THERMAL BRIDGING IN STEEL CONSTRUCTION

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FOREWORD

Buildings account for nearly half of the UK's total carbon emissions and are therefore targeted for significant improvement by regulations. In response to the Energy Performance of Buildings Directive and the UK Climate Change Act 2008, national regulations are requiring ever more energy efficient buildings.

In the UK climate, heat losses through the building envelope account for more than 75% of the total heat loss including air leakage. The thermal insulation provided by the building envelope is key to energy efficiency, but thermal bridges, which are weak spots in the insulation, lead to local heat losses that reduce the thermal efficiency.

The information presented in this publication illustrates various cases of thermal bridging and how local heat losses can be reduced. It describes the results of thermal modelling analyses of typical interface details used in steel construction. This publication focusses on thermal bridging issues associated with structural steel frames including beams penetrating the building envelope, balcony attachments to floor slabs and brickwork supports fixed to steel edge beams.

The information may be used as general guidance on how to minimise thermal bridging in steel framed construction.

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SCI publication P411 is a related publication focusing on thermal bridging in light steel framing and modular construction.

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CONTENTS

SUMMARY

Thermal bridges within the thermally insulated layer of a building or at junctions in building envelopes occur in all forms of construction and should be minimised as they add to the overall heat loss. This publication provides information and guidance on how thermal bridging can be minimised in various forms of construction; including multi-storey steel-framed construction.

This publication provides an introduction to thermal bridging, an explanation of the consequences of thermal bridging and describes how these effects are considered and quantified in the UK Building Regulations. It presents examples of ways in which thermal bridges in steel construction are minimised which are based on the results of thermal modelling of typical interface details.

The focus of this publication is the thermal bridging associated with hot-rolled structural steel frames that use light steel infill walls and various types of cladding. Common thermal bridges include:

- Penetrations through the building envelope, such as by canopies and balconies.
- Brickwork supports attached to steel edge beams.
- Lightweight cladding support systems attached to steel frame infill walls.
- Columns located partially within external walls.

Results of thermal analyses for various details are presented in terms of the linear thermal bridging parameter (psi-value). A sample calculation is shown to demonstrate how the psi-values may be summed over the building envelope to determine an effective additional heat loss parameter (y-value) for use in building energy models.

The final section provides guidance on the structural design of connections incorporating thermal break products.

Guidance on thermal bridges in light steel framing and modular construction is given in SCI publication P411.

INTRODUCTION

1.1 Thermal performance

The thermal efficiency of a building envelope is a function of the thermal performance of the planar elements, walls, roof and ground floor. In addition, local heat losses occur at the interfaces between these elements and where they are penetrated by other building components, such as balconies or canopy supports.

These areas of high local heat flow, commonly known as 'thermal bridges', can have a significant effect on the thermal performance of the building envelope and consequently, on the energy consumption of the building. The relative importance of thermal bridging has increased over recent years as the levels of thermal insulation and air-tightness of the building envelope have improved.

The relative importance of each mode of heat loss for new buildings in the UK depends upon the type of building under consideration and the level of performance being targeted. For detached housing, it is common for thermal bridges to account for 30 to 50% of all conductive losses through the building envelope, as calculated by thermal modelling. Non-conductive heat losses, i.e. air leakage and ventilation, typically account for 20% of all heat losses. For multi-occupancy residential building (apartments) thermal bridging is estimated to be 20 to 30% of the conductive heat losses. Particular features of multi-storey residential buildings, such as balcony connections, can be a major contributor to the total heat loss if effective thermal isolation is not included in the design of the connection system.

In England, the Government's Approved Document L (Conservation of fuel and power) [1] provides guidance on ways of complying with the energy efficiency requirements of the Building Regulations. Recent revisions to the Building Regulations for England and Wales (see Section 1.5) have emphasised the importance of the thermal efficiency of building envelopes, including limiting heat losses through thermal bridging.

As part of a thermal assessment of the building envelope, it is recognised that local heat losses due to penetrations or similar local effects have to be calculated and where necessary minimised, so that the thermal efficiency of the building envelope is within acceptable limits.

1.2 Thermal bridging

Thermal bridges occur where the insulation layer within the building envelope is penetrated by a material with a relatively high thermal conductivity, and at interfaces between building elements where there is a discontinuity in the insulation. Thermal bridges result in:

- Local heat losses, which mean that more energy is required to maintain the internal temperature of the building.
- Lower internal surface temperatures around the thermal bridge which can cause condensation that may lead to mould growth.

Local heat losses caused by thermal bridges have become relatively more important over recent years, as the thermal performance of the planar elements of building envelopes have been improved. The thermal performance of a planar element is expressed as a U-value with units of W/m^2K. Therefore, a lower U-value means a higher level of thermal insulation.

Thermal bridges are generally referred to as either 'repeating' or 'non-repeating'. Generally, the effect of repeating or regular thermal bridges, such as wall ties, and C sections in light steel walls are accounted for in the U value calculation of the planar elements. Therefore, heat losses through these repeating thermal bridges do not need to be considered as thermal bridges if they are properly accounted for in the heat loss through the planar element.

Non-repeating thermal bridges in building envelopes are generally geometry-induced or material-induced and may be caused by:

- Geometry, e.g. at corners which provide additional heat flow paths.
- Building envelope interfaces, e.g. window sills, jambs and headers.
- Structural interfaces, e.g. floor to wall junctions, wall to roof (eaves) junction.
- Penetration of the building envelope, e.g. balcony supports, fixings and structural elements.
- Structural considerations, e.g. lintels and cladding supports, especially brickwork support systems.
- Poor construction practice, e.g. gaps in insulation, debris in wall cavity.

Thermal bridges can be identified using thermal imaging cameras. The thermal bridges appear as areas of higher temperature when viewed from the exterior of a building. This is shown in Figure 1.1 where higher temperatures, i.e. thermal bridges, can be seen around the door, window and balcony slab.

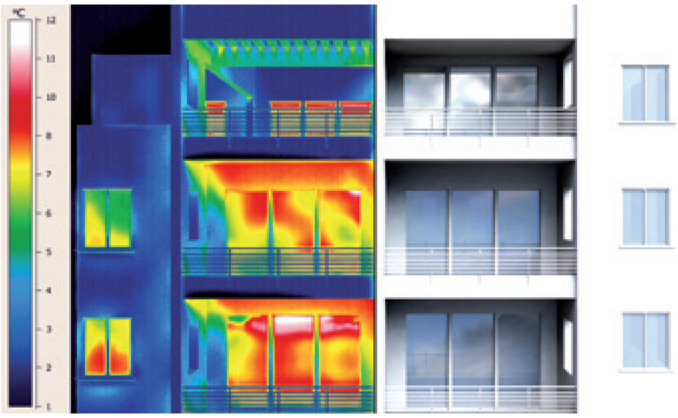


Figure 1.1 Thermal image of a residential building with higher temperatures at the windows, doors and balcony slabs

1.3 Thermal bridging in steel construction systems

The focus of this publication is the thermal bridging associated with structural steel frames. Guidance on thermal bridging in light steel framing and modular construction is provided in SCI publication P411 [2].

Steel has a high thermal conductivity (λ) compared with many other construction materials (see Table 1.1). The high thermal conductivity means that both the structural steel frame and steel cladding system, must be carefully designed to minimise unwanted heat flows. For example, built-up cladding and composite (sandwich) cladding panels with steel skins are designed to keep thermal bridging to a minimum by ensuring that the steel elements are not continuous through the cladding system. For example, in the built-up cladding system shown in Figure 1.2, a thermal break pad is provided beneath the steel brackets supporting the cladding rails.

Table 1.1 Thermal conductivity of common construction materials

Material	Thermal conductivity, λ (W/mK)
Steel	45 to 50
Stainless steel (20% Ni)	15 to 17
In-situ normal weight concrete	1.7 to 2.2
Brickwork	0.6 to 0.8
Gypsum based board	0.16 to 0.22
Plywood	0.12 to 0.15
Mineral wool insulation	0.03 to 0.04
Closed cell insulation	0.02 to 0.03

Source: CIBSE Guide A: Environmental Design, CIBSE [Ref. 3]

The thermal resistance of a planar element may be expressed as an R-value which is equal to the material thickness divided by the thermal conductivity. The R-value has units of m^2K/W. Regulations generally use the U-value as the measure of thermal insulation

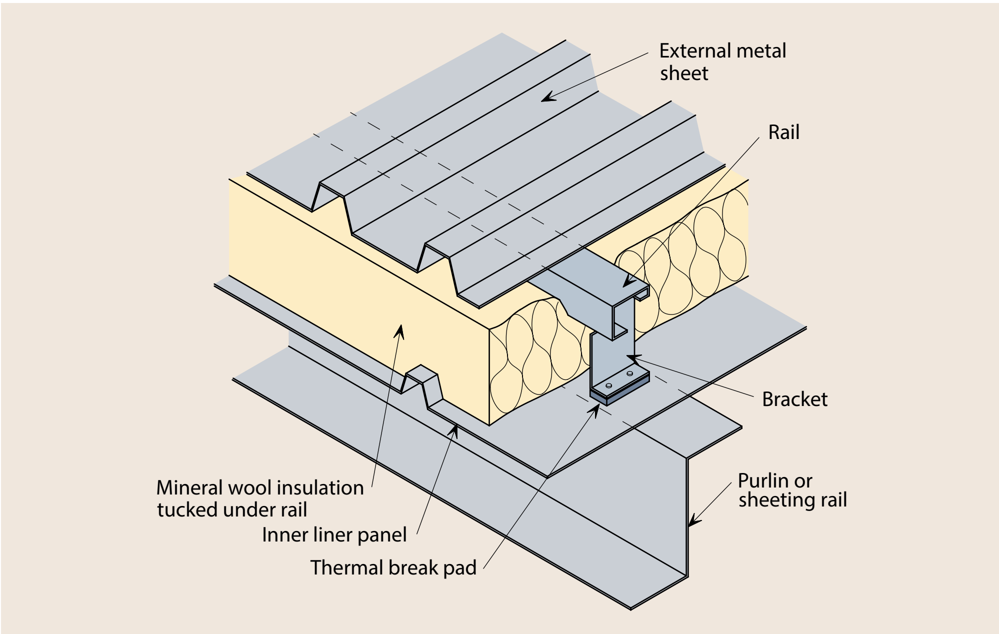


Figure 1.2 Example of a cladding detail to avoid thermal bridges

of planar elements because it includes the three major ways in which heat loss occurs; conduction, convection and radiation. R-values only take into account conduction.

For some buildings, steel elements may be required to penetrate the insulated envelope, for example canopies or roof members, or may be fixed to other steel components, such as balcony brackets and brick support units. These areas require careful consideration to minimise thermal bridging.

There are three ways to reduce thermal bridging in steel construction:

a. Ensure the steelwork is fully within the insulated envelope (‘warm frame’ construction).
b. Locally insulate any steelwork that penetrates the envelope.
c. Reduce the thermal transmittance of the thermal bridge by using thermal breaks, changing the detailing or by using alternative materials.

These methods are considered in greater detail in Section 2.

1.4 Calculation of heat loss by conduction

The heat loss through a linear thermal bridge, that is linear along the building envelope, such as a column within a wall, is defined by its linear thermal transmittance (termed Ψ-value or psi-value). Linear thermal transmittance is the rate of heat flow per degree temperature difference per unit length of the thermal bridge. The units for Ψ-values are Watts per metre per degree Kelvin (W/mK).

Repeating thermal bridges, such as C sections located within the insulated layer of light steel walls, or brick ties, should be included in the U-value of the planar element. Non-repeating thermal bridges, such as floor junctions, window sills and ridges, form additional heat transfer paths that are not accounted for in the elemental U value. These are accounted for in energy performance assessments by the linear thermal transmittance (Ψ-value) for each thermal bridge.

The heat transfer associated with intermittent or singular elements, e.g. beams or other projecting structural elements, can be quantified by determining the Point Heat Transmission coefficient (W/K). The symbol Chi (χ) is conventionally used to represent a point transmittance.

The total fabric conduction heat loss (per degree Kelvin) is therefore given by:

$$\Sigma\,(U.A) + \Sigma\,(\Psi.L) + \Sigma\,(\chi)$$

where:

U	is the U-value of the planar element (W/m^{2}K)
A	is the area of the planar element (m^2)
Ψ	is the linear thermal transmittance (W/mK)
L	is the length of the thermal bridge (m)
χ	is the point thermal transmittance (W/K)

The Ψ-values and χ-values for linear and point thermal bridges respectively, can be obtained from two- and three-dimensional thermal conduction modelling or they may be available from product manufacturers and system suppliers. For building products and systems, such as composite panels and built up steel cladding, manufacturers can usually provide these Ψ-values. Generic details and Ψ-values for metal clad buildings are available from MCRMA [4] and EPIC [5].

Example calculation

This hypothetical example considers a wall element that is 7.2 m high and 5.0 m wide and has a basic U-value of 0.20 W/m^{2}K. The wall has two horizontal linear thermal bridges at 3.6 m vertical spacing. The Ψ-value of each thermal bridge is 0.30 W/mK. There are no point thermal bridges considered in this example.

The total fabric conduction heat loss of the wall element is given by:

$$\Sigma(U.A) + \Sigma(\Psi.L) = (0.20 \times 5 \times 7.2) + (0.30 \times 2 \times 5)$$

$$= 7.20 + 3.00 = 10.20 \text{ W/K}$$

This calculation shows that the thermal bridges in this hypothetical example result in a 42% additional heat loss compared to the wall without thermal bridges.

1.5 UK Building Regulations

To satisfy Building Control requirements in the UK, it is necessary to demonstrate compliance with the Building Regulations. Building regulations that apply across England and Wales are set out in the Building Act 1984 while those that apply across Scotland are set out in the Building (Scotland) Act 2003. Part L of the Building Regulations (Conservation of fuel and power) [6] addresses energy efficiency requirements in buildings in England and Wales.

