorporate sealing measures to achieve the performance standard given paragraph 2.4. Some ways of achieving satisfactory airtightness include:

a) providing a reasonably continuous air barrier in contact with the insulation layer over the whole thermal envelope (including separating walls). Special care should be taken at junctions between elements and around doors and windows openings. For domestic type constructions, some satisfactory design details and installation practice are described in the robust details publication. Guidance for the design of metal cladding and roofing systems to minimise air infiltration is given in the MCRMA Technical Paper No 14.

b) Sealing gaps around service penetrations.

c) Draught-proofing external doors and windows.

Section 2 of the Approved Document contains requirements for demonstrating that the completed building has achieved a good standard of airtightness and establishes a performance standard:

2.2 Air barriers should be installed to minimise the adverse effects of air infiltration (see paragraph 1.19). In this case too, certificates or declarations should be provided or obtained by the persons carrying out the work, stating:

a) for buildings of any size, that the results of air leakage tests carried out in accordance with CIBSE TM23 are satisfactory; or

b) alternatively for buildings of less than 1000m^2 gross floor area, that appropriate design details and building techniques have been used, and that the work has been carried out in ways that can be expected to achieve reasonable conformity with the specifications that have been approved for the purposes of compliance with Part L2.

2.3 Certificates or declarations such as those mentioned in paragraphs 2.1 and 2.2 may be accepted by building control bodies as evidence of compliance. The building control body will however, wish to establish, in advance of the work, that the person who will be giving the certificates or declarations is suitably qualified.

2.4 If using the CIBSE TM 23 pressure procedures as the means of showing compliance:-

a) With effect from 1 October 2003, reasonable provision would be test results showing that the air permeability (see paragraph 0.20) does not exceed 10 m^3/h/m^2 at an applied pressure difference of 50 Pa.

b) In the period up to and 30 September 2003, reasonable provision in the event that initial test results are unsatisfactory would be the results of further tests carried out after appropriate remedial work showing:-

i) An improvement of 75% of the difference between the initial test result and the target standard of 10 m^3/h/m^2 at 50 Pa, OR, if less demanding

ii) A performance no worse than 11.5 m^3/h/m^2 at 50 Pa.

Section 6 discusses methods of meeting this requirement.

Methods for calculating heat loss through plane areas of cladding and roofing systems

3.1 The development of U-value calculation methods

The standard measure for calculating the heat loss through the building fabric is the U-value. This concept, which has been in use for many years, applies to plane areas of the walls or roofs and does not take account of any extra heat loss at the junctions between elements or around window and other openings, known as thermal bridges.

Until 1995, the Approved Document required that all U-values were calculated by assuming that constructions could be represented by a series of uniform layers as shown in Figure 1.

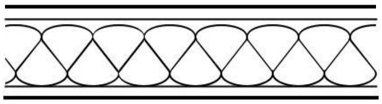

Fig 1: Construction made up of uniform layers

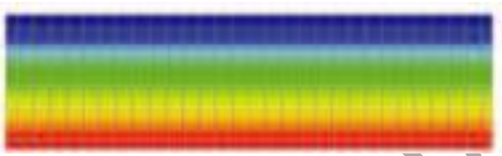

Fig 2: Temperature and heat flow through uniform construction

Figure 2 shows the temperature distribution from warm (red) to cold (blue) and heat flow lines within a uniform construction. In this case the heat flow is purely one dimensional and the U-value is easily defined as the reciprocal of the sum of the thermal resistances of the layers making up the structure and the internal and external surface resistances. So for a wall or roof containing n parallel layers:

$$U = \frac{1}{R_{so} + \sum_{i=1}^{n} R_i + R_{si}} \quad W/m^2K \qquad (1)$$

Where R_{so} is the external surface resistance in m^2K/W

R_i is the thermal resistance of the i^{th} layer in m^2K/W

R_{si} is the internal surface resistance in m^2K/W.

Standardised values of the surface resistances are quoted in BS EN ISO 6946[4] Table 2, and CIBSE Guide A3[6], section 3.3.9 (See Table 4).

Table 4: Surface resistances in m^2K/W

	Direction of heat flow		
	Upwards	Horizontal	Downwards
R_{si}	0.10	0.13	0.17
R_{so}	0.04	0.04	0.04

The thermal resistance of a material, R, depends on its thickness and thermal conductivity

$$R = d / \quad m^2K/W \qquad (2)$$

Where: d is the thickness of the material in m;

is the thermal conductivity in W/(mK).

Thermal conductivity values are tabulated in the CIBSE Guide A.3[6] Appendix 3.A7 and in BS EN 12524 : 2000[7]

Table 5 summarises typical values of some of the more important materials that are used in metal clad buildings. Conductivity values can vary and the Approved Document allows the use of properly documented manufacturer's values.

Table 5: Thermal conductivities of typical materials

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
Insulants	
Glass fibre	0.040
Mineral wool	0.037
Expanded polystyrene	0.035
Urethane	0.022

Metal cladding and roofing systems are made of combinations of materials, which differ in thermal conductivity by factors of over a thousand, in close proximity. This has important consequences for the methods of calculating U-values.

By the early 1990s, it was recognised that many constructions contained details, such as mortar joints in lightweight block work or timber studs in the insulation of timber framed walls in which increased heat flow is caused by higher conductivity elements crossing insulation. The 1995 revision to Approved Document L therefore required that these features, which are known as repeated thermal bridges, be taken into account with the ‘proportional area method’. This assumes that heat flow is still one dimensional through the wall or roof, but that the flow is locally higher through the bridging elements. For example, Figure 3 shows the temperature and heat flow through 100mm of mineral wool bridged by a 40mm wide timber stud. It can be seen that, although there is some distortion of the heat flow and temperature fields at the edges of the stud, the flow is generally one-dimensional, with higher flow density through the stud at the centre of the picture.

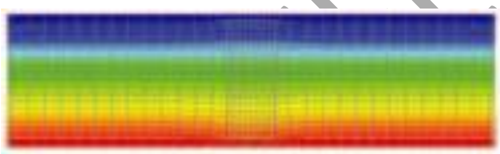

Fig 3: Temperature and heat flow through an insulation layer bridged with a timber stud

The total heat flow and therefore the U-value are calculated by adding the contributions of each element in proportion to their contribution to the total area. The thermal resistance of each layer of the construction that contains repeated thermal bridges is calculated from:

$$R = \frac{1}{\frac{F_{br}}{R_{br}} + \frac{1-F_{br}}{R_{nb}}} \quad m^2K/W \qquad (3)$$

Where F_{br} is the fraction of the wall area occupied by the repeating thermal bridges

R_{br} is the thermal resistance of the repeating thermal bridges in m^2K/W.

R_{nb} is the thermal resistance of the remaining unbridged wall in m^2K/W.

The individual layer thermal resistances are then added up as before to calculate the U-value with equation (1). This method assumes that there is no sideways flow of heat between the unbridged and bridged elements and therefore tends to overestimate the thermal resistance and underestimate the U-value.

This procedure assumes that, as shown in Figure 3, a) the repeating thermal bridges are reasonably large, occupying say 10% of the wall area and b) the conductivity of the bridge is not very different from the insulation; for example, the conductivity of timber is only four times that of mineral wool. Metal roofs and cladding systems, on the other hand, a) contain details in which the insulation is bridged by thin steel elements, such as zed spacers in a profiled metal roof, which occupy only 0.1% of the area and have conductivities over a thousand times higher than the insulation, and b) have profiled liner and outer sheets. Both of these factors cause distortions to the heat flow large enough to make the proportional area method very inaccurate. These lead to temperature and heat flow distributions like those shown in Figure 4, a section through a steel zed-spacer which penetrates 120mm of mineral wool. It is evident that heat flow is very far from one-dimensional in this case.

It was recognised, therefore, even before the 1995 Approved Document was available, that special techniques were needed for metal roofs and claddings. The MCRMA and BRE collaborated in a computer modelling exercise to produce an Information Paper IP 5/98[8], which gives more realistic U-values than the proportional area or combined methods for some metal cladding systems.

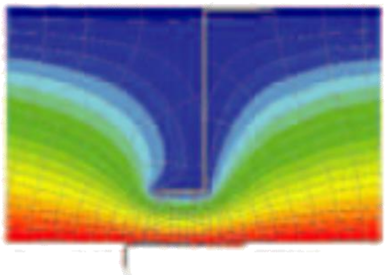

Fig 4: Distortion of temperature and heat flow caused by zed spacer

The 2001 revision to the Approved Document has introduced a more rigorous method of dealing with repeated thermal bridges, which is given in BS EN ISO 6946[4]. This standard deals with repeated thermal bridges using the more complex 'combined method', which is specified in more detail in CIBSE Guide A3[6] and in Appendix B of Approved Document L2[2]. This method carries out two calculations assuming a) no sideways flow of heat between the insulation and bridging elements, which gives a maximum thermal resistance and b) unlimited sideways flow of heat, which gives a minimum resistance. The U-value is then taken as the reciprocal of the average of these two resistances. However both the British Standard and Appendix B of the Approved Document make it clear that this method does not apply to metal roof and wall cladding systems.

3.2 Computer modelling

3.2.1 Principles

Clause B.4 of Approved Document L2, which states that the Combined Method for calculated U-values does not apply to elements containing metal connecting paths, directs users to BRE IP 5/98[8] for metal cladding and to BS EN ISO 10211-1[9] and BS EN ISO 10211-2[10] for more general cases. All these methods are based on two- and three-dimensional modelling of temperatures and heat flows through construction details using a range of software packages.

The thermal models, that are standardised in BS EN ISO 10211-1, divide the construction to be analysed into a number of homogenous material blocks and then impose a two- or three-dimensional grid over all. Figure 5 shows an example of a two-dimensional grid imposed on a twin skin system with a typical rail and bracket spacer detail.

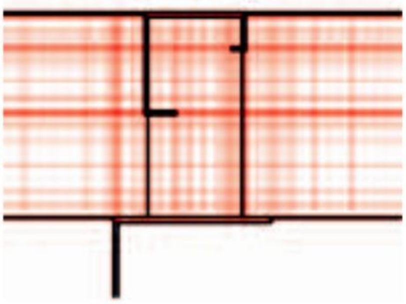

Fig 5: Grid definition for spacer detail

After internal and external temperatures and heat transfer coefficients have been defined, the model carries out a series of approximations of increasing accuracy to calculate the temperatures and heat flows at each of the nodes where the grid lines intersect. The total heat flow, which allows the U-value and temperatures at any specific points of interest such as the internal surface to be calculated, can then be displayed.

These models assume steady state internal and external conditions and that the material properties, such as thermal conductivity, are unaffected by changes in temperature. If the model is to provide accurate results it is essential that:

a) the model is extended away from the thermal bridge either into regions where the heat flow is unaffected by the presence of the bridge or to a line of symmetry between thermal bridges;
b) the grid, which defines the nodes, is appropriately specified, especially in areas where materials with very different thermal conductivities are in close contact.

BS EN ISO 10211-1 gives guidelines for both of these factors however, appropriate grid definition can be difficult, requiring considerable experience, especially in the case of metal roofing and cladding, which a) can contain metal spacers which are small compared to the extent of the roof and b) has metal and insulation materials directly in contact. Incorrect grid definition can lead to errors of 10 –20% in the calculated U-value.

3.2.2 Two-dimensional modelling

Many metal wall and roofing systems (for example the zed-spacer roof shown in Figure 6) contain linear features, such as zed-spacers or spacer rails and liner and outer sheet profiles that, although they run at right angles to each other, interact very little. They can therefore be modelled individually in two dimensions as shown in Figures 7, 8 and 9 and the results combined to give a realistic U-value of the structure. Note that as the models deal with rectangular elements, the inner and outer profiles have been approximated as a series of steps, this introduces a negligible error.

Fig 6: Roof with profiles and zed spacers at right angles

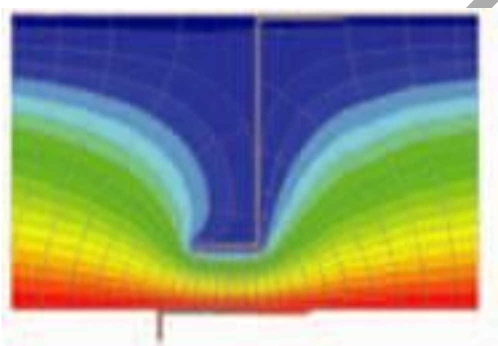

Fig 7: Distortion of temperature and heat flow caused by zed spacer

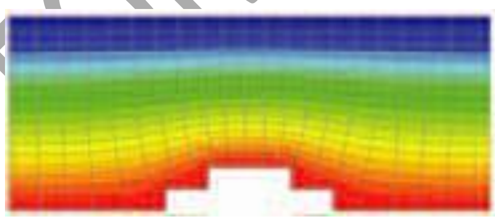

Fig 8: Distortion of temperature and heat flow caused by liner profile

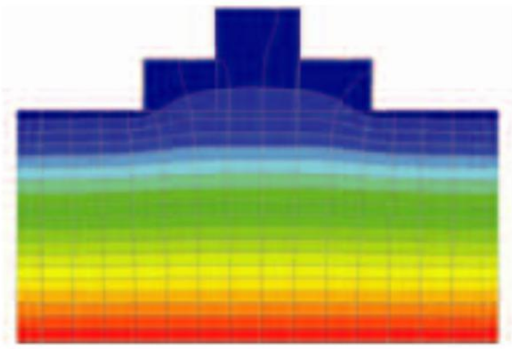

Fig 9: Distortion of temperature and heat flow caused by outer profile

BRE IP 5/98, describes procedures for determining thermal performance of some types of insulated double-skin metal roof and wall systems commonly in use in the UK. The procedures, which take account of the thermal bridging caused by the various metal connecting paths between the inner liner and outer sheet, are more realistic than other simplified methods and provide a reasonably accurate assessment of the thermal performance of such a system.