In England, the UK Government issues Approved Document L (Conservation of fuel and power) which provides practical guidance on ways of complying with the energy efficiency requirements of the Building Regulations. In Wales, it is the responsibility of the Welsh Government who issue similar, but not identical, Approved Documents. The latest versions of Approved Document L, for England, were published in 2013. Approved Document L1A [1] provides guidance for new dwellings and Approved Document L2A [7] provides guidance on buildings other than dwellings.

Section 6 of the Scottish Building Regulations [8] is the Technical Handbook that deals with Energy within the built environment.

SAP 2012 [9] and SBEM [10] are the two *National Calculation Methodologies* for calculating the energy performance of a building. Government approved implementation software is available that calculates the predicted and target carbon dioxide (CO_2) emissions rates. SAP 2012 is the Standard Assessment Procedure for dwellings and SBEM is the Simplified Building Energy Model for buildings other than dwellings. Both SAP 2012 and SBEM require the designer to have knowledge of the thermal bridges because heat losses through thermal bridges must be included in the calculations of predicted rates of CO_2 emissions.

One of the principal criteria given in Approved Documents L1A and L2A is the predicted emission rate of CO_2 from the building. The predicted emission rate of CO_2 should not exceed the target CO_2 emission rate, TER. The predicted CO_2 emission rate is based on the calculated annual energy requirements for space heating, water heating and lighting, less the emissions saved by renewable energy generation technologies. In addition, for dwellings only, the calculated Dwelling Fabric Energy Efficiency (DFEE) must not be greater than the Target Fabric Energy Efficiency (TFEE).

For dwellings, the TER and TFEE are calculated using a notional dwelling of the same size and shape as the actual dwelling which is constructed according to the reference values set out in Appendix R of SAP 2012.

Similarly, for buildings other than dwellings, the TER is based on notional building specifications defined in the NCM modelling guide [11].

1.5.1 Compliance for dwellings

The Building Regulations Part L (2013) and the associated guidance document for residential construction, Approved Document L1A, require that thermal bridging is minimised and is accounted for in the fabric heat loss calculations.

Approved Document L1A states that *'the building fabric should be constructed so that there are no reasonably avoidable thermal bridges in the thermal insulation layers caused by gaps within the various elements, at the joints between the elements, and at the edges of elements, such as those around window and door openings.'*

The following methods may be used to comply with Approved Document L1A:

1. The adoption of approved design details as set out in DCLG Accredited Construction Details, see below.
2. Use construction joint details that have linear thermal transmittance values that have been calculated by a person with suitable expertise and experience using the guidance set out in BRE Report BR 497 Conventions for calculating linear thermal transmittance and temperature factors [12]. The linear transmittance values can then be used directly in the dwelling CO_2 emission rate (DER) and DFEE calculations.
3. Use the linear thermal transmittance values in the 'default' column of Table K1 in SAP 2012 [9] directly in the DER and DFEE calculations, see Table 1.2.
4. Use a conservative default y-value of 0.15 W/m^2K rather than linear transmittance values for each construction joint, in the DER and DFEE calculations.

Note: The y-value is the term used to describe the sum of all the non-repeating thermal bridges divided by the total heat loss area of the building. The units of the y-value are

W/m²K, i.e. the same as for U-values. The junctions that should be included in the y-value calculation are listed in Table K1 in SAP 2012.

Accredited Construction Details

Accredited Construction Details for England and Wales [13] are available from the Technical Guidance section for Part L of The Building Regulations from the UK Government's Planning Portal website, www.planningportal.gov.uk.

Accredited Construction Details for Scotland [14] are published by the Scottish Building Standards Agency and are available from the building standards section of the Scottish Government website, www.gov.scot.

The Accredited Construction Details that are currently available for steel construction all relate to light steel framing systems that are used in housing and medium-rise buildings. Therefore, they do not provide significant assistance for determining the magnitude of potential thermal bridges in hot-rolled structural steel frames.

Table 1.2 Selected ψ values for different types of junction, from SAP 2012 Tables K1 and R2

Ref no	Junction	Approved ψ Value[c] (W/mK)	Default ψ Value[c] (W/mK)	Reference ψ Value[d] (W/mK)
E1	Steel lintel with perforated steel base plate	0.50	1.00	0.05
E3	Sill	0.04	0.08	0.05
E4	Jamb	0.05	0.10	0.05
E5	Ground floor (normal)	0.16	0.32	0.16
E7	Party floor between dwellings (a)	0.07	0.14	0.07
E8	Balcony within a dwelling (b)	0.00	0.00	0.00
E9	Balcony between dwellings (a, b)	0.02	0.04	0.02
E23	Balcony within or between dwellings, balcony support penetrates wall insulation	No value	1.00	0.02
E12	Gable (insulation at ceiling level)	0.24	0.48	0.06
E10	Eaves (insulation at ceiling level)	0.06	0.12	0.06
E16	Corner (normal)	0.09	0.18	0.09

Notes:

a. For these junctions, half of the ψ-value is applied to each dwelling.

b. This is an externally supported balcony (the balcony slab is not a continuation of the floor slab) where the wall insulation is continuous and not bridged by the balcony slab.

c. Values from SAP 2012 Table K1.

d. Values from SAP 2012 Table R2.

Due to the large diversity of building envelope systems that may be used in practice, details may vary between different building projects. Therefore, thermal performance of specific details may be required on a project specific basis.

Data Verification Schemes

Third party verification schemes such as *SCI Assessed* [15] and the BRE *Certified Thermal Details and Products Scheme* [16] may be used to certify thermal modelling data published by system manufacturers. The *SCI Assessed* scheme can also be used to certify the structural performance characteristics of thermal break materials.

Standard Assessment Procedure (SAP 2012)

SAP 2012 is used to provide evidence that the carbon emissions target (TER) has been achieved. The SAP calculation includes the term H_{TB} (heat loss due to thermal bridging) which is calculated or estimated as below:

a. The sum of all linear thermal transmittances (Ψ) times the length of detail (L).

$$H_{TB} = \Sigma (L \times \Psi)$$

Or, if no linear thermal transmittances are known:

b. Using the factor $y = 0.15$ W/m^{2}K in the equation below:

$$H_{TB} = y \times \Sigma A_{exp}$$

Where, A_{exp} = Area of exposed fabric.

Method (a) is always preferable as it avoids the conservative approach imposed by method (b), which can double the overall calculated heat loss in well-insulated buildings.

For smaller projects, it is better to use *Accredited Construction Details*, if possible. However, for larger projects, it may be economic to calculate the thermal bridge losses separately.

Linear thermal transmittance (Ψ) values used in (a) can be a combination of:

- Approved Construction Details (use the values in the ‘Approved’ column of SAP Appendix K Table K1, see Table 1.2).
- Un-calculated details (use the values in the ‘Default’ column of SAP Appendix K Table K1, see Table 1.2).
- Modelled details, in which numerical modelling has been carried out by a person of suitable expertise.

The target emissions rate (TER) is calculated using a notional building which is the same size and shape as the actual building and defined using the reference values given in Appendix R of SAP 2012. In terms of thermal bridging allowance:

1. If the thermal bridging in the actual building has been specified by using the default y-value of 0.15 W/m^{2}K, the thermal bridging in the notional building is defined by $y = 0.05$ W/m^{2}K.
2. Otherwise the thermal bridging allowance is calculated using the lengths of the junctions in the actual dwelling and the Ψ-values given in Appendix R Table R2, see Table 1.2 for reference Ψ-values for selected junctions.

SAP 2012 makes no specific references to point thermal bridges (χ-value). However, where point thermal bridges repeat along the façade of the building, e.g. balconies or canopy supports, these point thermal bridges can be converted into a linear (Ψ) value.

In a thermal analysis, the magnitude of the point thermal bridge can be determined by subtracting the heat loss in a particular section of the planar element from the same planar element including the point thermal bridge. The effective linear thermal bridge is obtained by dividing by the spacing of the point thermal bridges. The width of the planar wall element used in the thermal model may also be used as the notional spacing of the point thermal bridges.

Alternatively, where point thermal bridges like balcony attachments are associated with patio doors or similar linear openings, the combined effect of both the linear and point thermal bridge may be converted to an effective linear thermal bridge of higher magnitude.

1.5.2 Fabric energy efficiency standards

In 2009, in support of the Government's strategy to deliver 'zero carbon' new homes by 2016, the Zero Carbon Hub (ZCH) undertook an extensive R&D programme to develop a new Fabric Energy Efficiency Standard (FEES).

The Fabric Energy Efficiency Standard is a performance standard, setting minimum levels for overall fabric performance. The FEES sets a maximum limit on the amount of energy (in kWh/m^2/year) that would normally be needed to maintain comfortable internal temperatures in a home. Achievement of the FEES is affected by building fabric U-values, thermal bridging, thermal mass, and features which affect lighting and solar gains. It is not influenced by building services, for example heating system, fixed lighting, or ventilation strategy.

The ZCH Task Group proposed interim and full fabric energy efficiency standards (FEES) for different house types and recommended full implementation in 2016 with an interim step in 2013.

Interim FEES proposed by the ZCH were:

- 43 kWh/m^2/yr for apartment blocks and mid-terrace houses.
- 52 kWh/m^2/yr for end-terrace, semi-detached and detached houses.

Proposed ZCH full FEES were:

- 39 kWh/m^2/yr for apartment blocks and mid-terrace houses
- 46 kWh/m^2/yr for end-terrace, semi-detached and detached houses

Fabric Energy Efficiency (FEE) requirements were introduced in the 2013 edition of Approved Document L1A of the Building Regulations, which came into force in April 2014. The FEE metric was the same as the FEES metric proposed by the ZCH.

As for CO_2 emission rate targets, the target fabric energy efficiency (TFEE) is derived using a notional dwelling of the same size and shape as the actual dwelling being constructed. A summary of the Part L 2013 notional dwelling is published in Approved Document L1A and the full detail is set out in the Standard Assessment Procedure (SAP 2012) Appendix R [9].

Although the full FEES standard, as proposed by the ZCH, has been adopted in Part L1A, the TFEE has been relaxed by 15% following concerns that full FEES may not currently be reliably achieved in practice across the full range of house types.

Table 1.3 is taken from guidance produced by the Zero Carbon Hub [17] and shows two examples of how the full FEES can be achieved for a semi-detached, two-storey house of 76 m^2 floor area.

Table 1.3 Example thermal performance solutions required to achieve Fabric Energy Efficiency requirements for a semi-detached two-storey house

Building Element(1)	Example 1 Balanced Solution	Example 2 Part L 2013 backstop solution
External wall U-value (W/m^{2}K)	0.18	0.20
Party wall U-value(2) (W/m^{2}K)	0.00	0.00
Ground floor U-value (W/m^{2}K)	0.13	0.18
Roof U-value (W/m^{2}K)	0.13	0.16
Windows U-value (W/m^{2}K)	1.4 (double glazed)	1.2 (double glazed)
Doors U-value (W/m^{2}K)	1.0	1.0
Air permeability (m^3/hr/m^2@50pa)	5.0	4.8
Thermal bridging (W/m^{2}K)	0.05	0.04
Dwelling fabric energy efficiency (kWh/m^2/yr)	46.0	45.9

Note:

1. Wall, floor and roof U-values based on the limiting values proposed in the 2013 Part L consultation
2. Solid or fully filled cavity party wall with effective sealing at all exposed edges. A U-value of zero is assumed on the basis that both sides of the wall are within the heated envelope of a building and therefore there should be no temperature differential from one side to the other, and therefore no heat loss.

1.5.3 Compliance for buildings other than dwellings

The thermal bridging requirements of Approved Document L2A [7] are very similar to L1A. Demonstration of 'reasonable provision' in the case of buildings other than dwellings includes:

1. Use of construction joint details that have thermal transmittance values that have been calculated by a person with suitable expertise and experience following the guidance set out in BR 497 and following a process flow sequence that has been provided to the Building Control Body (BCB) indicating the way in which the detail should be constructed. The calculated value can then be used in the building emission rate (BER).
2. Use of construction joints with no specific quantification of the thermal bridge values. In such cases, the generic linear thermal bridge values given in IP 1/06 [19] increased by 0.04 W/m^{2}K or 50%, whichever is greater, must be used in the BER calculation.

A similar approach is taken for non-residential buildings in Part L2A, in which the Simplified Building Energy Model (SBEM) is used in place of SAP.

1.5.4 Contractual responsibilities

The responsibilities related to the design and specification of thermal break junctions and the products used should be clarified in the contractual documents.

Manufacturers of thermal break products do not necessarily provide thermal modelling services, except for particularly large projects, and so existing performance data is used for general design of details.

Sufficient time should be included within the design and construction process for specification, manufacture and delivery of thermal break products.

1.6 Control of condensation

Although heat loss is a very important effect of thermal bridging, low internal surface temperatures in the region of a thermal bridge can lead to surface condensation if they are below the dew point of the air. For non-absorbent surfaces, condensation can cause unsightly collection of moisture including dripping and pooling on surfaces beneath. For absorbent materials such as insulation products or plasterboard, interstitial condensation can occur, leading to loss of thermal performance and/or structural integrity and mould growth.

BS 5250: 2002 *Code of Practice for control of condensation in buildings* [18], describes the causes and effects of surface and interstitial condensation in buildings and gives recommendations for their control. Further information on condensation due to thermal bridges is provided in BRE Information Paper 1/06 [19].

An indicator of condensation risk is provided by the temperature factor f_{Rsi}. This factor is given by the following equation in the BRE paper:

$$f_{Rsi} = (T_{si} - T_e)/(T_i - T_e)$$

where:

T_{si} is internal surface temperature (from thermal modelling)
T_e is external air temperature
T_i is internal air temperature.

Minimum recommended values of f_{Rsi}, termed critical temperature factors f_{CRsi}, are presented in Table 1.4. The critical temperature factors depend upon the building use and the consequent internal relative humidity of the building. The higher the likely internal relative humidity, the higher the critical temperature factor should be to eliminate risk of condensation.