The two-dimensional computer package KOBRU, which is fully compatible with BS EN ISO 10211-1, was used to calculate the U-value of three different rail and bracket spacer and z-spacer roofs a) with a 25mm air gap between the spacer and the liner, b) with 25mm of insulation between the spacer and the liner and c) with 50mm of insulation between the spacer and the liner. The results revealed that the rail and bracket spacer had little effect on the thermal performance and could be ignored provided that the brackets are at least a metre apart. For the zed spacers, the U-value was calculated as a function of insulation thickness, spacer centres and insulation conductivity and the IP includes graphs from which the U-value can be read for any combination of these parameters. This U-value can then be corrected for the effect of any continuous air spaces above the insulation and the effect of the liner profiles intermittently compressing the insulation.

3.2.3 Three-dimensional modelling

BRE IP 5/98 and KOBRU provide realistic methods for calculating U-values for those constructions, such as zed-spacers or rails, which contain linear features that can be fully represented as individual or combined two-dimensional cross sections. Some constructions however, contain structural elements such as aluminium clips that recur regularly both up and across a roof, and cause local, relatively severe thermal bridging. These have to be analysed with a full three-dimensional model, which generally has to be individually developed for each case, a difficult and time consuming process for a complex detail.

A number of software packages are available that can carry out three-dimensional analysis. BRE uses a package called TRISCO, which is fully compatible with BS EN ISO 10211-1 and therefore meets the requirements of Approved Document L2.

3.3 Theory

3.3.1 Calculation of effective U-values

To provide an effective U-value of the structure, taking account of the effect of the repeated thermal bridging caused by the spacers etc., a two-dimensional model must extend between the lines of symmetry on either side of a spacer, i.e. if the spacers are at 1800mm centres, the model must be 1800mm wide, see Figure 10.

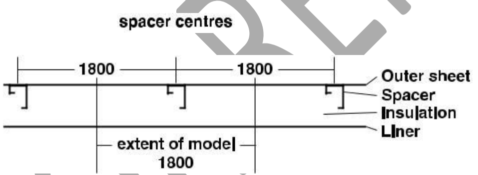

Fig 10: The necessary extent of a 2D model to calculate effective U-values

Similarly, a three-dimensional model should be extended to the points of symmetry between the spacers in both the dimensions in the plane of the wall or roof.

With inputs of appropriate internal and external temperatures and surface resistances (see Table 4), a two-dimensional model will output Q_{2D}, the total heat flow between inside and outside in W/m; a three-dimensional model will output Q_{3D} in total heat flow in W. The effective U-value will then be calculated from:

$$\text{in 2D}: U_{eff} = \frac{Q_{2D}}{L\cdot(T_i - T_e)} \qquad (4)$$

$$\text{in 3D}: U_{eff} = \frac{Q_{3D}}{A\cdot(T_i - T_e)} \qquad (5)$$

Where : L is the width of the 2D model in m (1.8 in the example shown in Figure 10).

A is the area of the 3D model in m^2.

T_i and T_e are the internal and external temperatures in ˚C.

The model will also produce the internal surface temperatures necessary to determine the risk of surface condensation, see section 4. Also, the internal surface temperature at the edge of the model remote from the effect of the spacer etc., T_{si}, can be used to calculate the unbridged U-value of the structure.

$$U_{unbr} = \frac{T_i - T_{si}}{R_{si}\cdot(T_i - T_e)} \qquad (6)$$

Where : R_{si} is the internal surface resistance in m^2K/W

3.3.2 Combining two-dimensional calculations

3.3.2.1 Combination of a flat liner, a spacer and a profiled outer

Develop two 2D models:

1. A model of the spacer system with flat liner and outer sheets. This will include the specified insulation thickness and any air gap between the outer sheet and the insulation and gives an overall effective U-value = U_{spacer}.

2. A model with a flat liner, the specified insulation and air gap as above and a profiled outer sheet. This will give an overall effective U-value = U_{outer1} and an unbridged U-value = U_{outer2}

The combined U-value U_{comb} is then calculated as shown below.

$$U_{comb} = \frac{1}{\frac{1}{U_{outer2}} - \frac{1}{U_{outer1}} + \frac{1}{U_{spacer}}} \qquad (7)$$

3.3.2.2 Combination of a profiled liner, a spacer and a profiled outer

To assess the combined effect of the spacer and the profiled liner and outer sheets, the following steps are necessary:

1) Develop two 2D models with a) a flat liner and profiled outer giving U_{outer} and b) flat outer and profiled liner giving U_{liner}

2) Calculate the total U-value of a combination of the liner and outer profile:

$$U_{comb1} = \frac{1}{\frac{1}{U_{liner}} + \frac{1}{U_{outer}} - (R_{si}+R_{so}) - \frac{t}{k}} \quad (8)$$

Where U_{comb1} is the combined U-value in W/m^{2}K

U_{liner} is the U-value of the liner profile from KOBRU in W/m^{2}K

U_{outer} is the U-value of the outer profile from KOBRU in W/m^{2}K

R_{si} and R_{se} are the inside and outside thermal resistances in m^{2}K/W

t is the thickness of the insulation in m

k is the thermal conductivity of the insulation in W/mK

3) Calculate the insulation thickness needed between flat faces to give the same U-value that resulted from the combined inner and outer profiles i.e. U_{comb}.

$$Th = k\left[\frac{1}{U_{comb}} - (R_{so}+R_{si})\right] \quad (9)$$

4) Use a liner profile calculation with the insulation thickness equal to the distance between the liner and spacer to calculate $U_{liner\,2}$ and use this to calculate the equivalent thickness of insulation under the spacer

$$th = k\left[\frac{1}{U_{liner\,2}} - (R_{so}+R_{si})\right] \quad (10)$$

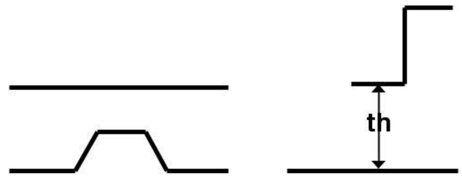

Fig 11: Calculation of the equivalent thickness of insulation under the spacer

5) Insert the two thicknesses derived in 4) and 5) into a 2D model of, for example, a zed spacer roof as shown in Figure 12, giving the bridged U-value U_{comb2}

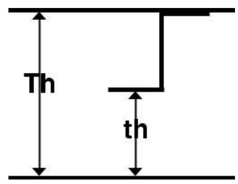

Fig 12: The equivalent insulation thicknesses in the spacer model

3.3.3 Additional heat loss through repeating point components

Some features which pass through the insulation, such as the brackets in rail and bracket roofs or fasteners, can increase the heat loss through a roof or cladding. Once the additional heat loss through an individual bracket or fastner Q_{add} W/˚C has been calculated, (using three dimensional modelling), the effect on the U-value may be calculated from

$U = Q_{add}/n_{add}$, where n_{add} is the number of such features/square metre of roof or wall surface.

For example, if a roof with U-value 0.25 W/m^{2}K is penetrated by 5.5 mm diameter stainless steel fasteners, with Q_{add} = 0.006 W/˚C, with 1.11 fasteners/m^2, U will be 0.007 W/m^{2}K. If steel fasteners with Q_{add} = 0.014 W/˚C were used, U would be 0.015 W/m^{2}K

3.4 Examples

Example 1: A twin skinned roof with zed-spacers that can be assessed by combining two-dimensional models

The roof is similar to that shown in Figure 6 with1.6 mm steel zed spacers at 1800mm centres. The space between the inner and outer sheets is filled with 120mm of mineral wool, with conductivity 0.04 W/mK, and there is 25mm of insulation between the liner and the zed-spacer. The outer profiles are 35mm deep, at 170mm centres and the liner profiles are 18mm deep, at 200mm centres.

The U-value of this system can be calculated by various methods:

a) Ignoring thermal bridging:
In the absence of any bridging from the zed spacer or the profiles, the U-value of the roof would be **0.32 W/m^{2}K.**

b) BRE IP 5/98
Graph 5 on page 6 of BRE IP 5/98 gives **U = 0.36 W/m^{2}K** if the profiles are ignored
Equation 3 on page 4 of the IP, gives a correction of 7 mm for the effect of the liner profiles compressing the insulation, changing the insulation thickness to 113mm, graph 5 then gives **U=0.38 W/m^{2}K**.

c) Combination of two-dimensional models
Following the steps specified in section 3.3.3.2

1) U_{liner} = 0.34, U_{outer} = 0.31.
2) R_{si} + R_{se} = 0.14, t= 0.12 and k = 0.04 giving U_{comb} = 0.330.
3) Th = 0.115 m
4) th = 0.0147 m.
5) **U = 0.40 W/m^{2}K**

Therefore ignoring thermal bridging completely underestimates the U-value by about 20% and using IP 5/98 underestimates it by 5%.

Example 2: A composite panel fully filled with insulation
Figure 13 shows a representative section of a cladding panel with profiled liner and outer sheets, fully filled with a foam insulation of conductivity 0.02 W/mK. The thickness of the insulation, measured from the lowest point of the top surface of the liner to the lowest point on the base of the outer sheet, is 80mm.

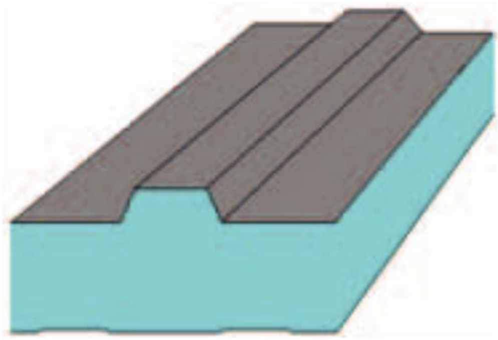

Fig 13: Representative section of composite panel

A simple one-dimensional calculation of the U-value taking account of the nominal 80mm of insulation alone, gives a U-value of 0.24 W/m^{2}K. Separate two-dimensional calculations of the U-values resulting from the profiled liner and flat outer and profiled outer and flat liner, give : U_{outer} = 0.24 W/m^{2}K and U_{liner} = 0.25 W/m^{2}K. Combining these with equation 8) gives U= 0.25 W/m^{2}K. Although, at the insulation thicknesses necessary to comply with the elemental U-values in Approved Document L, the effect of the profiles is small, taking them into account by simple proportional methods gives misleading answers.

Example 3: Three-dimensional modelling
Figures 14 and 15 show the results on an analysis of a detail of a profiled metal roof, containing 80mm of insulation of conductivity 0.037 W/mK between profiled sheets. Aluminium clips, which are isolated from the liner sheet with a thermal break pad, recur regularly at 400mm centres across the roof and at 1500mm centres up the roof, these are therefore the two horizontal dimensions of the model. The figures show the temperature on the liner and the heat flow into the roof. Both of these clearly show the local effect of the thermal bridging due to the clip, despite the thermal pad, with the internal surface temperature falling from 19.4˚C away from the clip to 16.4˚C immediately below the clip, and the corresponding heat flows rising from 6.6 to 36.5 W/m^2.

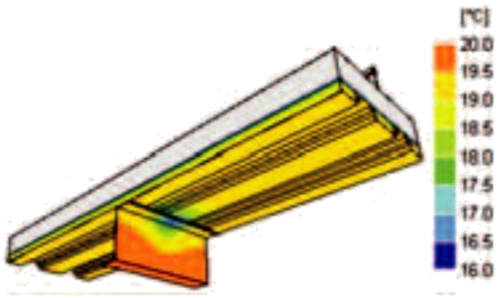

Fig 14: Temperature distribution on the base of a sheeted metal roof with aluminium clips

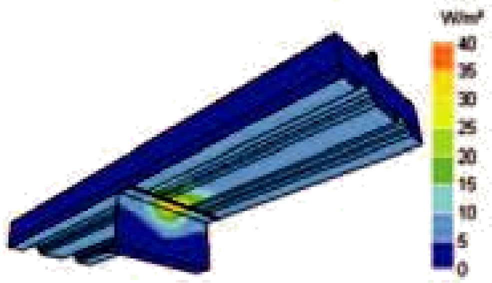

Fig15: Heat flow distribution on the base of a sheeted metal roof with aluminium clips

As the model is assumed to be representative of the whole roof the U-value can be calculated from:

In this case A = 0.4 · 1.5 = 0.6 m^2 and T_i - T_e = 20°C.

If the thermal bridging is ignored by removing the clip from the model

Q = 5.09 giving U = 0.42 W/m^{2}K

With a fully three-dimensional model as shown in Figures 14 and 15 with the correct clip size:

Q = 7.60 giving U = 0.63 W/m^{2}K

In this case, ignoring the thermal bridging underestimates the U-value by over 30%.

3.5 Summary of U-value calculation methods for metal roofing and cladding

1. The method contained in BS EN ISO 6496 and CIBSE Guide A does not apply to either twin skin or composite panel metal roofing and cladding systems.

2. If the construction is one of those covered in BRE IP 5/98, the U-value can be obtained from the graphs or other information in the IP and corrected for air spaces and compression of the insulation by the profiles using the equations in the IP.

3. If the component contains independent linear features that can be represented by a series of two-dimensional models, use a two-dimensional model and combine the results from the different models.

4. If the component contains repeating point thermal bridges, such as clips, develop a three-dimensional model to calculate the heat flows and then the U-value.

Thermal bridges

4.1 Introduction

Fabric heat loss from buildings is calculated and taken into account in the Regulations using the U-values of the plane surface of walls and roofs that were discussed in section 3. Further heat loss usually occurs at junctions such as between walls and roofs, at gutters and around openings such as windows, doors, rooflights and other penetrations. In these areas, known as thermal bridges, the geometry of the structure and/or the presence of high conductivity materials crossing the insulation lead to heat flows that are locally higher than in surrounding areas. These add to the total energy demand of the building.

A second consequence of thermal bridging is the lower internal surface temperatures caused by the increased heat flow. Depending on the environmental conditions within the building and the nature of the internal surfaces this can lead to surface condensation or, less commonly in industrial buildings, mould growth.

Figures 16 and 17 show the increased heat loss and lower surface temperatures through a corner where two panels meet with the liner of one bridging the insulation of the other. This example is discussed further in the Appendix.

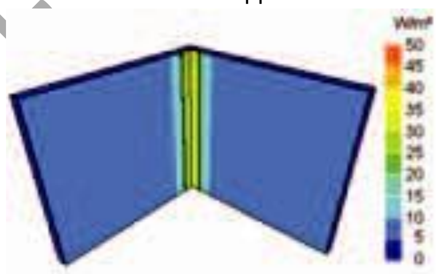

Fig 16: Increased heat flow caused by thermal bridging in corner

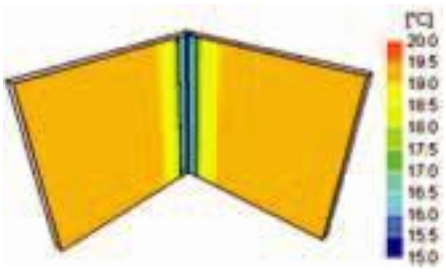

Fig 17: Lower temperatures caused by thermal bridging in corner

Approved Document L2 requires that the building fabric should be constructed so that there are no significant thermal bridges at the joints between elements and at the edges of elements such as those around window and door openings. One way of demonstrating compliance is to utilise details and practice that have been demonstrated as being satisfactory. A selection of satisfactory details for domestic style constructions is given in the report containing standard details. BRE IP 17/01and this MCRMA Technical Paper specify the criteria that have to be met at all the thermal bridges on a building to avoid condensation or mould growth and excessive heat loss. These are discussed in sections 4.2 and 4.3.

4.2 Surface condensation and mould growth

4.2.1 The conditions for condensation and mould growth

In many buildings, especially housing, which have absorbent surfaces, the main consequence of the lowered surface temperatures caused by thermal bridges, is mould growth which, besides being extremely unsightly, is a major cause of respiratory allergies such as asthma. Mould growth, which occurs at a surface relative humidity of 80%, is however, very rare on the impermeable internal surfaces of metal faced walls and roofs. Condensation, depositing drops of water on the surface, which does not occur until the surface relative humidity has reached 100%, is much more likely in this case. Even when condensation occurs, often only a few grams per square metre accumulates, seen as a fine mist on the surface, which rapidly disperses as temperatures rise. BRE work for the MCRMA has shown that at least 70 g/m^2 must accumulate before it will run from sloping surfaces and 150g/m^2 before dripping will occur from a horizontal surface.

The relationships between air and surface temperatures and humidity and the consequent risk of condensation or mould growth can be summarised on a psychrometric chart as shown in Figure 18.

Air at 20˚C and 60 % relative humidity will have a vapour pressure of 1.40 kPa*tem*(***p***ointerature*A*in*factor*Figure*f* 18). If it is cooled at constant vapour pressure it will reach the mould growth limit of 80% relative humidity at a surface temperature of 15.4˚C (point C). If the surface is likely to promote mould growth this temperature imposes the limit for the thermal design of the building. If mould growth is unlikely, the risk of surface condensation then defines the necessary temperature. Saturation and condensation occur, when the relative humidity reach 100%, (point B); given the assumed conditions this occurs at 12.0˚C which imposes a much less stringent design condition.

Conversely, if the air temperature is 20.0˚C and the surface temperature is 14.0˚C, mould will occur if the internal humidity rises above 55% (point X), while condensation will not occur unless the humidity rises above 68% (point Y).

Fig 18: Psychrometric chart showing the risk of condensation and mould growth

4.2.2 Surface temperature factor

The internal surface temperature of a point on a building, which determines the risk of condensation or mould growth (see below) depends on a) the internal and external environmental temperatures and b) the thermal quality of the component. In masonry construction, the mass of the structure, which can cause the internal surface to lag several hours after changes in the environmental temperatures is also important. However, profiled metal walls and roofs are much lighter weight and follow temperature changes much more rapidly. The thermal quality of a particular part of the envelope can be assessed irrespective of any particular environmental conditions by calculating the , which is defined by:

$$f = \frac{Ts - Te}{Ti - Te} \qquad (11)$$

where Ts is the local surface temperature

Te is the external air temperature

Ti is the internal air temperature.

Once the temperature factor of a specific detail, e.g. a corner, has been found by measurement or calculation (see below) at specific internal and external temperatures, the surface temperature can be found for any other combination of environmental temperatures from:

$$Ts = Te + f \cdot (Ti - Te) \qquad (12)$$

4.2.3 Criteria for assessing buildings

The robust standard details for domestic type constructions, produced for the guide to accompany Approved Documents L1 and L2 have been assessed for the risk of mould growth using the criterion that the internal surface temperature should be kept above 15˚C, given internal and external temperatures of 20˚C and 0˚C respectively. This can be expressed as a minimum allowable temperature factor, f_{min}, of 0.75 (using Equation 11).

There are various reasons why this may not be the most appropriate criterion for buildings with metal cladding and roofing:

a) The internal environment may be significantly different from the fairly severe ‘domestic type’ conditions, taken as 20˚C and 60% RH. A warehouse will have a much lower internal humidity, while a swimming pool or food processing plant may be significantly more humid.

b) Most metal walls and roofs have hard impermeable internal surfaces on which mould growth is much less likely than surface condensation. Condensation occurs at a surface relative humidity of 100% as opposed to the 80% necessary for mould growth. As discussed above, that will impose a significantly less stringent requirement on surface temperatures.

c) Metal cladding has little thermal mass compared to domestic constructions and will therefore respond rapidly to overnight falls in temperature that would be smoothed out by a masonry wall.

Surface temperature criteria, which define f_{min} and which are more appropriate to industrial buildings have been established using the methodology specified in BS EN ISO 13788.

4.2.4 BS EN ISO 13788

The current standard for the design of buildings against condensation risks is BS 5250:1989[11], which includes calculation procedures for surface and interstitial condensation risk as appendices C and D. A new CEN standard BS EN ISO 13788:2001[12] which contains more complex calculation procedures, has recently been introduced, and consequently the BS 5250 appendices are being withdrawn. BS 5250 is currently being extensively revised and a new version, which makes reference to the calculation procedures in BS EN ISO 13788, will be available in early 2002.

BS EN ISO 13788 contains a method for calculating the necessary thermal quality of building envelopes to avoid either condensation or mould growth, which includes categorising buildings into a number of 'climate classes' depending on their likely internal environment. This classification uses the difference between the inside and outside vapour pressure, the 'vapour excess', which is determined by the moisture generation rate, the volume of the building and the ventilation rate. The fact that ventilation rates vary as more windows are opened in warmer weather is allowed for by assuming that a) the vapour excess is constant below 0˚C as all windows are closed and b) the vapour excess falls linearly to zero at an external temperature of 20˚C, when the building is assumed to be well ventilated. This gives the boundaries between the classes shown in Figure 19, which also shows the internal relative humidity at an outdoor temperature of 0˚C and an indoor temperature of 20˚C.

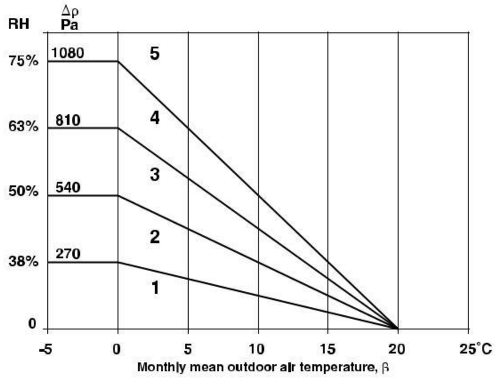

Fig 19: Variation of internal humidity classes with external temperature

In the case of air conditioned buildings in which the internal humidity is controlled independently of the external environment the set values of the temperature and relative humidity should be used to calculate the internal moisture load.

Different building types fall into the different classes shown on Figure 19 and summarised in Table 6, with the minimum f-values which are required to avoid condensation in the different internal environments

Table 6: Internal humidity classes and the minimum temperature factor necessary to prevent condensation

Humidity class	Building Type	Minimum f value
1	Storage areas	0.30
2	Offices, shops	0.50
3	Dwellings with low occupancy	0.65
4	Dwellings with high occupancy, sports halls, kitchens, canteens; buildings heated with un-flued gas heaters	0.80
5	Special buildings, e.g. laundry, brewery, swimming pool	0.90

The BS EN ISO 13788 methodology leads to the temperature factors necessary to avoid condensation shown in Table 6. These temperature factors can be put into context by comparing them with the values, in the absence of thermal bridging, for :

a) a single steel sheet 0.5mm thick, with no insulation, gives f = 0.28, i.e. there would be condensation in all building types;

b) a roof light made up of two sheets of polycarbonate separated by a 20mm air gap gives f = 0.59;

c) two steel sheets separated by 50mm of mineral wool gives f = 0.93.

Example 1:

We wish to prevent surface condensation in a warehouse, in climate class 1, with internal temperature of 15˚C when the external temperature falls to -5˚C. The required temperature factor from Table 6 is 0.3, so the fabric must be designed so that the internal

surface temperature is above $–5 + 0.3 \cdot (15 – (-5))$ = 1˚C (equation 12)

Example 2 :

We wish to prevent surface condensation in a swimming pool, in climate class 5, with internal temperature of 25˚C when the external temperature falls to -5˚C. The required temperature factor from Table 6 is 0.9, so the fabric must be designed so that the internal

surface temperature is above $–5 + 0.9 \cdot (25 – (-5))$ = 22˚C (equation 12)

4.2.5 Surface temperature calculations

Besides calculating heat flows and U-values, the two - and three-dimensional analysis software described in section 3 also calculates the internal surface temperature and therefore the risk of condensation or mould growth.

The zed-spacers and similar repeated thermal bridges that can be analysed in two dimensions have little effect on the internal surface temperature. For example, the detail analysed as example 1 in Section 3.3 gives a minimum internal surface temperature of 18.7˚C with internal and external temperatures of 20˚C and 0˚C respectively.

This gives f = 0.935, which means that this construction would not pose a risk of internal surface condensation with any reasonable internal environment. Similarly, the point thermal bridges caused by brackets or fasteners discussed in section 3.3.3 do not lower the f-value below 0.9. **It is however, important to remember that, unless the vapour control layer is complete, there may be a risk of interstitial condensation within the structure, particularly in high humidity environments.**

The detail shown as example 2 in Section 3.3, which requires three-dimensional modelling, gives a minimum surface temperature of 16.4˚C below the clip, (Figure 14) for the same environmental conditions. This means that f=0.82, so that this detail would not be suitable for a swimming pool but would not give problems with any other occupancy.

More serious problems can arise at non-repeating thermal bridges at the junctions between walls and roofs, at valley gutters or at openings such as doors and windows and other steelwork penetrations. The severity of the problem depends on whether the detail leads to any metal penetrations of the insulation layer other than those due to the standard spacers in the plane areas of wall and roof, that have been taken into account already. Examples of surface temperatures on thermal bridges are shown in section 4.4.