Table 1.4 Recommended critical temperature factors f_{CRsi}

Type of building	f_{CRsi}
Storage buildings	0.30
Offices, retail premises	0.50
Dwellings, residential buildings, schools	0.75
Sports halls, kitchens, canteens	0.80
Swimming pools, laundries, breweries	0.90

Source: BRE IP1/06 [19]

MINIMISING THERMAL BRIDGING IN STEEL CONSTRUCTION

Steel construction systems used at building façades must be designed and detailed to minimise thermal bridging through their steel components which have relatively high thermal conductivity compared to many other construction materials. There are effective methods of detailing steel components within, or penetrating, building envelopes to minimise heat loss and condensation risk. This section describes these methods.

2.1 Eliminate thermal bridging

Placing steel components within the insulated envelope of a building is the preferred means to eliminate thermal bridging and this is normally the case in practice. However, there will be situations where the steelwork has been designed to be partially located within, or to penetrate, the insulated layer of the building envelope.

An example of how to minimise thermal bridging is illustrated by comparison of the two balcony systems shown in Figure 2.1. The balcony shown in Figure 2.1(a) is cantilevered from the structural frame of the building. This requires significant structural connections that lead to thermal bridges. Figure 2.1(b) shows an alternative approach, where balconies are supported independently; which requires considerably fewer or smaller connection points to the building and so thermal bridging is reduced.

Figure 2.1 Steel balcony support options (a) Structure supported balconies (b) Independently supported balconies

2.2 Local insulation

Where a steel member penetrates the building envelope, insulation may be provided around the element to lengthen the heat flow path, thereby reducing heat losses and raising the internal surface temperature of the element. Additional insulation can be applied on either the internal or external side of the building envelope. Figure 2.2 shows a beam with local insulation applied internally. The amount of insulation required in terms of thickness and length along the member depends on the particular circumstance and can be determined by thermal modelling. Factors to be considered include: the size of the member, the U value of the building envelope and the internal conditions of the building (temperature and humidity).

The temperature of the insulated part of the beam is lower than that of the room and therefore a vapour control layer is also applied around the outside of the insulation to prevent condensation. Insulation boards with aluminium facings can be used to provide vapour control. Specialist adhesive tapes can be used to seal joints and edges. Section 3.1.1 presents the results of a thermal analysis for a similar penetration detail but with the insulation applied externally. Both solutions (i.e. insulation applied internally or externally) can be used, however, internally applied insulation is more effective.

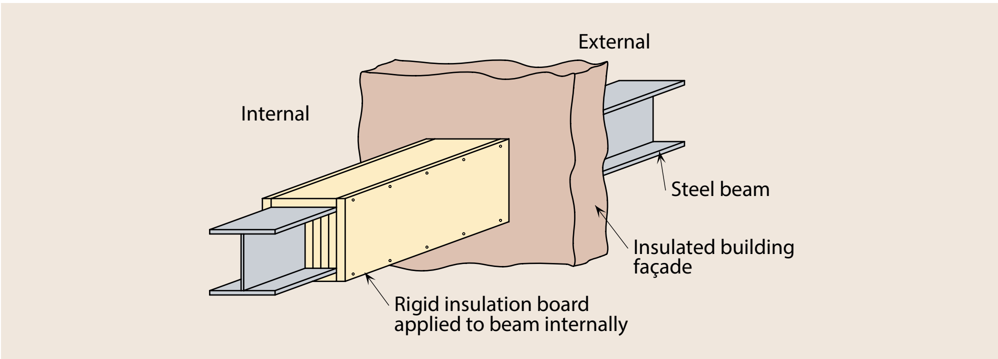


Figure 2.2 Principle of a locally insulated steel beam passing through the building envelope

2.3 Reducing thermal transmittance

The thermal transmittance of a detail that has been identified as forming a thermal bridge can be reduced by creating thermal breaks, usually by introducing materials with a lower thermal conductivity.

2.3.1 Thermal breaks

Thermal breaks may be provided by inserting a relatively stiff and strong material, with a low thermal conductivity, between the steel sections that are inside and outside the building envelope, as illustrated in Figure 2.3. Reducing the cross sectional area of an element can also be used to reduce its thermal transmittance where it crosses the building envelope.

Proprietary structural thermal break products are available to support balconies, canopies, external staircases and structural members that penetrate the insulated

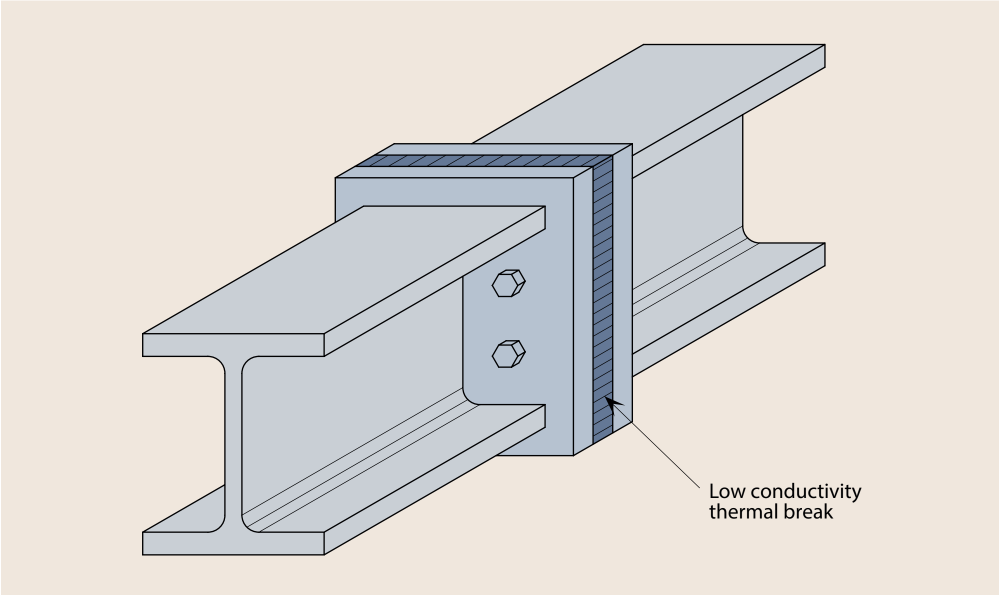


*Figure 2.3
Principle of a thermal break between two steel beams*

building envelope. These proprietary solutions are designed to minimise the amount of continuous metal passing through the thermal bridge. In many cases, stainless steel components are encased in an insulating material. Section 3.1.3 demonstrates the benefits of one such proprietary product produced by *Schöck*.

Thermal breaks are provided in manufactured elements, such as metal window frames and composite cladding panels, where the steel skins are separated at the junctions between panels by a layer of insulation. The same approach is adopted in built-up cladding systems where thermal break pads are provided beneath brackets.

Similarly, thermal break pads can be provided behind the brackets of brickwork support systems. Brickwork support systems are made from stainless steel, primarily to resist corrosion, but which also reduces thermal bridging because stainless steel has a significantly lower thermal conductivity than carbon steel (see Table 1.1).

Where structural actions are transferred through the steel elements that pass through the insulated envelope of a building, such as in balcony connections, brickwork support systems and in some roof structures, the precise form of thermal break must be considered to ensure that the structural performance remains acceptable. Materials used as thermal breaks will generally be more compressible than steel. Therefore, all of the following should be considered in the selection of the thermal break:

- Strength of thermal break material and its effect on the structural performance of the detail, see Section 5.
- Stiffness of the thermal break as this affects the deflection and dynamic response of attached components.
- Long-term durability.

Pads and spacers of high thermal resistance can be made from a range of engineered materials such as composite glass/resin and synthetic resin bonded fabric. Examples of details using a thermal break layer bolted between end plates and using a proprietary solution bolted between beam end plates are described in Sections 3.1.2 and 3.1.3, respectively.

2.3.2 Lower conductivity fixings

The thermal transmittance of a thermal bridge can be reduced by replacing some of its components with alternative components made from materials of lower thermal conductivity. For example, stainless steel bolts or screws have a thermal conductivity of less than a third of that of carbon steel. Their potential benefit is illustrated in the example given in Section 3.1.2.

Bi-metallic corrosion can occur when dissimilar metals are in contact in the presence of an electrolyte. The electrolyte can be in the form of rain water or condensation. Bi-metallic corrosion is not an issue if the amount of stainless steel is small compared to the amount of carbon steel, or if an electrolyte (i.e. moisture) is not present.

THERMAL BRIDGES IN STEEL FRAMES

A thermal bridge may occur wherever a structural connection is made between members that pass from inside to outside of the building envelope. In practice, without special provisions to minimise their effect, thermal bridges can lead to high heat losses and low internal surface temperatures with the inherent risk of condensation.

Cantilevered elements, such as balconies and canopies, lead to significant heat loss, as can be seen by the thermal image shown in Figure 3.1. Cantilevered balconies and exposed slab edges are generally the most critical thermal bridges in a building envelope. Non-insulated projections reduce the internal surface temperature significantly. As a result, the risk of mould growth is increased around the intersection of the interior floor slab and the exterior wall assembly, as shown in Figure 3.2.

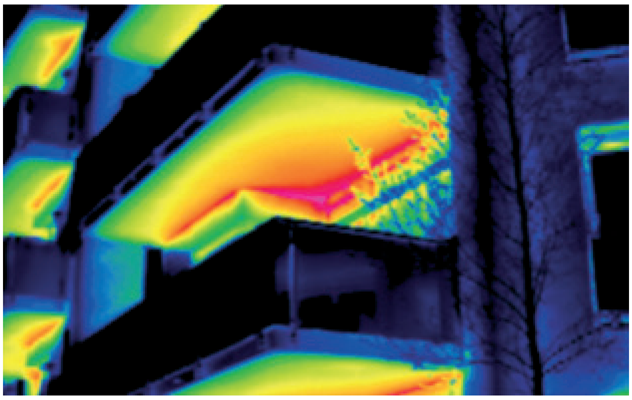


Figure 3.1 Thermal image of a thermal bridge at a balcony with higher temperature at the junction between the wall and slab

Figure 3.2 Mould growth on the ceiling of a concrete slab adjacent to an exposed slab edge thermal bridge

Common thermal bridging situations relating to the use of steel-framed systems in multi-storey buildings are described in this section. Examples show how thermal bridging is determined for common cases presented. Linear thermal transmittance (Ψ) and temperature factor (f_{Rsi}) data are provided to illustrate the influence of the available methods to reduce thermal bridging.

3.1 Beams penetrating the building envelope

An example of a steel beam penetrating the envelope of an industrial building is shown in Figure 3.3. The thermal image of the beam reveals the areas of higher temperature and heat loss around the penetration through the steel cladding.

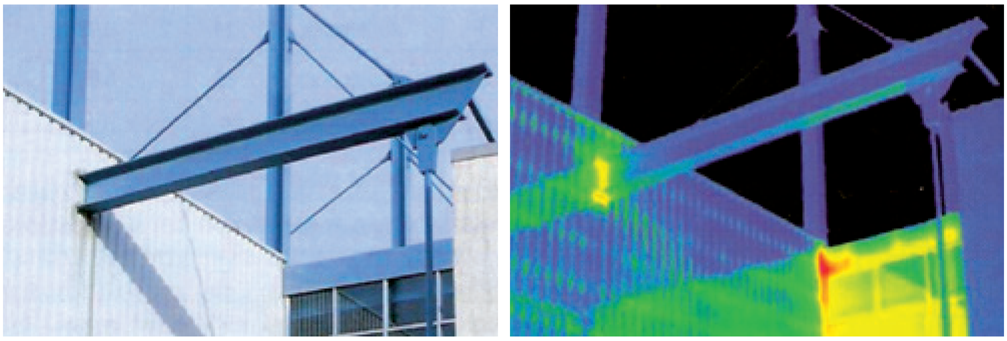


Figure 3.3 Structural steel beam penetrating the building envelope (a) Steel beam penetrating the building envelope (b) Thermal image

3.1.1 Beam with local external insulation

When a beam penetrates the insulated envelope of a building, it can be locally insulated externally to the building envelope to raise the internal surface temperature of the member. The detail is illustrated in Figure 3.4.

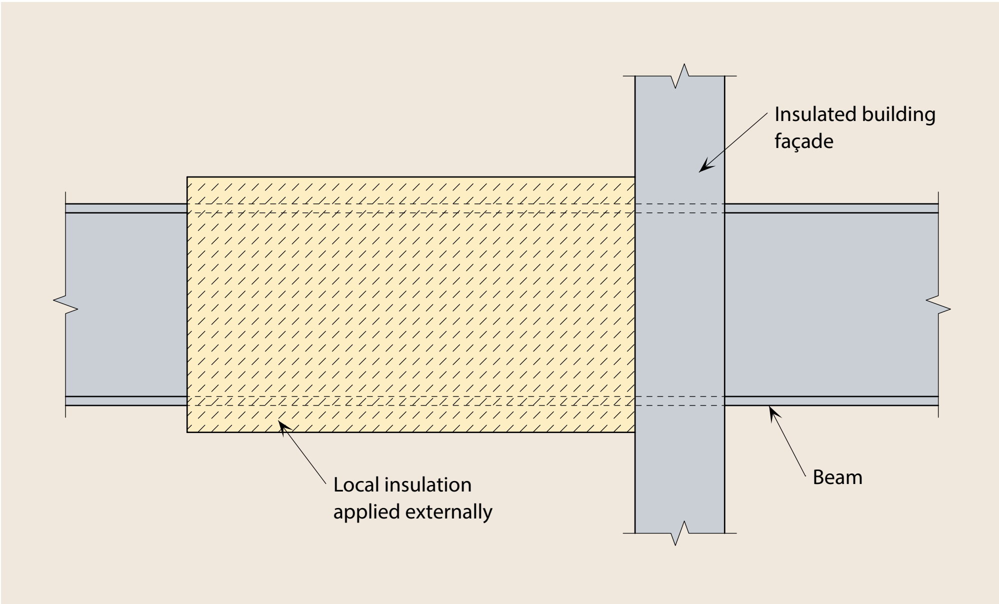


Figure 3.4 Principle of locally externally insulated beam

Thermal analysis was carried out using three-dimensional steady state modelling software. The objective was to determine the lowest surface temperatures on the beam at the interface with the (internal) wall line. These internal surface temperatures were compared to the local dew point for the internal part of the beam, thus assessing the risk of surface condensation.