Although their inclusion is not required by the Regulations, 'point' thermal bridges caused by penetrations of the building envelope, such as safety harness posts or protruding girders to support a canopy or gutter, can cause localised very low surface temperatures, see the Appendix for further details.

4.3 Heat loss through thermal bridges

4.3.1 Linear thermal transmission - -value

Heat loss through linear thermal bridges is expressed in terms of the linear thermal transmittance or -value. This is the extra heat loss through the thermal bridge over and above the heat loss through the adjoining plane elements.

For example, Figure 20 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. The model is extended sufficiently far along either panel so that the temperature and heat flow at the edges is unaffected by the presence of the thermal bridge. In practice this has to be about one metre, rather more than is shown here. A two-dimensional thermal model is used to calculate the heat flow from the inside to the outside and the -value is then calculated from:

$$\Psi = \frac{Q}{T_i - T_e} - U_A \cdot D_A - U_B \cdot D_B \quad \text{W/mK} \quad (13)$$

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

D_A and D_B are the lengths of cladding A and B out from the inside corner in m

Then if the total length of this corner detail is L m, its contribution to the heat loss from the building is L W/K. The contributions of all the thermal bridges in the building can be added giving a total heat loss of L W/K. This can then be added to the plane area heat loss to give the total fabric heat loss of A U + L.

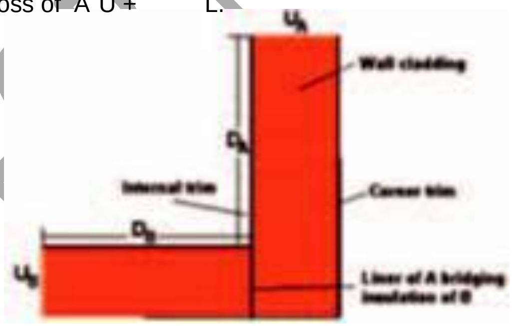

Fig 20: Calculation of -value

BRE IP 17/01 contains a table of -values for thermal bridges in typical domestic constructions; if the calculated -values in the building under design are less than or equal to these values, then no further action is necessary. If the thermal bridges under investigation do not appear in this table, which is most likely in the case of industrial buildings, the -value for the building fabric must be calculated, where:

$$\alpha = \frac{\sum \Psi \cdot L}{\sum A \cdot U} = \frac{\text{(sum of heat loss at junctions)}}{\text{(sum of heat loss through plane areas)}} \quad (14)$$

To satisfy the Regulations must be less than or equal 0.16 for domestic buildings and less than or equal 0.10 for non-domestic buildings. The lower value for non-domestic buildings reflects the fact that their larger size means that thermal bridges are relatively less important. Section 4.5 gives an example of the effect of specific thermal bridges on the calculation of the -value for a typical industrial building

Although their inclusion is not required by the Regulations, 'point' thermal bridges caused by penetrations of the building envelope such as safety harness posts or protruding girders to support a canopy or gutter, can cause additional heat loss; see the Appendix for further details.

4.4 Examples of surface temperature and heat loss through thermal bridges

4.4.1 Roof ridge

The ridge detail, shown in Figure 21, contains no penetrations of the insulation, apart from the spacers on either side, which are part of the basic cladding and will have been taken into account in the calculation of the cladding U-value.

Analysis of this ridge detail gives f_{min} = 0.91 and =0.01 W/mK. These confirm, as expected from the drawing, that this detail will not cause any condensation problems in any of the building types shown in Table 6 and will lead to a very small addition to the heat loss from the building.

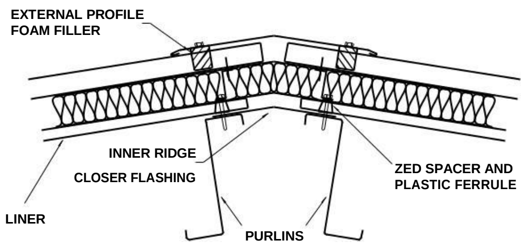

Fig 21: Ridge detail with no apparent thermal bridging that is likely to lead to internal surface condensation

4.4.2 Valley gutter

In the purlin hung valley gutter shown schematically in Figure 22, the steel gutter top and roof cladding liner are penetrating through the insulation layer, suggesting that severe thermal bridging is likely. Because, as noted in section 3.2, the simulation programs work on rectangular shapes, the roof panel, which would be sloping down to the gutter in practice, has been flattened out. This makes little difference to the calculated internal surface temperature values. Figure 23 shows the calculated temperatures for internal and external temperatures of 20˚C and 0˚C respectively. Because of the thermal bridging caused by the gutter top and the metal liner, the internal surface temperature is reduced to 13.7˚C, giving f=0.69. This means that this detail would work adequately in a warehouse, but in a sports hall or factory with any wet process, and especially a swimming pool, there would be a risk of condensation.

Analysis of the heat flows gives =1.5 W/mK, suggesting that this detail is a much more significant extra source of heat loss from the building, than the ridge above.

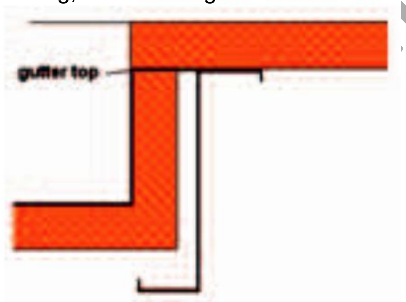

Fig 22: Valley gutter detail

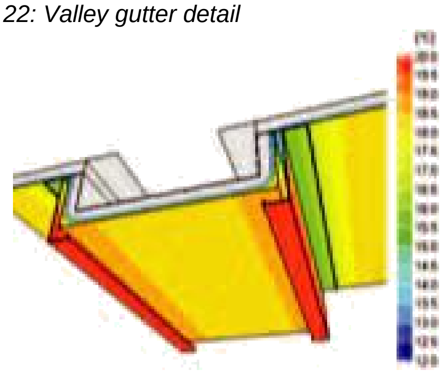

Fig 23: Calculated temperatures on base of valley gutter and roof lining

If the gutter top is modified so that the part that crosses the insulation is made of a rigid plastic with conductivity = 0.2, the f-factor rises to 0.84 and the -value falls to 0.66, significantly improving the energy performance. If the liner of the main roof does not cross the insulation, the f-factor rises to 0.95 and the -value falls to 0.17, considerably reducing the thermal bridge.

4.5 Example of the effect of thermal bridging on overall heat loss

To illustrate the relative effect of different components, the fabric heat loss through the notional building shown in Figure 24 was calculated; The contribution of air leakage to the total heat loss is estimated in section 6.4.

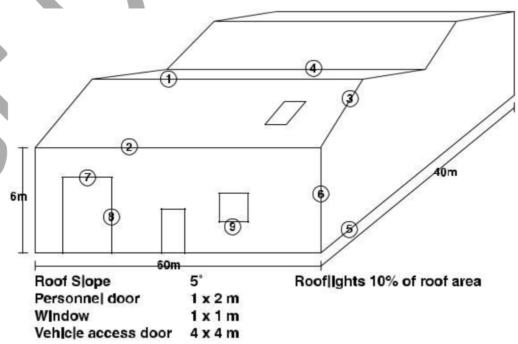

Fig 24: Notional industrial building showing thermal bridges

The building is assumed to be a typical medium sized industrial unit with the dimensions shown on the sketch. There is just one large vehicle door, a personnel door and one office window in one of the end walls; 10% of the roof area is made up of rooflights. The nine possible thermal bridges identified on the sketch are discussed below.

Plane elements

Table 7 shows the areas and U-values of each of the plane elements and their product that is summed to calculate AU. In the example shown, it has been assumed that each of the U-values is equal to the required value quoted in the table in paragraph 1.8 of Approved Document L2. In practice, specific values would be quoted by the system suppliers and it would also be necessary to take account of other components such as smoke vents or gutters.

Table 7: Areas and U-values of the plane elements

Plane element	Area m²	U-value W/m²K	A U W/K
Side walls	514.8	0.35	180.2
End walls	701.0	0.35	245.4
Access door	16.0	0.7	11.2
Personnel door	2.0	2.0	4.0
Window	1.0	2.0	2.0
Rooflights	240.9	2.2	530.0
Roof	2168.2	0.25	542.1
Ground floor	2400.0	0.25	600.0
		AU = 2114.8	

Thermal bridges at junctions and openings

The sketch in Figure 24 shows nine possible thermal bridges in the notional building. The total length and assumed -value of each of these are shown, together with their product, in Table 8. For simplicity, it has been assumed the surrounds of each of the two doors and window are identical; in practice it may be necessary to deal with these separately. The -values have been chosen to represent examples of current practice, some of which produce relatively severe thermal bridges, as illustrated in section 4.4. In a real building the added heat loss from features, such as projecting girders supporting a canopy or gutter, or safety harness posts, should also be considered.

Table 8: Lengths and -values of each of thermal bridges shown in Figure 24

Thermal Bridge	Length m	-value W/mK	L W/K
1) Ridge	120	0.01	1.2
2) Eaves	120	0.25	30.0
3) Verge	80	0.10	8.0
4) Valley Gutter	60	1.50	90.0
5) Sill	195	0.41	80.0
6) Corner	24	0.25	6.0
7) Window or door head	6	1.50	9.0
8) Window or door jamb	14	1.50	21.0
9) Window sill	1	0.30	0.3
		L= 245.5	

In this case L/=SAU = 245.5 / 2114.8 = 0.12, slightly exceeding the limit of = 0.10 specified in IP 17/01 for non-domestic buildings for compliance with the Regulations. It can be seen from Table 8 that, although the window and door head and jambs are relatively severe thermal bridges with large -values, their short length in this example building, means that their contribution to the overall totalLis small (this would obviously not be the case in a building with many more doors and windows). Much more important are the valley gutter and the sill at the base of the building, which both have large -values and long lengths. If the valley gutter was modified as described in section 4.4.2 to reduce its -value to 0.17, this alone L to 165.7 reducingwould reduce to 0.078, which complies with the Regulations. Alternatively, if the sill/drip was modified as described in the Appendix, reducing its -value to 0.01, this would reduceLto 167.5 reducing to 0.79.

This demonstrates that, provided that there is no risk of condensation given the particular internal environment, apparently quite large linear heat transmission (-values) can be acceptable on individual details, so long as the total heat loss from all the details on the building can be controlled.

4.6 Summary of methods to reduce the risk of condensation and heat loss due to thermal bridging

1. It is necessary to consider both the risk of condensation on each individual thermal bridge and the effect of the increased heat loss through thermal bridges on the overall heat from the building.

2. Condensation, which occurs at a surface relative humidity of 100%, is much more likely in metal constructions than mould growth, which occurs at a surface humidity of 80%.

3. Condensation is unlikely on ‘repeating thermal bridges’ such as spacers or profiles, but is more likely on systems with discrete aluminium clips.

4. If a detail contains metal components crossing the insulation that would not otherwise be

present in a plane element, condensation may occur in humid environments. The severity of the bridge, and therefore the risk of condensation, is determined by the f-factor which is calculated by modelling the structure. Values of the f-factor for a range of details are given in the Appendix of this document.

5. If this type of thermal bridge is to be included in a building, which is likely to have a humid internal environment, consideration should be given to re-designing the detail.
6. It is also necessary to calculate the linear thermal transmittance (-value) and do a heat loss calculation for the whole building. If the total heat loss through the thermal bridges is greater than 10% of that through the plane areas, individual details must be modified to reduce the loss through the bridges. Values of the -value for a range of details are given in the Appendix of this document.

One way of demonstrating compliance with the requirements of Approved Document L2 is to submit evidence that an infra-red thermography inspection has shown that the insulation is 'reasonably continuous over the whole visible envelope'. It is however, not clear how complete is 'reasonably continuous', which could well be grounds for dispute in marginal cases. Also infra-red surveying is a complex process which, even if it is carried out under controlled conditions and analysed carefully, requires a degree of subjective interpretation by experienced operators who are familiar with metal cladding systems and buildings.

This section discusses methods for carrying out and interpreting infra-red surveys of buildings with metal walls and/or roofs.

5.1 Thermal imaging

The instruments used in infra-red thermography measure the thermal radiation from an object and construct an image on a monitor. This image can be in black and white, with brightness proportional to the radiation intensity or have artificial colours assigned to intensity bands. The radiation emitted by any object depends on:

a) the temperature of the surface;
b) the emissivity of the surface

Emissivity is a parameter that depends on surface texture; some values for typical building materials are:

Timber	0.85
Plasterboard	0.90
Brick	0.90
Concrete	0.92
Oil based paint	0.94
Black lacquer	0.97
Polished steel	0.07
Galvanised steel	0.23
Aluminium foil	0.09
Anodised aluminium	0.55

If all the materials have similar emissivities, an infra-red image can be interpreted as showing surface temperatures. However, the low emissivities of metal surfaces means that they will *appear* much colder than their surroundings, although they are in fact at a similar temperature.

A further complication is caused by reflection of thermal radiation. The reflectivity of a surface is equal to the emissivity value subtracted from one, therefore a metal surface will be very sensitive to the temperatures of the people carrying out the survey, lights in the room, or equipment in the background.

In principle, it is possible to use thermal images to obtain quantitative measurements of surface temperatures that can be compared with temperatures calculated using the methods described in section 4. However, in practice, the factors outlined above make it difficult to obtain more than a qualitative agreement between the patterns of internal temperature distribution on the internal surface. This difficulty is reflected in the title of the one available standard for infra-red surveys, BS EN 13187:1999 : *Thermal performance of buildings - qualitative detection of thermal irregularities in building envelopes - infra-red method*. This means that it is not possible to use thermal imaging surveys to measure U-values or quantify the effects of thermal bridges.

Areas on a thermal image of the inside of a building, which appear to have low surface temperatures compared to their surroundings, can therefore be caused by :

a) low emissivity materials; these can usually be identified visually and a correction factor included in the analysis;

b) increased heat flow through the component caused by thermal bridging due to the materials present or missing insulation;

c) increased heat flow due to moisture increasing the thermal conductivity of thermal insulation;

d) evaporation of moisture from the surface;

e) cooling of the surface due to cold air infiltration.

The appearance of the thermal image can give some guide to which of these problems is the likely cause of any cold areas. For example, missing insulation or thermal bridging gives a cold patch with clearly defined edges, wet insulation gives a diffuse cold area and air infiltration has a characteristically ‘feathery’ appearance.

When a building is surveyed from the outside, the effect of factors b) and c) will be to increase the local external surface temperature compared to surrounding areas. However, because the effects of sun, wind and rain tend to blur out the thermal patterns, external surveys are much less sensitive than internal ones.

5.2 Conditions for a survey

Detailed guidance on thermal imaging surveys is given in a BRE Guide[13] and an Energy Efficiency Office Best Practice Report[14], which describe the conditions that are necessary for a meaningful survey. The thermal conditions to which a building is exposed before and during a thermal imaging survey are very important. To minimise external climatic interference and to maximise thermal resolution the survey should, wherever possible, be carried out from within the building. In general, the following conditions should be met:

For typical masonry constructions, the numerical value of the temperature difference between the inside and outside should be at least 3/U, where, U is the U-value of the wall or roof under investigation, for at least 24 hours before, and for the duration of the survey; therefore a temperature difference of at least 8.5˚C is necessary for a wall with U=0.35 W/m^{2}K. This length of time may be relaxed to 12 hours in the case of lightweight metal structures that respond more rapidly to changes in temperature.

The outside air temperature variation should be small and the internal air temperature should not vary by more than ±2˚C.

For at least 12 hours before and for the duration of the survey the building façade under investigation should not be exposed to sunshine sufficient to affect the results. The best conditions are usually found on cold overcast days.

The external façade must not be visibly wet

For visualisation of air leakage, the internal pressure must be at least 10 Pa lower than external.

It can be seen that the conditions for a successful survey are fairly restrictive. As surveys are generally carried out by specialist contractors who may need to be booked some time in advance, it can be very difficult to arrange a survey for an appropriate weather window. There may therefore be a delay of several weeks before a survey can be carried out and if hand over of the building is dependent on completion of a survey, this can cause contractual difficulties. It is much better to remove the need for a survey by being able to demonstrate to a client that the cladding has been properly designed and installed.

5.3 Examples

BRE has carried out a series of tests on different metal cladding systems using the PASSYS test cells at East Kilbride. These are well insulated, air tight, welded steel boxes, with a 2.7 metre aperture in one side - see Figure 25. Each cladding system was sealed into a heated test cell and, after the temperatures had stabilised, an infra-red survey of the cladding details was carried out. These were used to evaluate the suitability of such surveys for assessing the performance of cladding systems. During the surveys, various sealing options were investigated and after testing the basic system, the cells were depressurised to investigate the effect of air infiltration (see Section 6). Measured areas of insulation were then removed to investigate how well the survey could reveal these 'defects'.

Fig 25: Cladding panels under test at BRE

Figures 26-29 show examples of the type of information that can be obtained from infra-red surveys

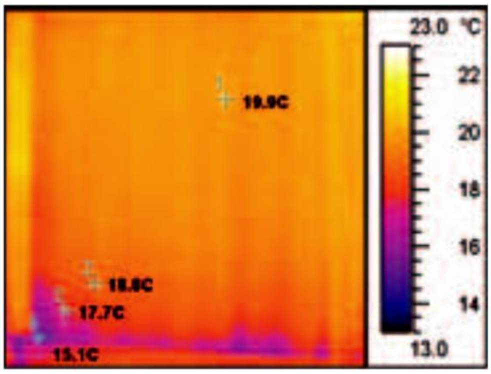

Fig 26: Twin skin construction with 'standard' joints and seals

Air leakage through the lower perimeter liner fillers, is cooling the bottom rail reducing the surface temperature from 19.9˚C to 15.1˚C.

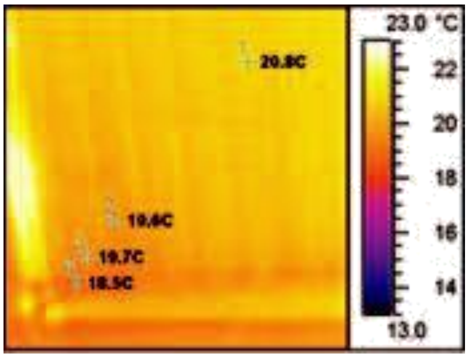

Fig 27: Twin skin construction with improved seals

Reducing the air flow has raised the surface temperature to 18.5˚C

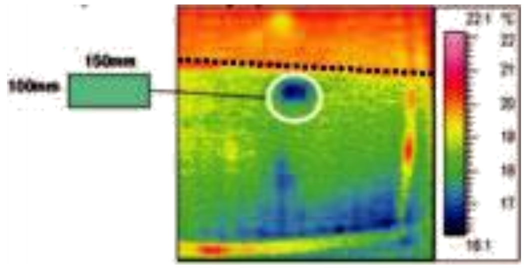

Fig 28: Twin skin construction

Removing a 100 x 150 mm section of insulation shows a well defined cold patch about 1.5 - 2˚C cooler than the surrounding area. There is a generally cooler region below the dashed line (representing the central horizontal rail) due to circulation of cooler air entering the test room through open door.

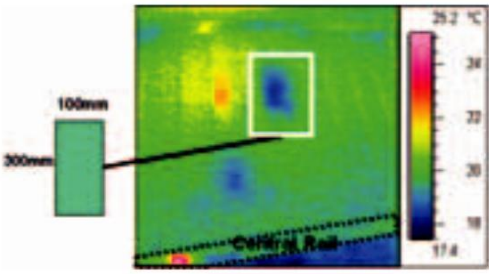

Fig 29: Twin skin construction

Removing a 100 x 300 mm piece of insulation leaves a well defined cold area The bright yellow area, adjacent to the darker region representing the missing insulation, and the red area on the central rail are due to the reflection of the inspection lamp.

5.4 Summary of the use of infra-red surveys

1. Infra-red surveys of the envelope of a building should preferably be done from the inside and ideally require calm, dry, cold and cloudy conditions; there may therefore be a considerable delay before conditions are suitable. The conditions for external surveys are even more restrictive.

2. For a survey to be successful, the building should be heated for at least 12 hours before the survey, there should be no sun and no rain on the external surface.

3. Given the right conditions, infra-red surveys can provide useful qualitative information about thermal bridges, air leakage and missing or wet insulation.

4. The presence of metal components, with emissivities much lower that those of other building materials, can lead to confusing results which need careful interpretation.

5. The interpretation of infra-red surveys is subjective,requiring experienced staff with a knowledge of metal cladding systems. This may lead to disputes concerning whether an apparent defect is significant or not.

6. Rather than relying on thermal imaging, with the complications and ambiguities summarised above, it is preferable to rely on demonstrating satisfactory design and installation.

6.1 Introduction

As buildings become more highly insulated, the effect of air leakage through the envelope on energy consumption becomes relatively more important. The new version of Approved Document L2 lays more stress on the need to achieve a reasonable standard of airtightness, and makes suggestions as to how this might be achieved by appropriate sealing measures. It also suggests that it may be necessary to demonstrate compliance with a report from a ‘competent person’ that appropriate design details and building techniques have been used or, for buildings larger than 1000m^2 floor area, to carry out an air leakage test.

This section describes the background to air leakage testing and the factors that affect the results in the case of metal walls and/or roofs. It is however, important to remember that the cladding system is only one of the areas of the building envelope that contribute to the leakage. Junctions and openings such as doors, loading bays, windows, rooflights, smoke vents and service penetrations may be more important. This section will enable the manufacturers of cladding and associated components to demonstrate that their systems or components are capable of being installed to a specified standard of airtightness

6.2 Whole building testing of air leakage

6.2.1 Test method

Techniques for the testing and analysis of the air leakage of buildings are described fully in CIBSE Guide TM23, which should be consulted for detailed information[15].

An air leakage test is carried out by mounting a fan (or fans) in a suitable aperture within the building envelope, usually a doorway (Figure 30); running the fan to blow air into the building creates a pressure difference across the building envelope. The fan speed is increased slowly to create a pressure difference of about 50 Pa (1Pa = 1N/m^2). At this setting the air volume flow through the fan, i.e. the air leakage through the building envelope and the pressure difference across the building envelope, is recorded. The fan’s speed is then reduced to give approximately equally spaced values (ideally between 5 and 10) of pressure difference, with none lower than 10 Pa, and the readings repeated at each point

The equipment can vary from a simple fan mounted in a replacement door and powered from the building's electrical supply (Figure 31) that delivers up to 1 m^3s^{-1} and is suitable for small 'domestic sized' buildings, up to large externally mounted fans that have their own power supply and can supply up to 30 m^3s^{-1} (Figure 32) ; these are used to test large non-domestic buildings. In some cases it may be possible to use the building's own HVAC system air supply fans. The pressure difference is measured with a micromanometer with an operating range of at least 0 – 60 Pa and accuracy of ±2 Pa. The external pressure should be measured at a point at least 10m away from the building to minimise local wind effects. The internal pressure must be measured at a point away from the direct influence of the pressurisation fan.

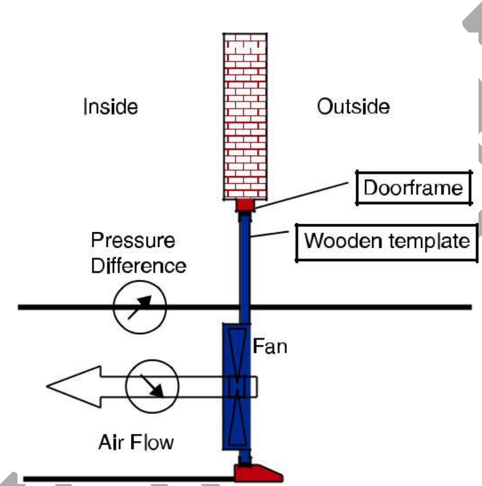

Fig 30: Diagrammatic representation of whole building leakage test

Fig 31: Typical 'Blower Door' for testing domestic buildings

Fig 32: Large fan for testing industrial buildings

A pressure test relies on the assumption that the pressure difference is uniform over the entire building envelope. This imposes certain restrictions on the external climate parameters that prevail during the test. Ideally the internal to external temperature difference should be less than 10˚C and the wind speed should be less than 3 ms^{-1}. Higher temperature differences lead to high stack pressure differences that distort the test results, especially in very tall buildings, and high wind speeds cause random pressure differences, which make accurate readings difficult. These conditions are however, much less restricting than those necessary for infra-red surveys described in section 5.2.

During a test, all internal doors should be wedged open and, where appropriate, combustion appliances must be switched off and any open flues and air supply openings temporarily sealed. Flues from room-sealed appliances, such as balanced flues in domestic appliances, do not need to be sealed. External doors and other purpose-made openings in the building envelope should be closed and mechanical ventilation systems turned off, with the inlet and outlet grilles sealed. Fire dampers and ventilation louvres should be closed. Drainage traps should contain water.

6.2.2 Data Analysis

The data obtained from a fan pressurisation test consist of volume flow rates, which need to be corrected for the difference between the density of warmer, indoor and colder, outdoor air, for a range of internal/external pressure difference values. A plot of the volume flow rate (Q) versus pressure difference (Dp) is drawn (Figure 33). The points lie on a curve, called the air leakage characteristic curve of the building.

Fig 33: Typical results from pressurisation and depressurisation tests

The relationship between the fan flow rate, and therefore the air leakage of the building, and the pressure difference is of the form:

$$Q = C(\ p)^n \qquad (15)$$

Where C and n are constants that relate to the building under test that can be found by transforming equation (15) using natural logarithms to give:

$$\ln(Q) = \ln(C) + n \cdot \ln(\ p) \qquad (16)$$

Plotting ln(Q) against ln(p) gives a straight line with slope n and intercept ln(C). C and n are then used to calculate the conventional value of the flow rate at a pressure difference of 50 Pa:$Q_{50} = C(50)^n$. This, Q_{50}, normally in m^3/h, is reported as the parameter which defines the 'leakiness' of the building.