Three cases were modelled; the beam without insulation, and the beam with two alternative insulation options. The results of the modelling are shown in Table 3.1.

Table 3.1 Thermal modelling results for a beam penetrating a building façade

Description of model	Minimum internal surface temperature	Temperature factor, f_{Rsi}
Beam without insulation	8.90°C	0.51
Beam insulated externally for 360 mm	9.48°C	0.54
Beam insulated externally for 1000 mm	9.66°C	0.55

Note: This modelling was carried out with an internal air temperature of 17.5 °C and an external temperature of 0 °C.

It can be seen from the results that insulating the beam to a length of 1 m on the external side of the wall has only a modest effect on the minimum internal surface temperature. In this particular case, the results show that the temperature factor for the beam without any insulation is acceptable for office, retail and storage buildings. However, for other applications, the beam should ideally be insulated internally or boxed-in over its exposed length.

For other situations with different beam sizes and wall constructions the temperature factor for a beam without insulation may not be acceptable for office, retail or storage buildings.

3.1.2 Beam with a thermal break pad

A thermal break may be created in a steel beam that penetrates the insulated envelope of a building by inserting a layer of thermal break material between welded steel end plates. In this simplified example, four M24 bolts are used to connect the steel end plates and thermal break material. For connections that incorporate thermal breaks, additional design checks may be required to ensure that the structural performance of the connection is acceptable, see Section 5.

The model of the thermal break connection is shown in Figure 3.5. In this example, an HEA 240 steel section was analysed. Six variations of the thermal break were modelled; 5, 10 and 20 mm layers of thermal break material and either carbon or stainless steel bolts. The insulated ($\lambda = 0.035$ W/mK) external wall cavity was assumed to be 80 mm wide. The thermal conductivity of the thermal break material layer was 0.25 W/mK. The results of thermal

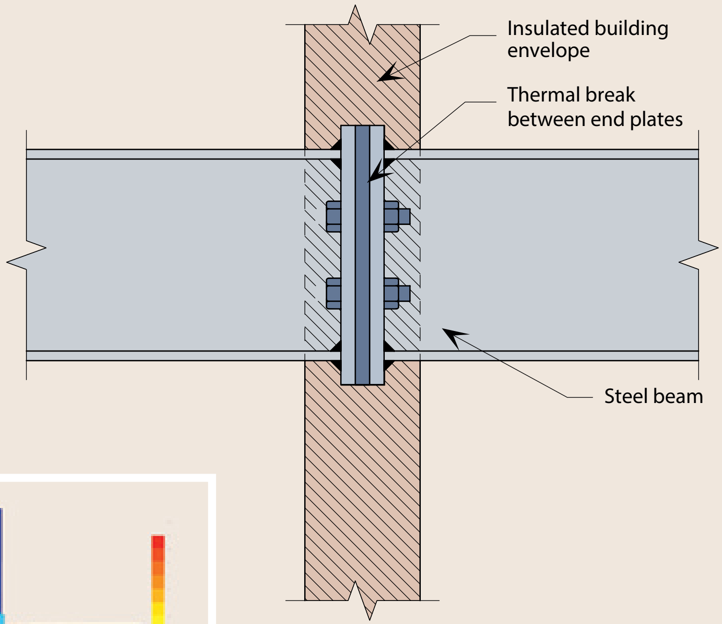


Figure 3.5 Steel beam connected by end plates with thermal break pad

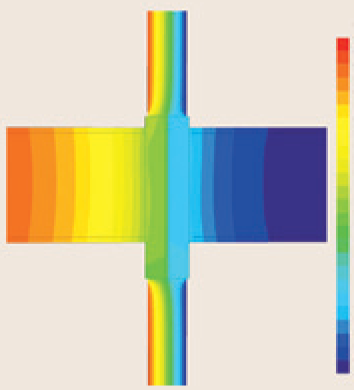


Figure 3.6 Temperature distribution for model with 10 mm thermal break pad and steel bolts

modelling are shown in Table 3.2 and Figure 3.6 shows the temperature distribution for the model with 10 mm thermal break pad and carbon steel bolts.

Table 3.2 Thermal modelling results for a beam with and without a thermal break pad

Description of model	Equivalent thermal conductivity *, λ_{eq} W/mK	Thermal bridge heat loss, χ W/K	Minimal internal surface temperature	Temperature factor, f_{Rsi}
Continuous steel beam HEA 240 with no thermal break	3.48	1.0	7.5°C	0.50
5 mm thermal break pad with carbon steel bolts	7.60	1.4	5.8°C	0.43
5 mm thermal break pad with stainless steel bolts	5.80	1.3	6.8°C	0.47
10 mm thermal break pad with carbon steel bolts	5.70	1.3	6.9°C	0.48
10 mm thermal break pad with stainless steel bolts	3.90	1.1	8.6°C	0.55
20 mm thermal break pad with carbon steel bolts	1.00	1.1	8.4°C	0.53
20 mm thermal break pad with stainless steel bolts	0.55	0.88	10.7°C	0.62

Note: * This is expressed as an equivalent thermal conductivity over the thickness of the building envelope. This modelling was carried out with an internal air temperature of 20°C and an external temperature of 5°C. The internal surface resistance was taken as 0.13 m^2K/W.

It can be seen from the results that the use of end plate connections with a thermal break pad contained within the building envelope can potentially make the thermal bridge worse than for a continuous beam. This is because the extra area of contact created by the end plates counteracts the effect of the increased thermal resistance of the thermal break layer. Another contributing factor is that for the continuous beam case, the insulation in the building envelope is placed around the beam, whereas with the end plate connection, the steel end plates replace part of this insulating layer. These results highlight the importance of accurate thermal modelling to determine the influence of different details.

The results for continuous beams and beams separated by 5, 10 and 20 mm thermal break pads all fail to meet the minimum recommended critical temperature factor for dwellings, i.e. $f_{Rsi} < 0.75$. Furthermore, continuous beams and beams separated by 5 mm and 10 mm thermal break pads are also marginal or fail against the recommended minimum value for commercial buildings. However, the details used in this example were chosen to illustrate the effect rather than optimise the junction for cold bridging. As can be seen from Figure 3.6, the end plates are relatively thick (40 mm) compared to the insulated layer and the external wall was modelled as a single layer rather than a representative wall construction. Details using thermal break pads can be configured to meet the minimum recommended critical temperature factors.

The thermal performance of this type of thermal break detail is sensitive to connection geometry, e.g. beam size, end plate thickness and bolt diameter, and the thickness of the thermal break material.

3.1.3 Beam with an *Isokorb* thermal break

The thermal performance of structural steel connections can be significantly improved by use of proprietary systems, such as a *Schöck Isokorb* thermal break unit. In this example, the *Isokorb* unit is used to connect two parts of a steel beam that penetrates the insulated envelope of a building.

The Isokorb unit is shown in Figure 3.7. The main body of each unit is made from dense polystyrene foam through which pass threaded stainless steel studs with the necessary washers, nuts and plates. The lower part of the unit includes a stainless steel box section to provide compression and shear resistance. The structural capabilities of the *Isokorb* units are provided in the product literature from *Schöck* [20].

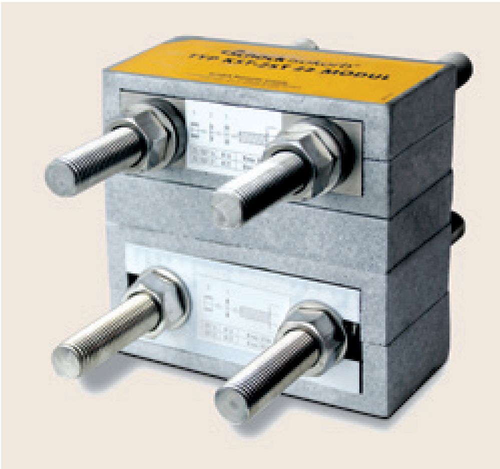


Figure 3.7 Isokorb KST 22 thermal break

Figure 3.8 shows a steel frame building with *Isokorb KST* units installed. External steelwork, such as balconies and walkways, will be attached directly to the *Isokorb KST* units after the façade has been installed.

Figure 3.8 Isokorb units attached to steel frame

An *Isokorb KST 22* unit with M22 bolts was modelled using three dimensional, steady state thermal conduction analysis software. In the model, the building envelope insulation was 80 mm thick, the *Isokorb* unit was also 80 mm thick and the HEA 240 steel beams were bolted to the *Isokorb* unit using 40 mm thick end plates. The thermal model is shown in Figure 3.9. The results of the thermal modelling, with and without the *Isokorb* unit, are presented in Table 3.3.

Table 3.3 Thermal modelling results for a beam with and without Isokorb thermal break

Description of model	Thermal bridge heat loss W/K	Minimum internal surface temperature	Temperature factor, f_{Rsi}
HEA 240 beam with Isokorb KST 22 unit thermal break	0.43	15.2°C	0.81
Continuous steel beam HEA 240 with no thermal break	1.0	7.5°C	0.50

Note: This modelling was carried out with an internal air temperature of 20°C and an external temperature of 5°C. The internal surface resistance was taken as 0.13 m²K/W.

The temperature distributions from the thermal modelling are shown in Figure 3.10. It can be seen from the results that using the *Isokorb* connection significantly improves the thermal performance of a beam passing through the building envelope. The heat loss is reduced by almost 60% and the temperature factor is improved by over 60% relative to the case of a continuous beam.

Without this thermal break, the temperature factor is acceptable for non residential buildings (such as office and retail buildings), but with the *Isokorb* unit, the temperature factor of 0.81 exceeds the recommended minimum temperature factor of 0.75 for dwellings, residential buildings and schools.

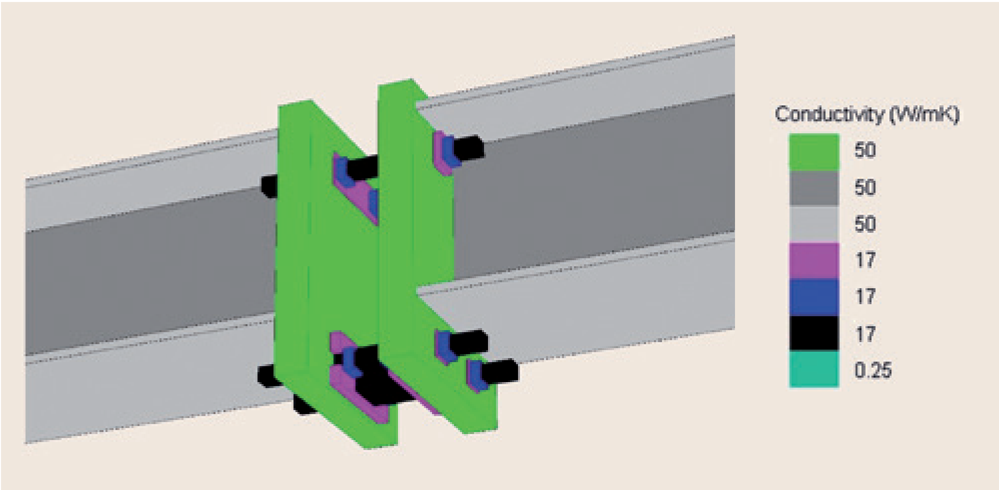


Figure 3.9 Thermal model for an Isokorb unit

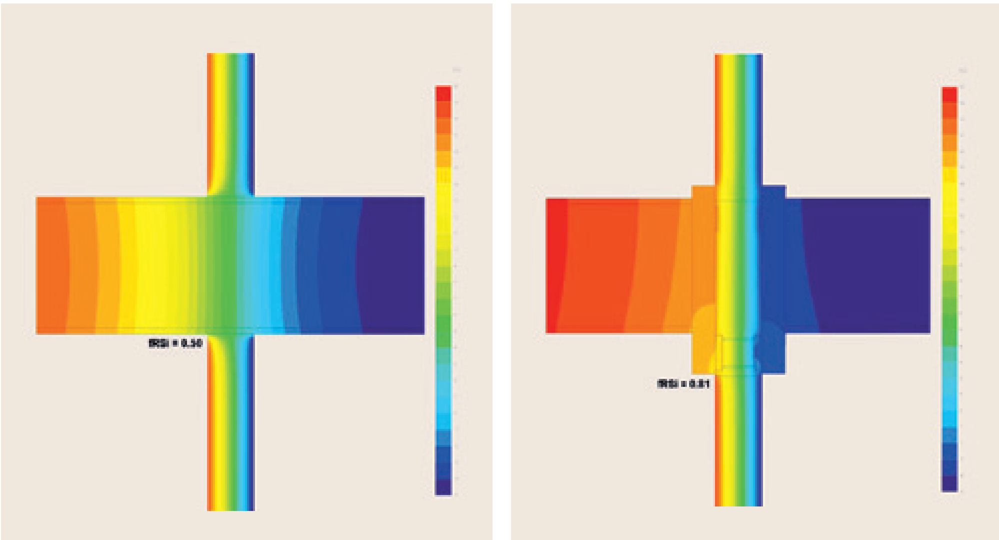


Figure 3.10 Temperature distributions for HEA 240 steel beam a. (Left) Continuous HEA 240 steel beam passing through 80 mm insulation b. (Right) HEA 240 steel beam with Isokorb KST 22 thermal isolator

3.2 Balcony attachments

For balconies supported by the internal structure, as shown in Figure 3.11, the thermal losses at the thermal bridges between the balcony and the structural frame of the building can be significant.

Figure 3.11 Steel balconies thermally broken from primary structure by Schöck Isokorb

3.2.1 Steel beam connected to a concrete floor slab

A common design requirement is to connect a steel balcony to a concrete floor slab that is supported by a steel or reinforced concrete frame.

Figure 3.12 shows Isokorb units attached to a reinforced concrete frame that are ready to be connected to external steelwork, such as balconies and walkways.

Figure 3.12 Isokorb KS units incorporated into concrete floor slab prior to installing the steel balcony supports

A three-dimensional thermal analysis of a steel balcony connected to a 200 mm thick concrete floor slab has been undertaken. The cladding was brickwork and the 100 mm cavity was filled with mineral wool insulation. The analysis included a glazing element above the floor as shown in Figure 3.13 and Figure 3.14.

Three cases were modelled:

1. Direct connection of the balcony support bracket to the concrete floor slab, see Figure 3.13.
2. Thermal break pad of 10 mm thickness ($\lambda = 0.29$ W/mK) between the balcony support bracket end plate and the concrete floor slab.
3. *Isokorb KS 14* thermal break connecting the balcony support bracket to the concrete floor slab, see Figure 3.14 and Figure 3.15.

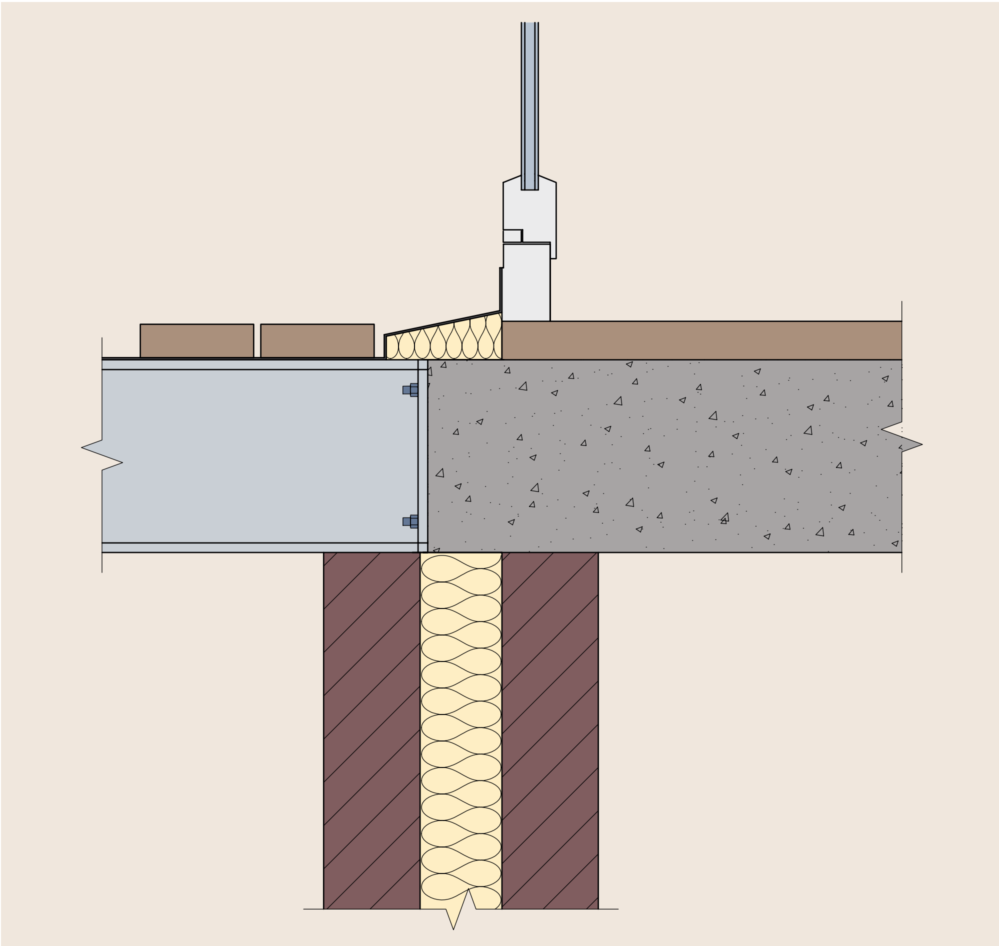


Figure 3.13 Detail of direct connection of the steel balcony to the concrete slab (Case 1)

The surface resistances were set in accordance with BS EN ISO 6946 [21] ($R_{si} = 0.13$ m^{2}K/W and $R_{so} = 0.04$ m^{2}K/W). The inside temperature was taken as 20 °C and the outside temperature as 0 °C. Wall and glazing U-values were taken as 0.29 W/m^{2}K and 1.0 W/m^{2}K, respectively. For the purpose of calculating the linear thermal bridging effect (Ψ-value), the balcony support brackets were assumed to be spaced at 0.7 m, which was the width of the planar element used in the thermal model. The insulating element of the *Isokorb KS14* is 80 mm in thickness.

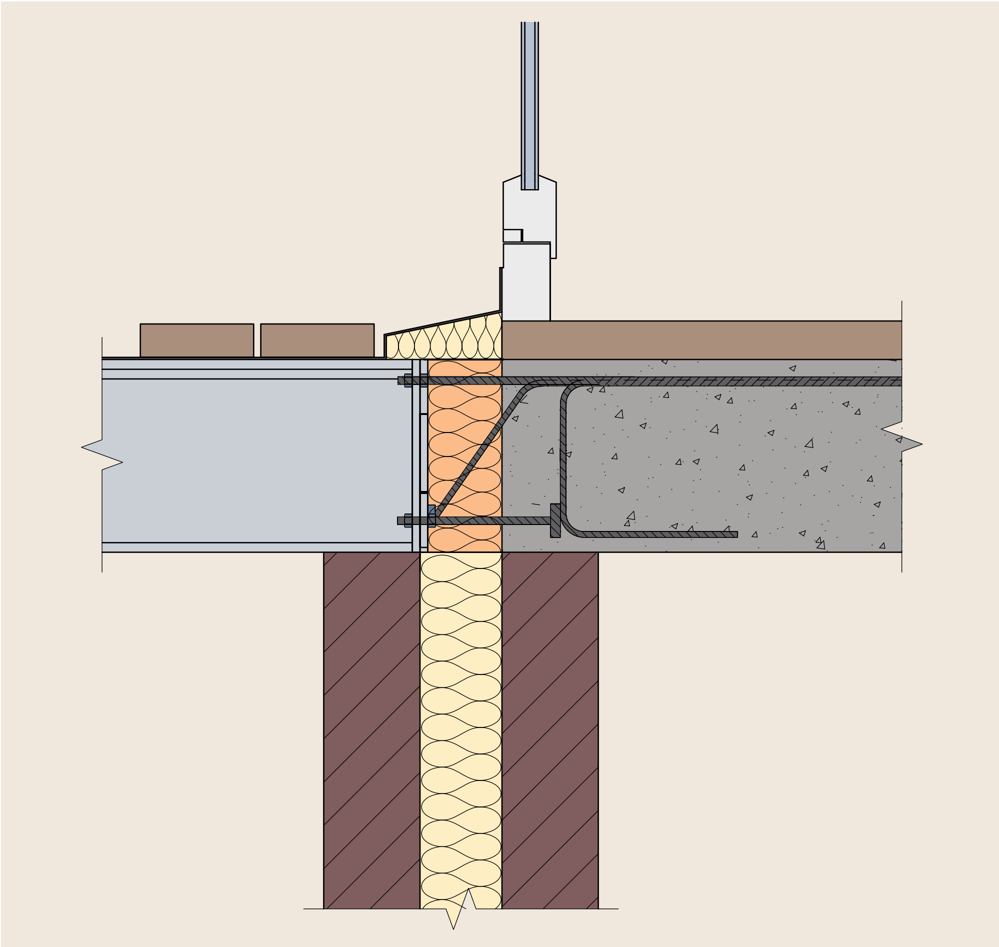


Figure 3.14 Detail of Schöck Isokorb KS 14 used to connect a steel balcony to a concrete slab (Case 3)

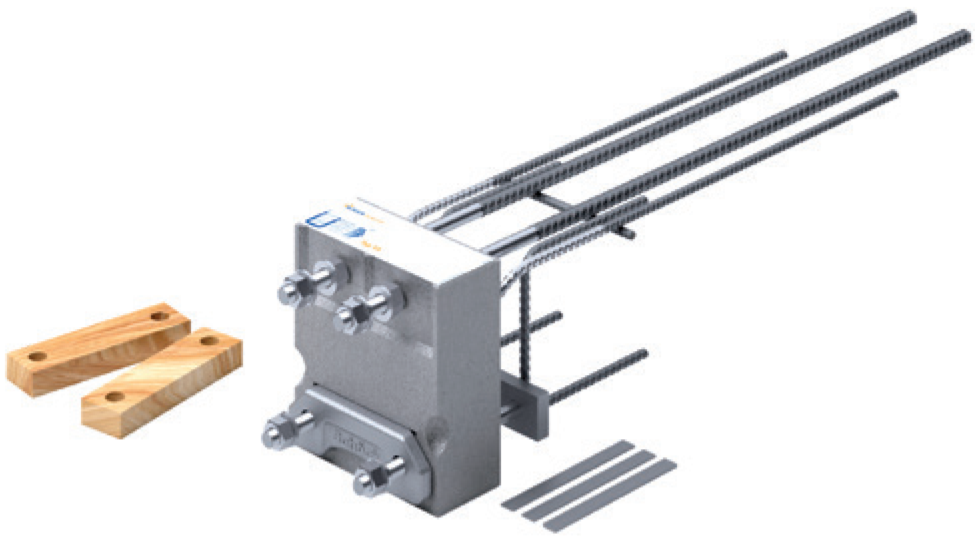
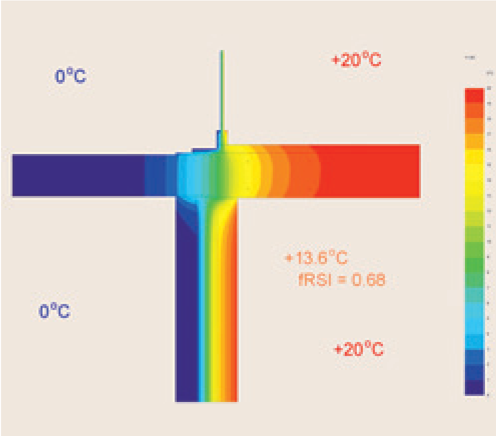


Figure 3.15 Schöck Isokorb KS 14 thermal break for connecting steel balconies to concrete floor slabs

The modelled temperature distributions in the connection details are shown in Figure 3.16 and Figure 3.17 for Cases 1 and 3, respectively. The modelled linear transmission values and temperature factors are given in Table 3.4.



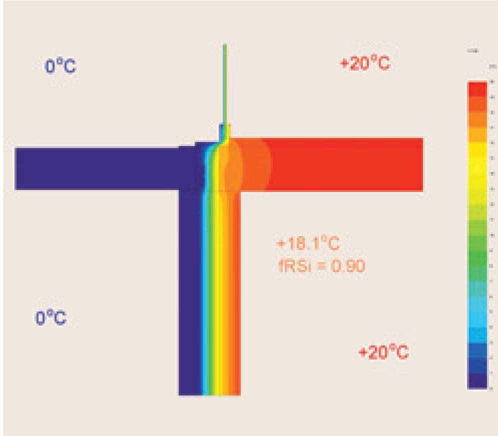


Figure 3.16 (Left) Temperature distribution of direct connection of a steel balcony to a concrete slab (Case 1)

Figure 3.17 (Right) Temperature distribution of Schöck Isokorb KS 14 used to connect a steel balcony to a concrete slab (Case 3)

Table 3.4 Linear and point thermal bridge values for a steel balcony connection to a 200 mm concrete floor slab

Case	Description of model	Linear thermal transmission (W/mK)	Point thermal transmission (W/K)	Temperature factor, f_{Rsi}
1	Beam connected directly to floor slab	0.983	0.564	0.681
2	Connection with 10 mm thermal break pad	0.874	0.488	0.713
3	*Isokorb KS 14* thermal break	0.287	0.077	0.904

In Table 3.4, the linear thermal transmission values include the effect of other parts of the detail that was modelled. The point thermal transmission values are for the connection detail only. Therefore, the linear thermal bridge values are higher than the point values divided by 0.7 m, i.e. the spacing of the support brackets.

Use of a 10 mm pad connection gives a small advantage, and reduces the Ψ-value by 11%. The *Isokorb KS 14* connector reduced the Ψ-value of the direct beam connection by 70%.

From the three cases modelled, only the analyses using the *Isokorb* thermal break meets the recommended critical temperature factors for dwellings [19], i.e. $f_{Rsi} > 0.75$.

3.3 Brickwork supports

3.3.1 Brickwork support fixed to slim floor edge beam

The thermal performance of a brickwork support system connected to a steel slim floor edge beam has been assessed using thermal modelling.

The bottom flange of an asymmetric slim floor edge beam (mono-symmetric I section) may penetrate into the wall cavity and can interfere with insulation placed in the cavity. Therefore, in this example, the bottom flange is cropped to avoid this problem, see Figure 3.18. Mineral wool insulation is placed between the flanges of the outer face of the slim floor beam. The brickwork support angles are stainless steel angles with stainless steel brackets modelled at either 400 mm or 1000 mm spacing. In practice, the actual spacing for storey high brickwork is likely to be 600 mm.