Under very calm conditions, when all the measured points lie close to one curve, Q_{50} may be estimated directly from the measured data; in more windy conditions when there will be considerably more scatter about the curve it is essential to derive Q_{50} from the values of C and n calculated from the fitted curve. The standard pressure difference of 50 Pa is chosen, as it is much greater than the normal wind and stack pressure differences, which are 5 – 10 Pa at most. However, this means that the Q_{50} value does not reflect the air infiltration into a building in practice. Comparison of pressurisation test and tracer gas measurement in buildings has shown that the following general rule can be used for office buildings, the average ventilation rate in air changes per hour is equal to $Q_{50}/(S \times 60)$, where S is the surface area of the walls and roof. As no similar comparison has been made for industrial buildings, this relationship should be regarded as, at best, a very rough approximation.

If a building is tested and just complies with the standard of 10 $m^3/h/m^2$ at 50 Pa specified in section 2.4 of Approved Document L, the total flow rate at 50 Pa, Q_{50}, will be 10 x A m^3/h, where A is the area of walls, roof and floor. Substituting this for Q_{50} in the above expression means that the average ventilation rate under typical wind conditions can then be estimated as $A/(6 \times S)$ air changes per hour. This can then be used to assess the heat loss due to air leakage as shown in section 6.4.

6.2.3 Location of air leakage

The cladding or roofing system is only one of the possible leakage routes from a building and a simple fan pressurisation test quantifies the total air leakage of a building, but does not directly identify the leakage paths. There are however, a number of qualitative and quantitative methods that can be used in parallel to provide more information:

Releasing smoke from smoke pencils or puffers

within a building that is being pressurised can be used to visualise and identify specific flow paths.

An internal infra-red survey (see Figure 26) of a depressurised building in cold weather will rapidly reveal areas that are being chilled by incoming air.

Repeated testing of a building as successive specific components are sealed, a technique known as reductive sealing, can quantify the contribution of each. For example, Figure 34 shows the results from an initial test of a building as found, which gives a Q_{50} value of 13.8 m^3s^{-1}; sealing around all the window frames with tape and repeating the test reduces this to 10.5 m^3s^{-1}, then sealing around all the doors as well, reduces Q_{50} further to 7.6 m^3s^{-1}.

The air leakage associated with specific building element or component can be tested directly by pressurisation. The component can be isolated by containing the area of interest within a temporary sealed compartment; this has the advantage of requiring a smaller fan than is needed for reductive sealing of a whole building. This method is further refined by the laboratory test method described in BS EN 12114:2000 - see 6.4.

Fig 34: Results from an 'as found' test and two successive stages of reductive sealing

6.3 Air leakage parameters

Two parameters are currently used to quantify the air leakage rate through the building envelope. These are the *air leakage index* and the *air permeability*. Both are measured by the fan pressurisation technique and are expressed in terms of the volume flow of air per hour ($m^3 h^{-1}$) supplied to the space, per square metre (m^2) of building envelope for a specified inside to outside pressure difference of 50Pa; for example 10 $m^3h^{-1}m^{-2}$ at 50Pa.

The two parameters differ in the way the external building envelope is defined. The *air leakage index* does not include the solid ground floor area, while the *air permeability* does include the solid ground floor. It is not possible to standardise on one air leakage parameter at present, because a) European Standard BS EN 13829 : 2001[16] and Approved Document L use *air permeability* and b) the historical database of air leakage characteristics that may be used to put a building into context is based on *air leakage index*. The choice of which parameter to use is therefore dependant on the context of use however, for Regulation purposes the air permeability is the essential parameter, i.e. the floor area is taken into account.

6.4 Heat loss due to air leakage

The heat loss from a building due to air infiltration is given by:

$$Q_{leakage} = C_p \dot{V} \dot{n} / 3600 \text{ W/K} \qquad (18)$$

Where C_p is the heat capacity of the air
V is the building volume in m^3
n is the ventilation rate in air changes per hour (ach)

As shown in section 6.4.2, if a building is tested and just complies with the standard of 10 $m^3/h/m^2$ at 50 Pa specified in section 2.4 of Approved Document L, the average ventilation rate under typical wind conditions can then be approximately estimated as A/(6 x S) ach.

In the case of the notional building discussed in section 4.5 : S = 3644 m^2, A = 6044 m^2 and

V = 15444 m^3. The ventilation rate, n, will be 0.28 ach. Substituting these values into Equation (18)

= 1502 W/K

gives: $Q_{leakage}$

The total fabric loss estimate in section 4.5 was 2361 W/K, giving a total loss of 3863 W/K, 61% of which is through the fabric and 39% by air leakage.

6.5 Laboratory tests for individual components

Individual components, a window in its frame or a specific area of a liner sheet, with representative laps, for example, can be tested in the laboratory with the methods specified in BS EN 12114:2000[17]. This involves sealing the component into a rigid air tight frame and measuring the flow rate resulting from a series of positive or negative pressure differences applied across it (Figure 35).

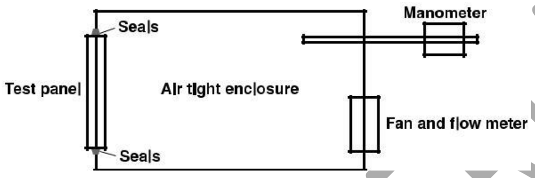

Fig 35: Diagram of laboratory air tightness apparatus

This test can provide values of a parameter that is useful for characterising metal cladding and roofing systems, the leakage per linear meter of joint or side lap, $R_{50,j}$. This is derived by identifying the flow through an individual joint ($Q_{50,j}$) by reductive sealing and then dividing by the length of joint under test (l_j).

$$R_{50,j} = Q_{50,j} / l_j \qquad (19)$$

Once this is known for each type of joint in a building, the building leakage rate Q_{50} can be estimated from :

$$Q_{50} = \sum_{Joints} R_{50,j} \cdot L_j \qquad (20)$$

Where L_j is the total length of each type of joint in the building. Section 6.6.2 gives an example of using the results from small scale tests to estimate the air leakage from a building and the effect of providing additional seals.

6.6 Examples of testing carried out at BRE

6.6.1 Test method

In parallel with the infra-red surveys, described in section 5, BRE has been carrying out a series of pressurisation tests on different metal cladding systems at East Kilbride. Each cladding system was sealed into the PASSYS test cell and depressurised as described above. A series of repeat tests was then carried out with various sealing options to identify the contributions of individual joints. Two site assembled profiled metal wall constructions and two metal faced composite panel wall constructions were tested.

6.6.2 Site assembled systems

The two systems tested were:

a) Twin skin wall of typical construction intended to achieve the 1995 Approved Document L U-value of 0.45 W/m^2K

This was made up of profiled liner and outer sheets, containing 83mm of glass wool insulation and a rail and bracket spacer system. The liner side laps and the liner vertical perimeter were not sealed. Liner fillers were included in the top and bottom horizontal perimeter and there were approximately four fasteners/metre, as is typically used at these points. There were no seals or fillers to the outer sheets.

b) Twin skin wall intended to achieve the originally proposed U value of 0.30 W/m^2K and achieve the air tightness requirements of Approved Document L2 :2001.

This was made up of profiled liner and outer sheets, containing 135mm of glass wool insulation and rail and bracket spacer system. The liner side laps and the liner vertical perimeter were sealed with butyl tape. Liner fillers were included in the horizontal perimeter, as before, but with approximately ten fasteners/metre to improve the compression of the fillers. There were no seals or fillers to the outer sheets.

The effect of sealing the three possible leakage paths shown on Figure 36 on the leakage was investigated.

Table 9: Results from pressurisation tests of site assembled system

Description (see figure below)	Air leakage at 50Pa [m^3/h per linear meter]	
	Current standard	Improved
(1)Liner sheet overlaps	junctions 2.3	less than 0.1
(2)Upper & lower horizontal perimeter junctions	8.6	1.1
(3)Vertical perimeter	10.4	less than 0.1

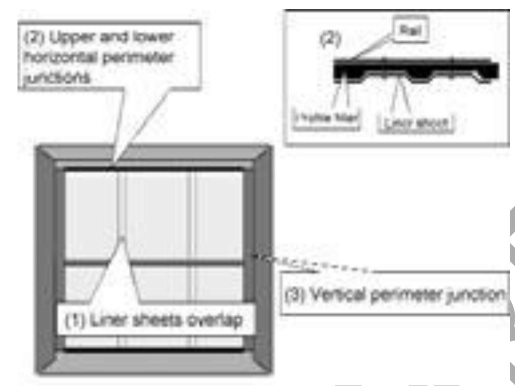

Fig 36: Areas of built up panel tested for air leakage

The results from this type of test can then be used to assess the effect on leakage from a whole building - see section 6.7.

6.6.3 Composite panel

Two flat composite panels wall constructions were tested:

a) Standard panels designed to achieve the 1995 Approved Document L U-value of 0.45 W/m^2K

This was made up of standard factory made panels with profiled liner and outer sheets, containing 50mm of rigid urethane insulation. The panel to panel side joints had standard factory installed compressible seals, the vertical perimeter and upper horizontal junction contained butyl seals. The lower horizontal perimeter was sealed with a butyl tape trapped between the panels and lower horizontal rail, but light could be seen from the outside indicating that the seal was not completely effective.

b) Sealed panel to achieve the proposed U-value of 0.30 W/m^2K

This was made up of standard factory made panels with profiled liner and outer sheets, containing 80mm of rigid urethane insulation. The panel junctions, vertical perimeter and upper and lower horizontal junctions all incorporated additional sealing.

The effect on infiltration of sealing the four possible leakage paths, shown in Figure 37, was investigated.

In this case the dominant leakage path was the horizontal gap at the base of the panel. Sealing this eliminated 90% of the infiltration.

Table10: Results of pressurisation testing of composite panels.

Description (see figure below)	Air leakage at 50Pa [m^3/h per linear meter]	
	Current standard	Improved
(1)Panel seam	0.5	0.1
(2)Lower horizontal perimeter junction	11.7	0.7
(3)Upper horizontal perimeter junction	1.6	0.6
(4)Vertical perimeter junction	0.3	0.1

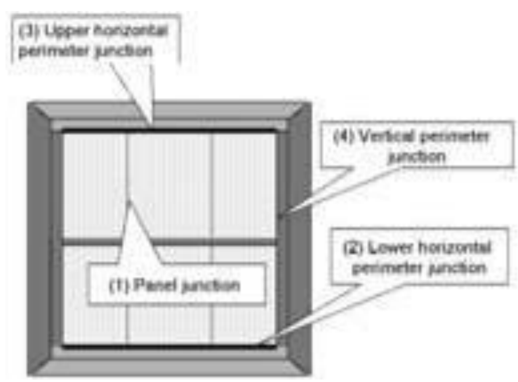

Fig 37: Areas of composite panel tested for air leakage

Table11:Contribution of individual joints to leakage from the cladding

			1995 standard		Improved	
		Length m	Leakage $m^3/h/m$ @ 50 Pa	Total leakage m^3/h at 50Pa	Leakage $m^3/h/m$ @ 50 Pa	Total leakage m^3/hr @ 50Pa
	Walls					
1	Base perimeter	200	11.7	2340	0.7	140
2	Side joint	1000	0.5	500	0.1	100
3	Top perimeter	200	0.3	60	0.1	20
4	End joint	432	1.6	691	0.6	259
5	Corners	48	11.7	562	0.7	34
						132
	Roof					
6	Eaves	120	8.6	1032	1.1	
7	Verge	80.3	10.4	835	0.2	16
8	Ridge	240	8.6	2064	1.1	264
9	Valley gutter	120	8.6	1032	1.1	132
10	End laps	480	2.5	1200	0.1	48
11	Side laps	2360	2.5	5900	0.1	236
	Total			16216		1381

6.7 Example of the effect of individual joint leakage on whole cladding leakage

To illustrate the method of combining individual joint leakages to give the overall leakage from the cladding system, Figure 38 shows the building that was used to illustrate heat loss through thermal bridges in section 4.5. It is assumed that the walls are covered with horizontal composite panels each one metre wide by five metres long and the roof is covered in a site assembled system with liner sheets of the same size.

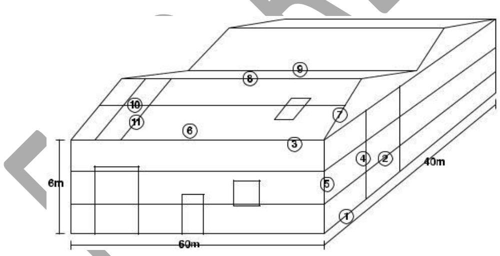

Fig 38: Typical industrial building showing leakage paths at joints

Table 11 shows the length of each joint in the external envelope and the leakage characteristics for a standard construction and one upgraded with additional seals. It should be noted that, at many of the details, for example the ridge and valley gutter, two sheets/panels meet; the length of joint will therefore be twice the length of the detail. The leakage values for each joint are based, as far as possible, on the values measured in the BRE tests discussed in section 6.6; it should be recognised however, that appreciably higher values may be found in practice.