The linear thermal transmittance (Ψ-value), the internal surface temperature and the temperature factor (f_{Rsi}), were calculated using thermal modelling. Modelling was

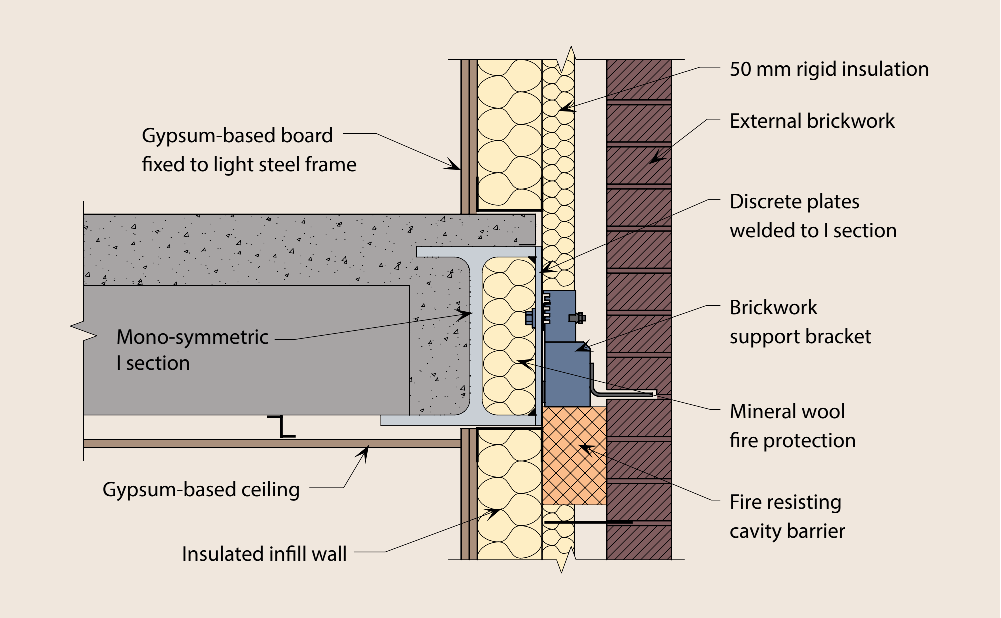


Figure 3.18 Typical section through an external wall with a cropped mono-symmetric I section edge beam

carried out with and without the mineral wool insulation on the external web of the mono-symmetric I section. The thermal model is shown in Figure 3.19.

The temperature distribution for the detail is shown in Figure 3.20 and the numerical results are presented in Table 3.5.

Table 3.5 Thermal modelling results for brickwork support fixed to mono-symmetric I section edge beam

Description of model	Linear thermal transmittance Ψ W/mK	Minimum internal surface temperature	Temperature factor, f_{Rsi}
With mineral wool infill brackets at 400 mm centres	0.245	18°C	0.90
Without mineral wool infill brackets at 400 mm centres	0.260	18°C	0.90
With mineral wool infill brackets at 1000 mm centres	0.126	18.5°C	0.93

Note: This modelling was carried out with an internal air temperature of 20°C and an external temperature of 0°C.

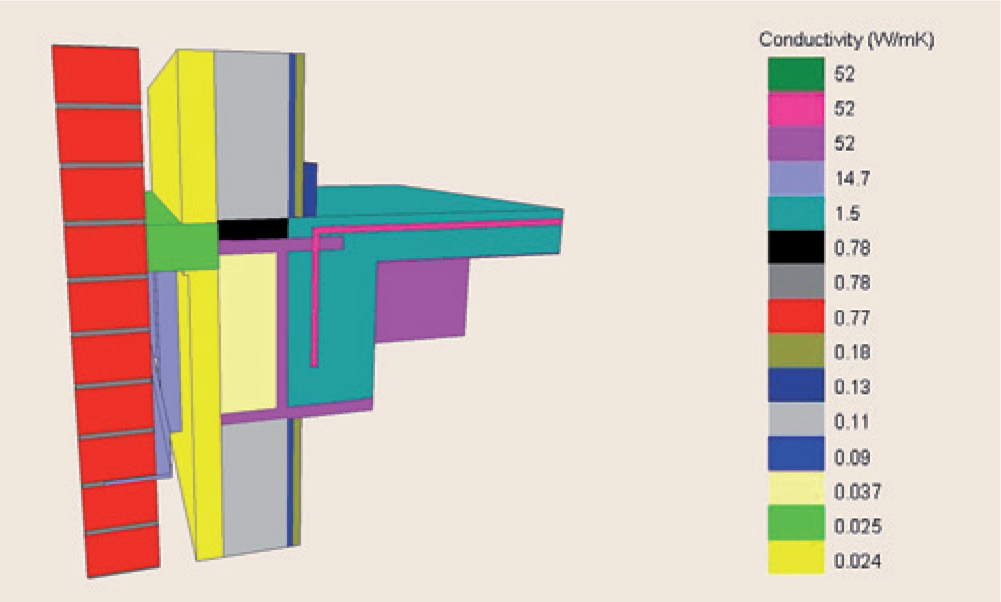


Figure 3.19 Model for brickwork support fixed to mono-symmetric I section edge beam (with mineral wool on external web)

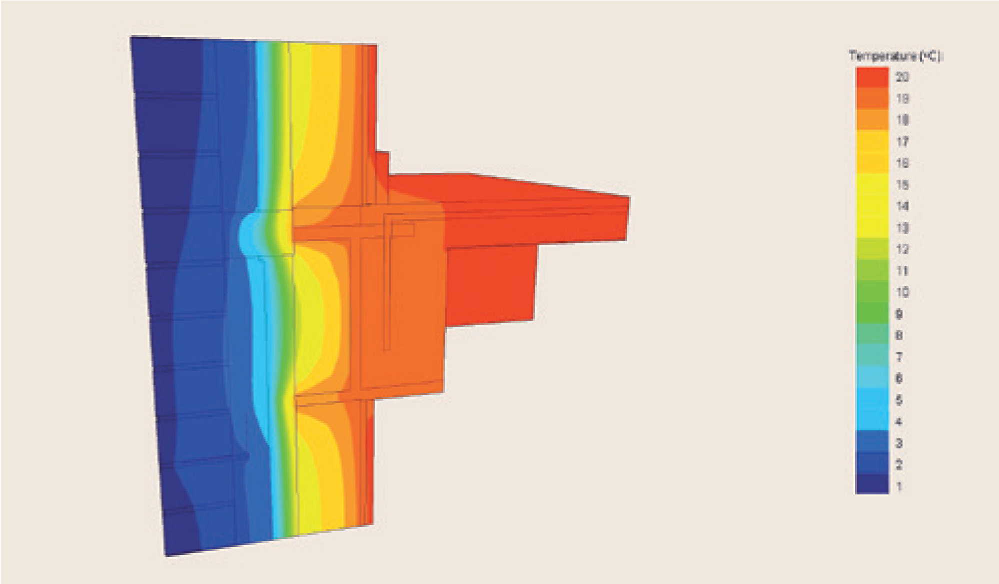


Figure 3.20 Temperature distribution for brickwork support fixed to mono-symmetric I section edge beam (with mineral wool on external web)

From the results it can be seen that:

- Placing mineral wool between the flanges of the mono-symmetric I section makes very little difference to the Ψ-values and f_{Rsi}, and, hence, the thermal performance.
- The temperature factor is well above the minimum level of 0.75 recommended for dwellings [19].
- The spacing of the brackets is an important factor in the results. For a bracket spacing of 400 mm, the detail satisfies the Ψ-value for intermediate floors between dwellings for *Accredited Construction Details* [13]. However, bracket spacing will usually be dictated by structural requirements.

The following recommendations are made as a result of the analyses:

- No insulation is required for thermal performance on the external face of the mono-symmetric I section (but it may be needed for fire resistance).
- No insulation is needed to the underside of the mono-symmetric I section for thermal performance.
- For bracket spacings less than 600 mm, thermal spacers between the bracket and the mono-symmetric I section may need to be considered.

Most manufacturers of brickwork support systems offer some form of thermal spacer which can be inserted between the bracket and the steel structure to which it is connected. The thermal spacer is typically HDPE (high density polyethylene) in the order of 3 mm thick. HDPE has a thermal conductivity λ of 0.45 to 0.52 W/mK.

3.3.2 Brickwork support fixed to downstand edge beam

The thermal performance of a brickwork support system fixed to a 250 mm deep steel edge beam has been assessed using thermal modelling.

In this case, the steel brickwork support angles are connected via brackets to steel plates welded between the flanges of the beam, in which the 100 mm wide plates are placed at the same spacing as the brackets. This type of downstand edge beam is commonly used in composite construction, see Figure 3.21.

The model used to determine the thermal performance of this detail is shown in Figure 3.22.

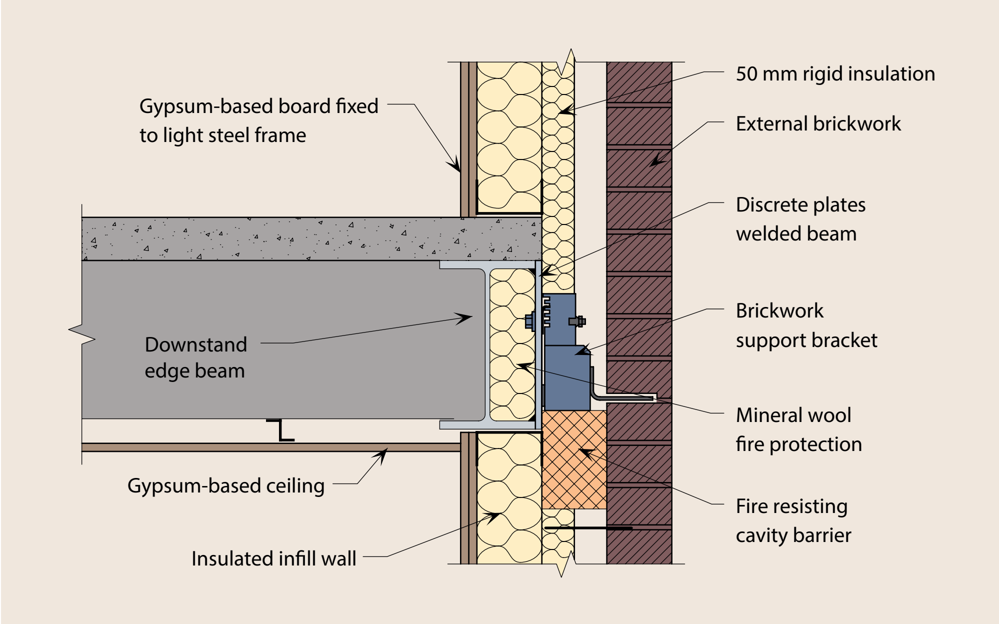


Figure 3.21 Section through an external wall with a downstand edge beam

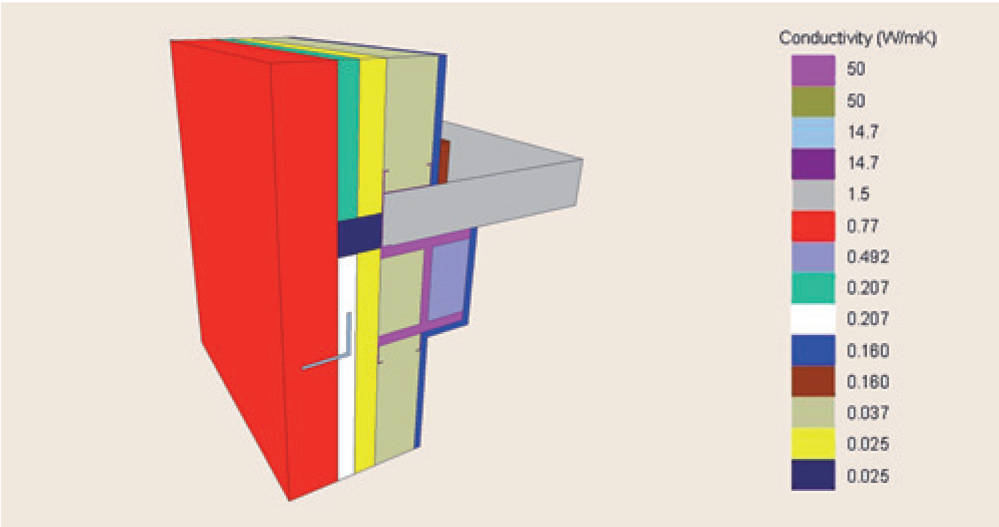


Figure 3.22 Thermal model for brickwork supports fixed to downstand edge beam

The temperature distributions are shown in Figure 3.23 and the results are presented in Table 3.6. Thermal modelling was carried out for brackets at 600 mm and 900 mm centres.

Table 3.6 Thermal modelling results for brickwork support fixed to downstand edge beam

Description of model	Linear thermal transmittance Ψ W/mK	Minimum internal surface temperature	Temperature factor, f_{Rsi}
Brick supports at 600 mm centres with mineral wool between flanges	0.341	17.7 °C	0.885
Brick supports at 900 mm centres with mineral wool between flanges	0.262	18.0°C	0.901
Brick supports at 600 mm centres without mineral wool between flanges	0.348	17.6 °C	0.884

Note: This modelling was carried out with an internal air temperature of 20°C and an external temperature of 0°C.

From the results, it can be seen that:

- Placing mineral wool between the flanges of the downstand beam makes very little difference to the Ψ-values and f_{Rsi}, and, hence, the thermal performance.
- The thermal transmittance is higher than the Accredited Construction Details default Ψ-value for intermediate floors between dwellings (0.14 W/mK). This implies that the default value is unconservative for this form of junction detail.
- The temperature factor is above the minimum level of 0.75 recommended for dwellings and 0.5 recommended for offices [19].
- The bracket spacing is a significant factor for thermal transmittance but not for the temperature factor. Increasing the spacing of the brackets by 50% decreases the linear thermal transmittance by 23%.

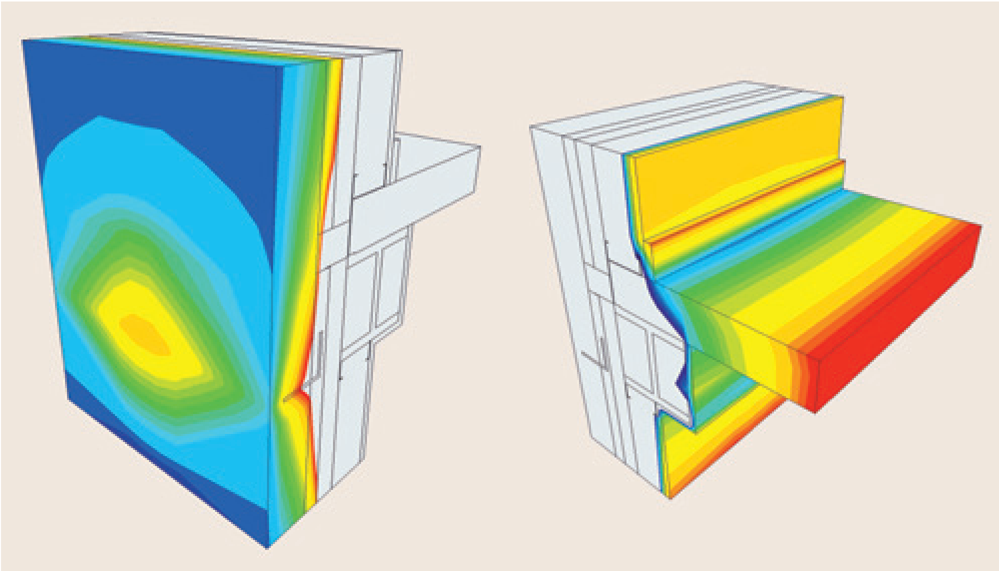


Figure 3.23 Temperature distributions for brickwork supports fixed to a downstand edge beam (with mineral wool between the flanges) a. (Left) External b. (Right) Internal

3.3.3 Brickwork support fixed to channel section edge beam

The thermal performance of a brickwork support system fixed to a 300 mm deep channel section edge beam has been assessed using thermal modelling. Figure 3.24

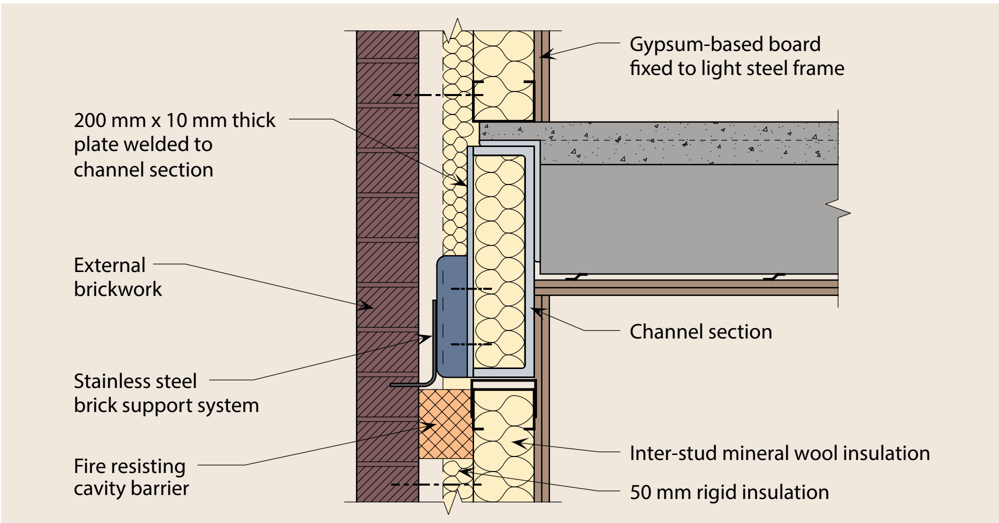


Figure 3.24 Section through an external wall with a channel section edge beam

shows a typical detail of this type of edge beam. Steel plates 100 mm wide were welded between the flanges to provide support to the stainless steel brackets.

The linear thermal transmittance (Ψ-value), the internal surface temperature and the temperature factor (f_{Rsi}), were calculated using thermal modelling. The model is shown in Figure 3.25. Fixings to the brickwork support angles are located at 600 mm or 900 mm spacing along the channel section edge beam.

The temperature distributions are shown in Figure 3.26 and the results are presented in Table 3.7.

Table 3.7 Results of thermal analyses of channel section supporting proprietary floor

Description of model	Linear thermal transmittance Ψ W/mK	Minimum internal surface temperature	Temperature factor, f_{Rsi}
Brick supports at 900 mm centres with mineral wool between flanges	0.273	17.5°C	0.876
Brick supports at 600 mm centres with mineral wool between flanges	0.338	17.2°C	0.860
Brick supports at 600 mm centres without mineral wool between flanges	0.343	17.1°C	0.859

Note: This modelling was carried out with an internal air temperature of 20°C and an external temperature of 0°C.

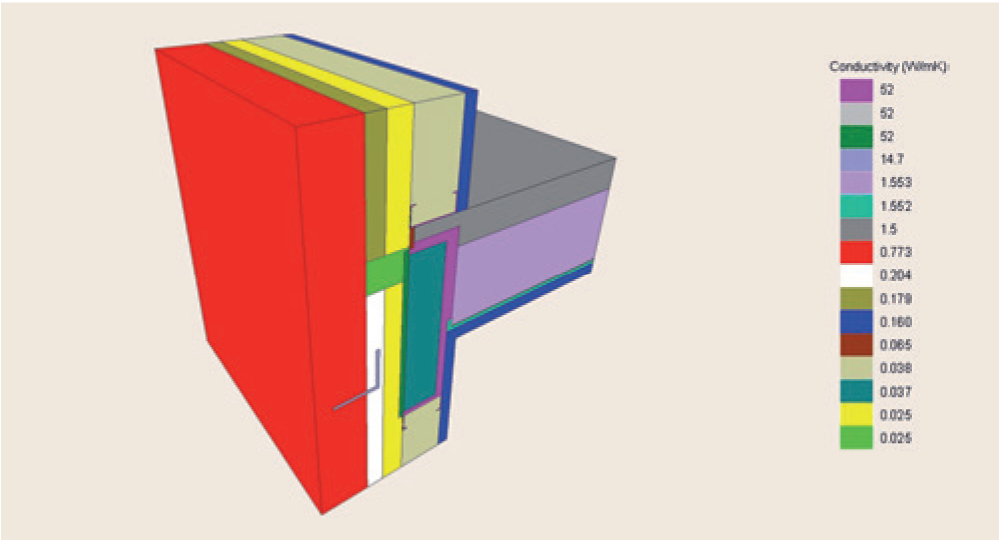


Figure 3.25 Thermal model for brickwork supports fixed to channel section edge beam (with mineral wool on external web)

From the results it can be seen that:

- Placing mineral wool between the flanges of the channel section makes very little difference to the Ψ-values and f_{Rsi}, and, hence, the thermal performance.
- The thermal transmittance is higher than the Accredited Construction Details default Ψ-value for intermediate floors between dwellings (0.14 W/mK). This implies that the default value is unconservative for this form of junction detail.
- The temperature factor is significantly above the minimum level of 0.75 recommended for dwellings and 0.5 recommended for offices [19].
- The bracket spacing is a significant factor for the thermal transmittance but not for the temperature factor. Increasing the spacing of the brick support angle fixings by 50% decreases the linear thermal bridging by 19%.

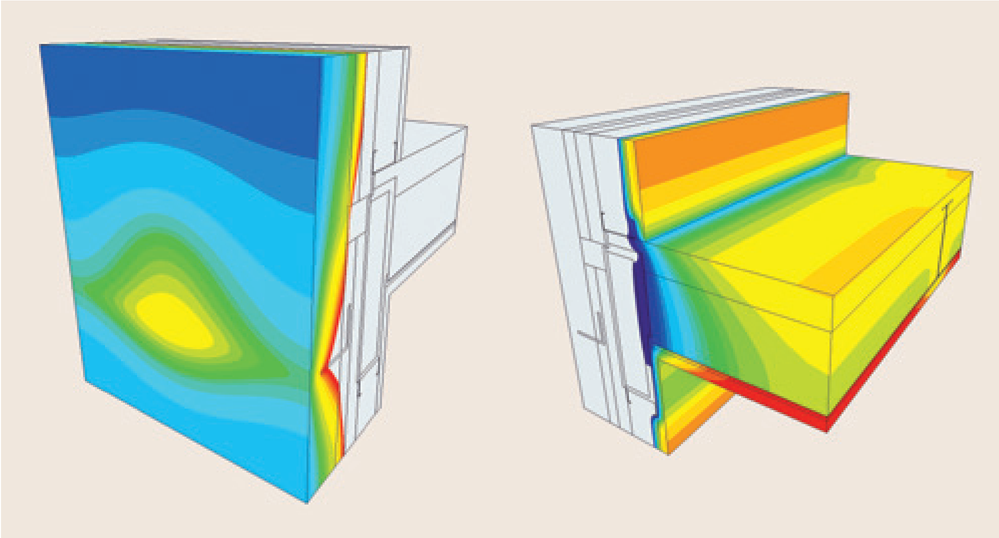


Figure 3.26 Temperature distributions for brickwork supports fixed to channel section edge beam (with mineral wool on external web) a. (Left) External b. (Right) Internal

3.3.4 Brickwork support fixed to hollow section edge beam

A rectangular Structural Hollow Section (SHS) slim floor beam supporting a deep composite slab is shown in Figure 3.27. In this case, the stainless steel angles used

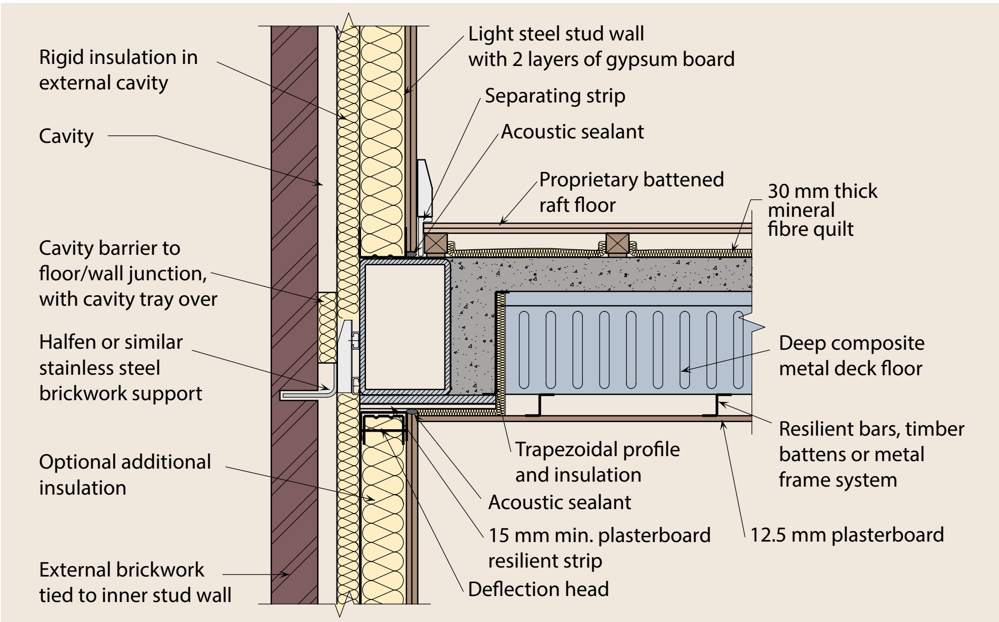


Figure 3.27 Brickwork support fixed to hollow section edge beam

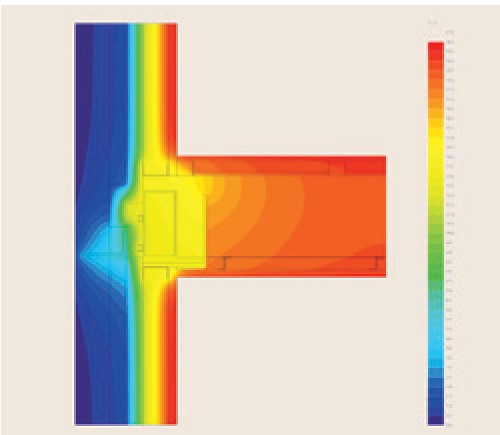


Figure 3.28 Temperature distributions for hollow section edge beam junction.

to support the brickwork are connected to the face of the hollow section via adjustable connection brackets.

Table 3.8 gives results of thermal modelling analysis that has been carried out for the junction. The junction between the façade and edge beam was modelled for two thicknesses of external closed cell insulation placed in the cavity between the edge beam and the brickwork. The linear thermal bridge due to the combined effect of the stainless steel brackets at 600 mm spacing and the edge beam is determined together with the same case without the brackets, which would apply if the brickwork is supported from the ground.

Table 3.8 Results of thermal analyses of hollow section edge beams supporting brickwork (stainless steel brackets at 600 mm spacing)

Description of model	PUR insulation thickness (mm)	f_{RSi}	Linear thermal transmittance Ψ (W/mK)
Hollow section edge beam with brackets to support brickwork	50	0.830	0.383
	100	0.857	0.343
Hollow section edge beam without brackets to support brickwork	50	0.940	0.042
	100	0.966	0.030

The results show that 90% of the linear thermal transmittance at this junction is due to the brickwork support brackets.

3.4 Steel beams supporting other cladding systems

3.4.1 Steel edge beams with insulated render cladding

The junction detail between a steel edge beam and a light steel frame infill wall with insulated render cladding is shown in Figure 3.29. Thermal modelling was carried out for a detail with a steel edge beam of 300 mm depth and 60 to 120 mm of insulation applied externally and 12.5 mm sheathing board attached to the infill wall with mineral wool placed between the C sections.