Setting the leakage rates out like this readily identifies the contribution of individual leakage paths facilitating the development of an appropriate reduction strategy, if necessary.

The exposed area of the building envelope, which includes the ground floor, is 6044 m^2. This means that the air permeability for the cladding part of the notional building is 2.68 $m^3/h/m^2$ at 50 Pa. This reduces to 0.23 $m^3/h/m^2$ at 50 Pa for the improved building. Both of these are well within the limit of 10 $m^3/h/m^2$ at 50 Pa, imposed by Approved Document L2. This suggests that metal cladding **when properly installed to current standards**, may be able to meet the requirements of Part L of the Regulations. It is however, important to emphasise two considerations here:

1) This calculation has assessed only the loss from the cladding, not the loss from the other parts of the building, such as blockwork walls at ground level and all the various penetrations of the walls

and roof. These have to achieve the same standard if the building is to meet the Part L criterion on testing.

2) As has been emphasised, the leakage values above have assumed that the cladding has been properly installed to current standards. Measurements quoted in CIBSE Guide TM23, have shown that many industrial buildings in the UK are very leaky and would fail if tested to the Part L standard. However well designed a system is; it will fail and require expensive retesting, possibly delaying the completion of a contract by many weeks, if it has not been well installed. It is therefore essential that installation is carried out by experienced contractors, is well supervised and follows the cladding manufacturer's guidance.

6.8 Summary of methods for air leakage testing of metal roofing and cladding

1. Pressurisation testing of whole buildings gives a good estimate of their energy loss from air leakage in practice.

2. The contribution of individual areas of the building envelope to the overall leakage can be identified and quantified by the use of smoke tubes, infra-red surveys and reductive sealing.

3. The leakage through individual cladding systems and other components and the effect of sealing joints etc. can be measured in laboratory tests. The results from these tests can be scaled up to quantify the leakage contribution of **well installed** cladding to the leakage of a full scale building.

and installed to a good

4. Details currently in use **standard** may meet the air leakage requirements of Part L; however it is recommended that side and end laps/joints and all perimeter joints should be effectively sealed, not only to reduce the air leakage but also to provide vapour control.

5. However well designed a system is: it will fail and require expensive retesting, possibly delaying the completion of a contract by many weeks, if it has not been well installed. It is therefore essential that installation is carried out by experienced contractors, is well supervised and follows the cladding manufacturer's guidance.

Appendix : Details

The following pages present some common details that occur in industrial and commercial buildings with metal cladding which are likely to lead to thermal bridges that affect the internal surface temperature and heat loss from the building. Their locations are shown on Figure 24. For each detail, the following information is presented:

1) A brief description of the detail and the possible causes of thermal bridging;

2) A diagram of a typical detail, with the important features that are likely to lead to thermal bridges highlighted.

3) The f_{min} and -values of the standard detail that determine its performance, calculated with U_{wall} = 0.35 W/m^{2}K and U_{roof} = 0.25 W/m^{2}K.

4) In those cases where the usual detail is likely to lead to problems of low surface temperatures (low f_{min}-value) or high heat flow (high -value), a range of modifications that might be made to improve performance are discussed and the resulting f_{min} and -values presented.

The diagrams are only intended to be indicative and concentrate on thermal bridging issues. The f_{min} and -values quoted are typical of each detail; slightly different values may be calculated for a specific system. Cladding manufacturers' details for their specific systems should be used for design, provided that a cladding design on a particular building adopts the same principles regarding thermal bridging, which are outlined in the diagrams and text. This Appendix should be read in conjunction with Section 4, which explains the significance of the f-value and the -value, and how to decide on appropriately detailed designs for a particular building.

; or

The f-values and -values shown in the sections below can be used directly by manufacturers and designers to demonstrate compliance with the requirements of Part L as shown in sections 4.2 and 4.3 of this Technical Paper and in BRE Information Paper IP 17/01. The features that cause thermal bridging at junctions, openings and other penetrations of the insulation are generally similar in both twin skin and composite panel systems. The diagrams in the sections below therefore represent both systems. So, for example, a twin skin corner is shown in Figure A.1 and a composite panel corner is shown in Figure A.2. In the figures, the features particularly relevant to thermal bridging are marked with ***bold italics.***

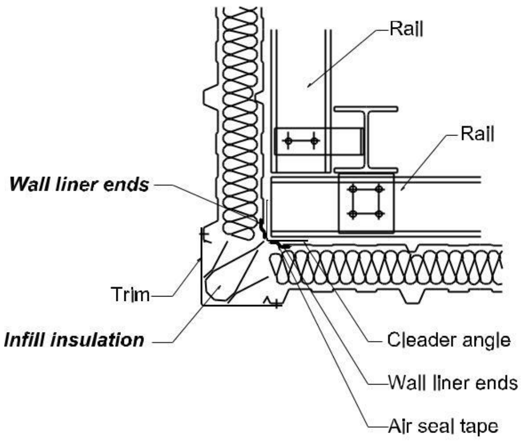

Fig A.1: Corner detail in built-up system

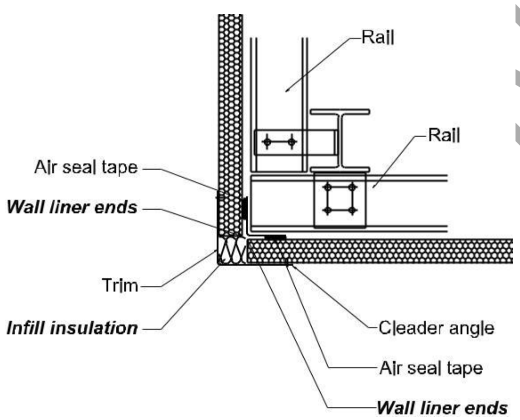

Fig A.2: Corner detail in composite panel

Detail 1 : Roof Ridge

Provided that the insulation is continuous over the ridge (as shown in Figures A.3 and A.4) and the detail contains no metal crossing the insulation, other than any spacers normally present in the roof panels (which are taken into account in the calculation of the plane area U-value) this detail causes a negligible thermal bridge.

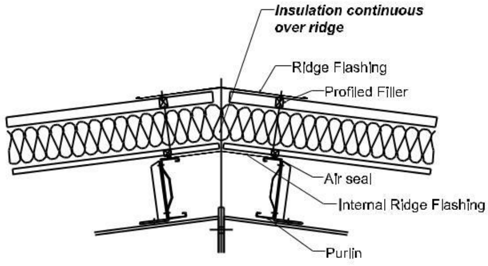

Fig A.3: Built-up roof ridge

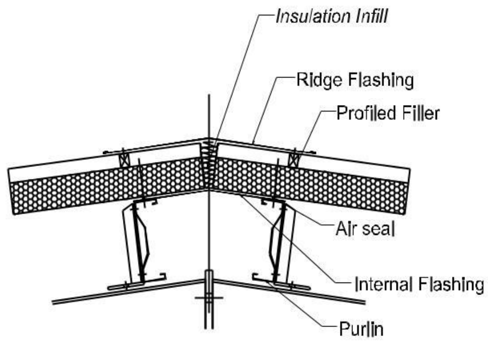

Fig A.4: Composite panel roof ridge

Summary of roof ridge

Insulation continuous over the ridge f_{min} = 0.91

= 0.01 W/mK

Detail 2 : Roof Eaves

Possible thermal bridging can result if the liner of the roof extends across the wall insulation to touch the outer trim. A gap between the wall and roof panels can introduce cold air directly to the liner.

Leaving a gap of only 5mm between the roof liner and the outside trim can give significantly better performance however, stopping the roof liner short at the wall liner as shown in Figures A.5 and A.6, gives the best performance. Filling any gap between the wall and roof panels with an appropriate site applied insulation is also important for optimum performance.

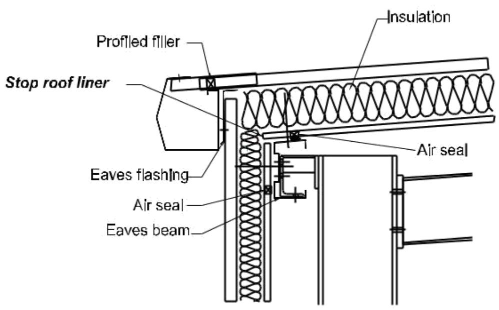

Fig A.5: Built up roof eaves

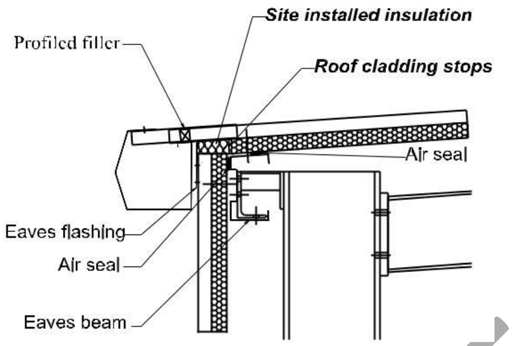

Fig A.6: Composite panel roof eaves

Summary : roof eaves

Roof liner extends to touch the outer sheet or trim of wall, air gap between wall and roof — f_{min} = 0.76, = 0.25 W/mK

5mm gap between roof liner and wall outer, air gap filed with insulation — f_{min} = 0.90, = 0.07 W/mK

Roof cladding liner taken back to wall liner, air gap filled with insulation as Fig A.5 or A.6 — f_{min} = 0.95, = 0.01 W/mK

Detail 3 : Roof Verge

There are two possible thermal bridges in this situation:

a) If the liner of the roof crosses the wall insulation to touch the outer sheet of the wall (or vice versa); the roof liner should be stopped level with the wall liner - see Figure A.7.

b) If a void is left between the roof and wall insulation; this should be filled with site installed insulation. - See Figure A.8.

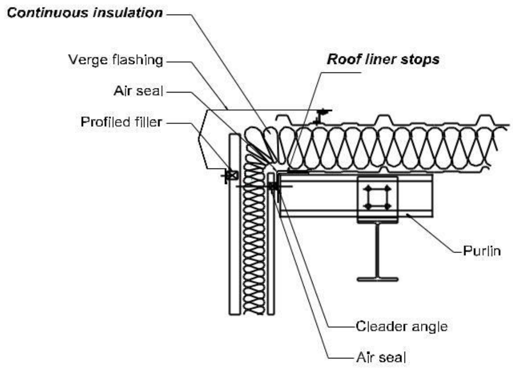

Fig A.7: Built up roof verge

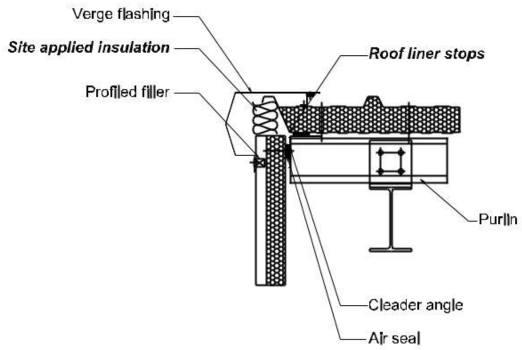

Fig A.8: Composite panel roof verge

Summary : roof verges

Roof cladding and liner cut across wall insulation (or vice versa) — f_{min} = 0.79, = 0.28 W/mK

Roof cladding stops short of wall liner, void unfilled — f_{min} = 0.85, = 0.20 W/mK

Roof cladding stops short of wall liner, void filled with site installed insulation as Figs A.7 and A.8. — f_{min} = 0.95, = 0.02 W/mK

Detail 4 : Valley Gutter

This detail can cause a very severe thermal bridge if the metal outer layer of the gutter top and roof liner cut across the gutter insulation.

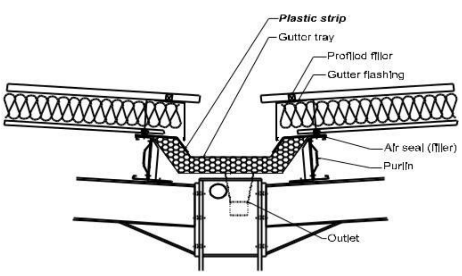

Fig A.9: Valley gutter in built up roof

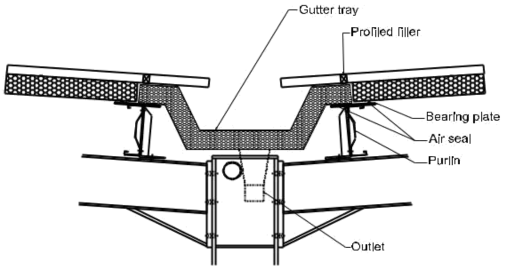

Fig A.10: Valley gutter in composite panel roof

Making the gutter liner more robust and replacing the gutter outer with a lower conductivity material such as plastic where it cuts across the insulation will reduce the thermal bridge, if the roof liner is stopped short as well so that the insulation layer is continuous, the thermal bridge will be largely eliminated (Figure A.9). if the gutter could be made as in Figure A.10, thermal bridging would be negligible.

Summary : valley gutters

Metal gutter outer and roof liner crossing insulation (typical current construction)	f_{min}= 0.81 = 1.50 W/mK
Crossing gutter insulation with plastic with k=0.2 W/mK instead of metal, liner stopped short as Fig A.9	f_{min} = 0.95 = 0.17 W/mK
Gutter as Fig A.10	f_{min} = 0.95 = 0.15 W/mK

Detail 5 : Drip sill at the base of a wall panel supported on a masonry wall or ground floor slab

This thermal bridge is particularly important as it often extends the full length of the building perimeter. The intensity of the thermal bridge depends on the interaction between the detailing of the cladding panel and the masonry wall and floor slab to which it is fixed.

If the cladding is connected to the wall or slab as shown in Figure A.11 or A.12, a very severe thermal bridge is caused by conduction a) through the blockwork and brickwork, and b) through the steel flashing, which is connected directly to the liner of the wall cladding. Use of lightweight blockwork, or screed on a floor slab will reduce the severity slightly; replacing the steel drip with plastic will bring some further improvement.

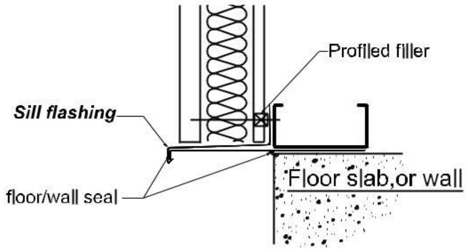

Fig A.11: Drip sill in built up wall

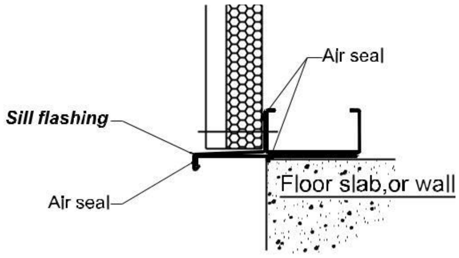

Fig A.12: Drip sill in composite panel wall

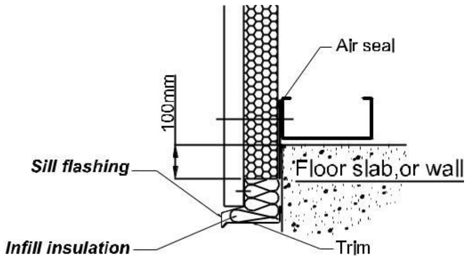

Fig A.13: Modified drip sill in built up wall

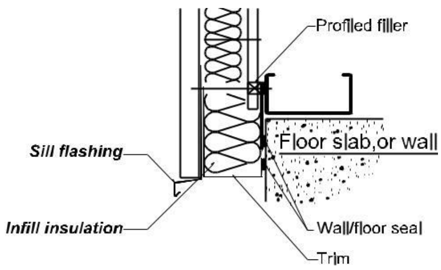

Fig A.14: Modified drip sill in composite panel wall

More significant improvement can be achieved by moving the drip so that it is fixed to the outer sheet of the cladding and installing a trim, fixed to the outer sheet and wall/floor. This trim supports site fixed insulation infill that covers the top of the wall or edge of the floor slab and extends 100mm down the wall or slab; see Figure A.13 or A.14. Again, it is preferable to use a lightweight block or screed.

Summary: Drip sills

1. As Fig A.11 or A.12

Medium weight blockwork (k=0.6) and steel flashing — f_{min} = 0.48, = 1.10 W/mK

Light weight blockwork (k=0.11) and steel flashing — f_{min} = 0.54, = 0.91 W/mK

Medium weight blockwork (k=0.6) and plastic flashing — f_{min} = 0.60, =0.81 W/mK

2. As Fig A.13 or A.14

Medium weight blockwork (k=0.6) and insulation extended 100mm down the wall — f_{min} = 0.84, = 0.22 W/mK

Light weight blockwork (k=0.11) and insulation extended 100mm down the wall — f_{min} = 0.91, = 0.10 W/mK

Detail 6 : Corner

Possible thermal bridging can result if the liner of one side extends across the insulation on the other side to touch the outside corner trim. Leaving a gap of only 5mm between the liner and the outside trim can give significantly better performance however, stopping the liner short at the wall liner gives the best performance, see Figure A.15. There is also a possible gap between the wall panels that could allow outside air to penetrate to the liner. If the panels stop short at the corner and the resulting void is infilled with insulation (Figure A.16), the thermal bridge is effectively eliminated.

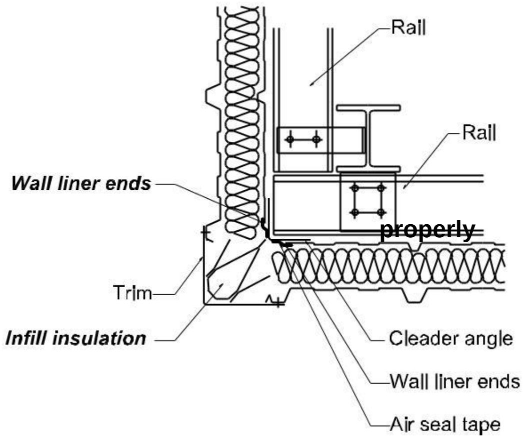

Fig A.15: Corner in built up wall

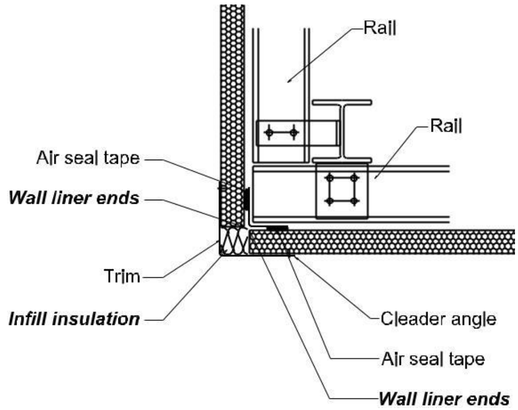

Fig A.16: Corner in composite panel wall

Summary of corners

Liner extends to touch the external corner trim — f_{min} = 0.76, = 0.25 W/mK

Air gap between the insulation at the corner — f_{min} = 0.81, = 0.20 W/mK

5mm gap between liner and external corner trim — f_{min} = 0.90, = 0.07 W/mK

Liner taken back to liner of other cladding and gap infilled with insulation as Fig A.15 and A.16 — f_{min} = 0.95, = 0.01 W/mK

Details 7, 8 and 9 : Door or window lintel, jamb or sill

As these three details are essentially the same from the point of view of thermal bridging, they have been treated together.

If, as is shown in Figure A.17 or A.18, the window or door frame is fixed to the structural frame within the cladding, leaving a gap of 50mm between the frame, the steel of the structural frame and the drip sill will form a marked thermal bridge.

Moving the window frame forward so that the outer edge is in line with the liner of the wall, brings some improvement and moving further forward so that it half overlaps the wall insulation is even better, but this may cause structural difficulties.

If a 25mm layer of thermal insulation is placed between the structural framework and the window/door frame, either as insulation board or infill insulation as shown in Figures A.19 to A.23, the thermal bridge is greatly reduced. However, if as shown in Figure A.20, the sill flashing crosses the insulation because there is no adequate attachment point on the outside, the benefit is reduced.

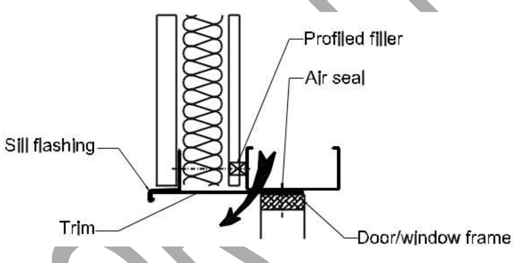

Fig A.17: Lintel in built up wall

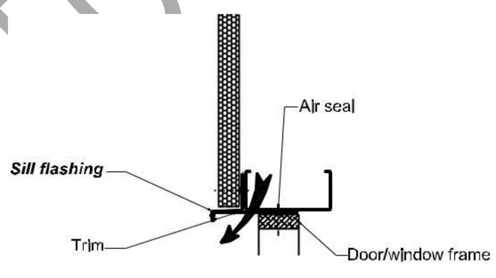

Fig A.18: Lintel in composite panel wall

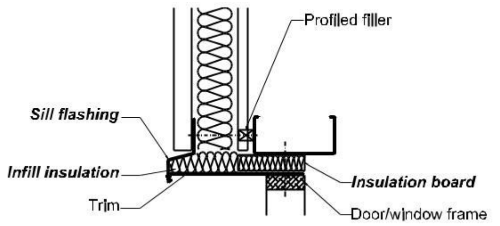

Fig A.19: Modified lintel in built up wall

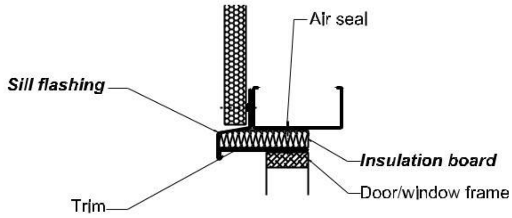

Fig A.20: Modified lintel in composite panel wall

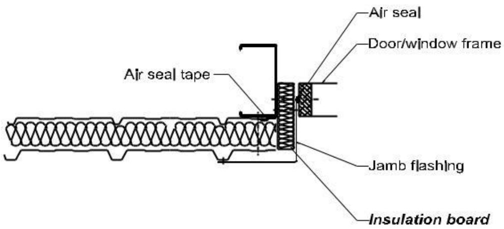

Fig A.21: Modified jamb in built up wall

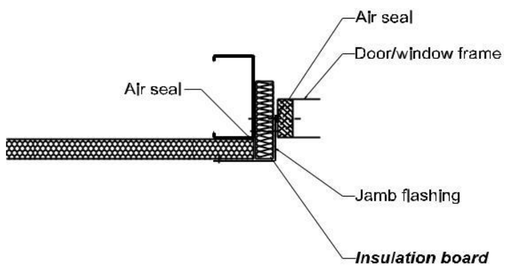

Fig A.22: Modified jamb in composite panel wall

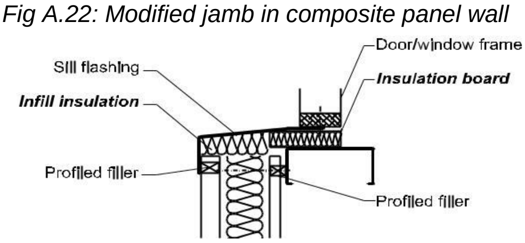

Fig A.23: Modified window sill in built up wall

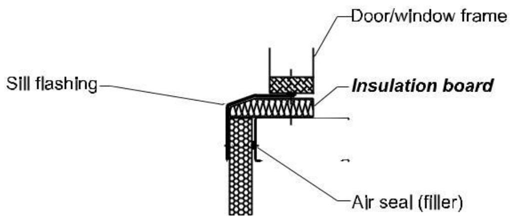

Fig A.24: Modified window sill in composite panel wall

Summary of window and door lintels, jambs and sills

Gap between window or door frame and cladding as Figs A.17 and A.18	f_{min} = 0.46 = 1.27 W/mK
Frame moved forward in line with wall liner	f_{min} = 0.67 = 0.69 W/mK
Insulation included between window or door frame and structural steel and cladding, as Fig A.19 to A.24, but not A.20	f_{min} = 0.91 = 0.23 W/mK
Lintel with insulation included between window or door frame and structural steel and cladding, but sill flashing crossing the insulation, as Fig A.20	f_{min} = 0.80 = 0.43 W/mK

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 building 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 harness attachment post, which is a hollow steel post, with 2mm thick walls, which is attached to the structural steel inside the building and passes through the roof;

b) a girder, 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 value of f_{min} 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.

Fig A.25: Harness attachment post

Fig A.26: Internal surface temperature

f_{min} = 0.77 , Heat loss = 0.17 W/K

Fig A.27: Canopy girder

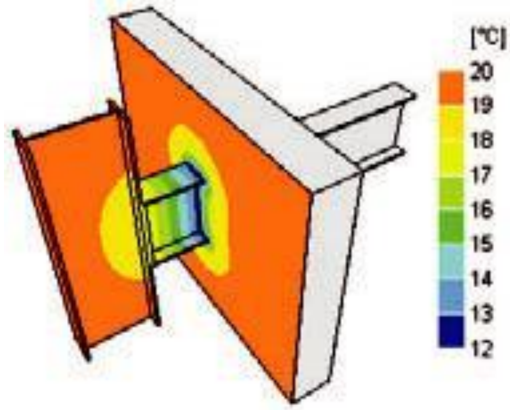

Fig A.28: Internal surface temperature

f_{min} = 0.62 , Heat loss = 0.69 W/K

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

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