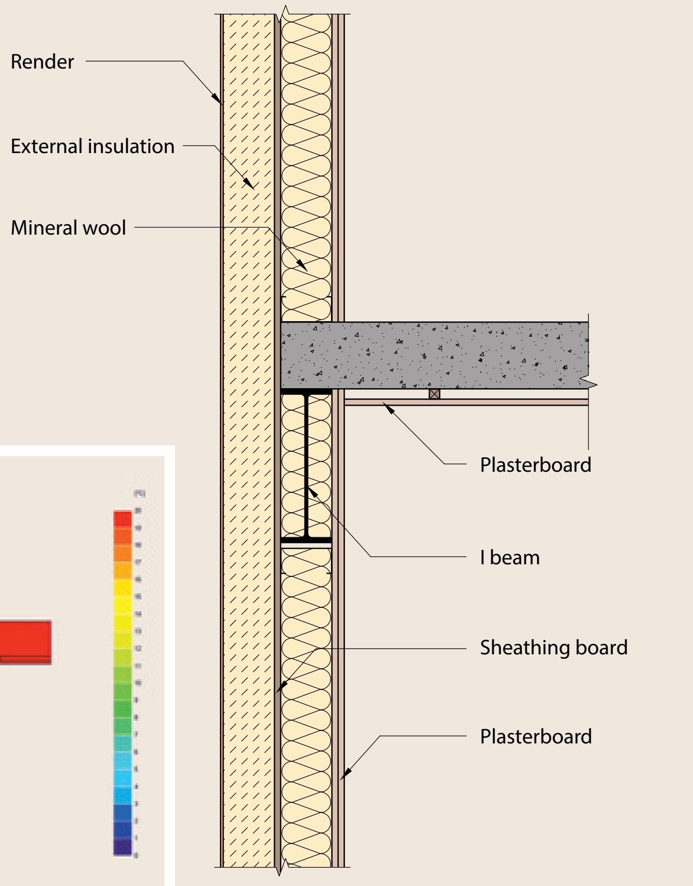


Figure 3.29 Light steel infill wall with insulated render cladding in a steel framed building (non-cavity system with sheathing board)

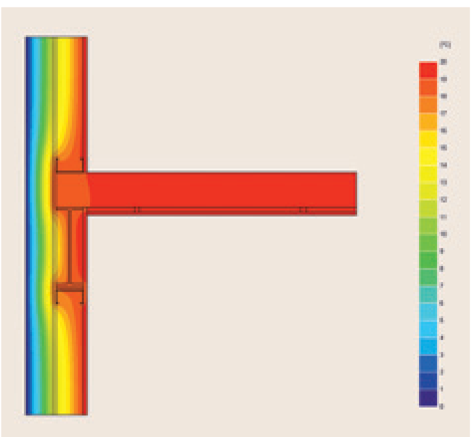


Figure 3.30 LThermal profile at an edge beam supporting a light steel infill wall with insulated render cladding

The insulated render may be directly fixed to the sheathing board or a cavity may be used behind the insulation and the sheathing board. The case without a cavity results in higher thermal bridging and is the detail shown in Figure 3.29. Table 3.9 presents the results of the thermal modelling for the 'direct-fix' case with EPS insulation and Table 3.10 gives the comparable results with PUR insulation externally.

Table 3.9 Linear thermal bridging at edge beam for the direct fix (non cavity) case with EPS

Thickness of EPS placed outside the C sections and beam (mm)	f_{RSi}	Linear thermal transmittance Ψ (W/mK)
60	0.913	0.094
80	0.927	0.066
100	0.936	0.049
120	0.944	0.037

Table 3.10 Linear thermal bridging at edge beam for the direct fix (non cavity) case with PUR insulation

Thickness of PUR placed outside the C sections and beam (mm)	f_{RSi}	Linear thermal transmittance Ψ (W/mK)
60	0.937	0.068
80	0.950	0.046
100	0.964	0.033
120	0.971	0.026

The thermal modelling results show that:

- The linear thermal transmittance for this junction detail is significantly reduced compared to junction details which include brickwork support brackets.
- The temperature factors are above the minimum level of 0.90 recommended for swimming pools, which is the most onerous building type.
- The linear thermal transmittance values are lower than the *Accredited Construction Details* approved Ψ-value of 0.07 W/mK for intermediate floors between dwellings.

3.4.2 Slim floor beam supporting insulated render or rain screen cladding

A slim floor beam supporting a tiled façade system is shown in Figure 3.31. Thermal modelling of the detail has been carried out for three thicknesses of insulation applied

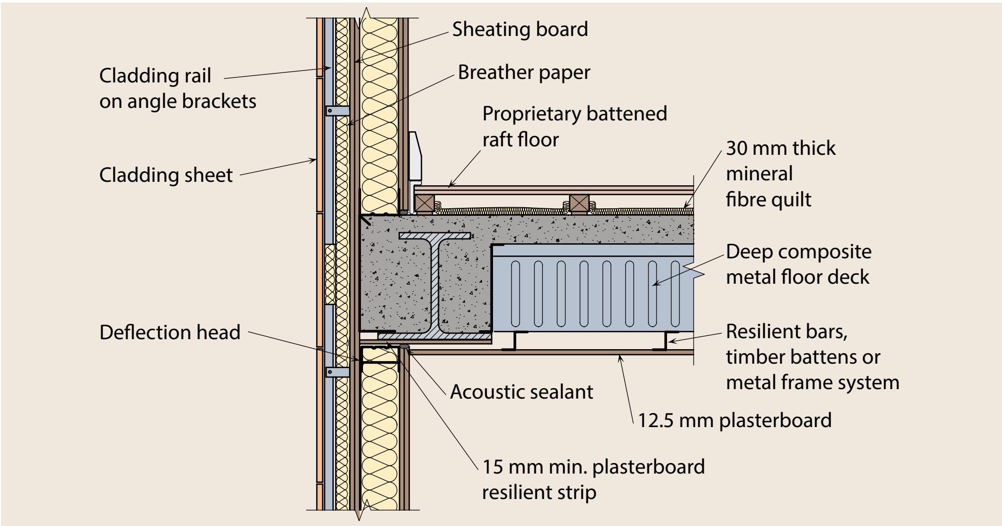


Figure 3.31 Slim floor beam supporting insulated render or rain screen cladding

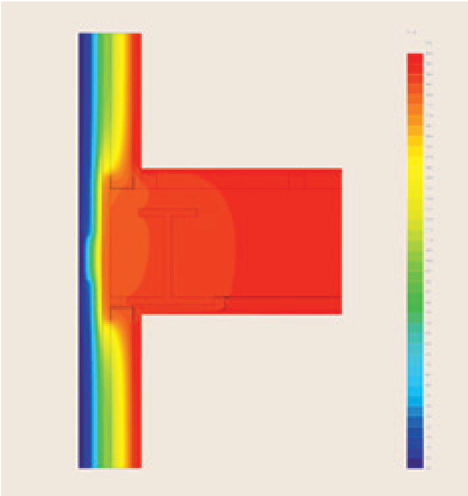


Figure 3.32 Thermal bridge at the façade/slim floor beam junction

externally to the slab edge. Figure 3.32 shows the temperature distribution for this detail. The linear thermal bridge results at the junction between the façade and floor for both carbon steel and stainless steel attachments to the C sections in the infill walls are presented in Table 3.11.

Table 3.11 Results of linear thermal transmission at slim floor edge beam supporting a lightweight facade with various connection details

Fixings to facade	PUR insulation thickness (mm)	f_{RSi}	Linear thermal bridging Ψ (W/mK)
Carbon steel bracket	50	0.929	0.044
Carbon steel bracket with plastic gasket		0.931	0.043
Stainless steel bracket		0.932	0.044
Stainless steel bracket with plastic gasket		0.932	0.043
Carbon steel bracket	70	0.941	0.029
Carbon steel bracket with plastic gasket		0.942	0.028
Stainless steel bracket		0.944	0.030
Stainless steel bracket with plastic gasket		0.944	0.030
Carbon steel bracket	100	0.953	0.015
Carbon steel bracket with plastic gasket		0.954	0.014
Stainless steel bracket		0.956	0.016
Stainless steel bracket with plastic gasket		0.956	0.016

Note: PUR insulation is external to the wall and mineral wool is placed between the C sections.

The thermal modelling results show that the use of plastic gaskets and stainless steel brackets make a small improvement to the thermal transmission performance. In all cases the temperature factor is greater than the minimum level of 0.90 recommended for swimming pools, which is the most onerous building type. In addition, the linear thermal transmittance values are lower than the *Accredited Construction Details* approved Ψ-value of 0.07 W/mK for intermediate floors between dwellings.

3.4.3 Hollow section edge beam supporting curtain walling

A typical curtain walling system supported by a rectangular hollow section slim floor beam is shown in Figure 3.33. Thermal modelling of the detail has been carried out for two different arrangements of insulation. The first case has 70 mm of PUR insulation applied externally plus 50 mm of PUR insulation in the cavity. The second case has 120 mm of PUR insulation applied externally and no insulation within the cavity.

The thermal model temperature distribution is shown in Figure 3.34. The linear thermal bridge results at the junction between façade and hollow section edge beam

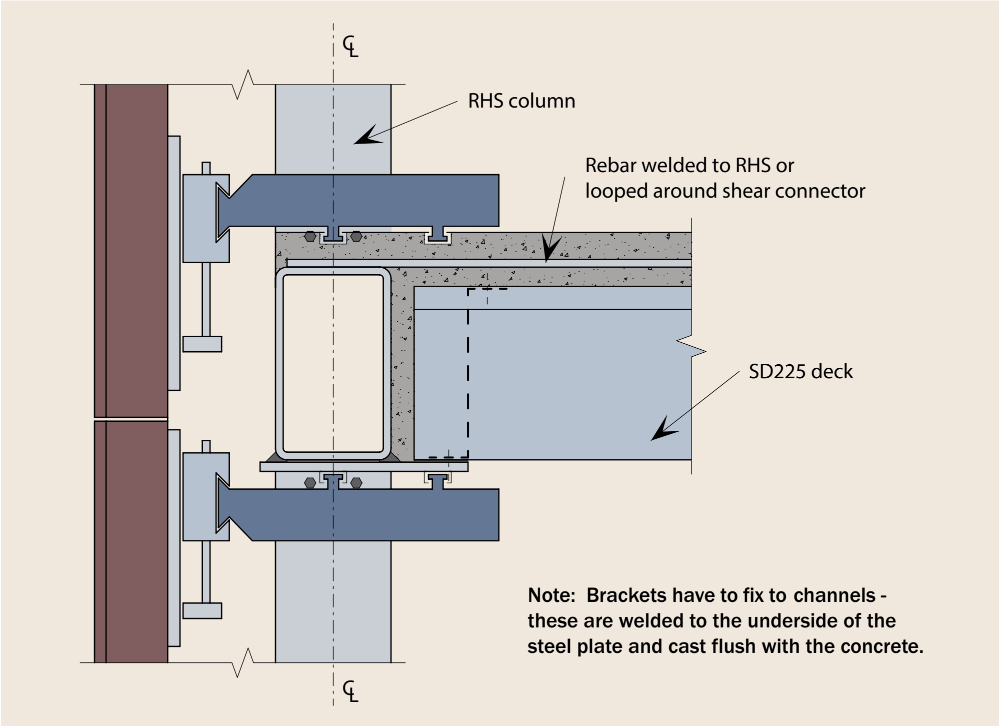


Figure 3.33
Hollow section edge beam supporting curtain walling

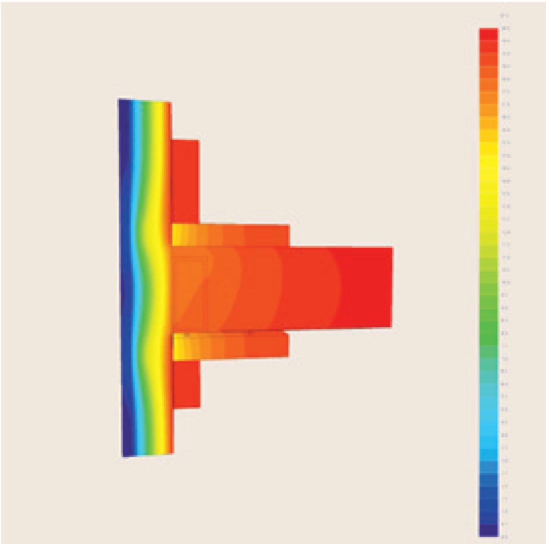


Figure 3.34
Thermal bridges at façade and edge beam junction

for both carbon steel and stainless steel connectors are provided in Table 3.12. The linear thermal bridge results for the connectors at 600 mm spacing, and without connectors, are presented. The results without connectors take account of the thermal bridging due to the edge beam only.

Table 3.12
Results of linear thermal transmission at edge beam for connections to curtain walling

Connection to Façade	PUR insulation thickness	f_{RSi}	Linear thermal ransmittance (W/mK)
Carbon steel connector	70 mm externally plus 50 mm in cavity	0.662	1.141
	120 mm externally	0.746	0.877
Stainless steel connector	70 mm externally plus 50 mm in cavity	0.626	0.716
	120 mm externally	0.693	0.604
No connector	70 mm externally plus 50 mm in cavity	0.961	0.005
	120 mm externally	0.976	0.001

Note: Connectors modelled at 600 mm spacing.

The results show that the thermal bridging due to the edge beam alone is insignificant compared to the thermal bridging due to the steel connectors.

3.5 Columns in external walls

The details considered in this section represent typical cases where thermal bridging occurs due to the presence of steel columns that are partially located within the building envelope. The cases considered are:

- Open section column contained within a wall (with insulated render cladding).
- Open section column contained within a wall (with brickwork cladding).
- Hollow section column contained within a wall (with insulated render cladding).
- Hollow section column contained within a wall (with brickwork cladding).

3.5.1 Open section column contained within a wall with insulated render and brickwork cladding

A steel open section column contained within a façade wall with insulated render cladding is shown in Figure 3.35. The results of thermal modelling of the detail are presented in Table 3.13. Linear thermal bridge results for two HE column sizes, two cladding systems and two thicknesses of external insulation are presented. In all cases PUR insulation is used externally and mineral wool is placed between the C sections. The differences between the results for insulated render and brickwork cladding are relatively small. The temperature distribution for the detail with insulated render is shown in Figure 3.36.

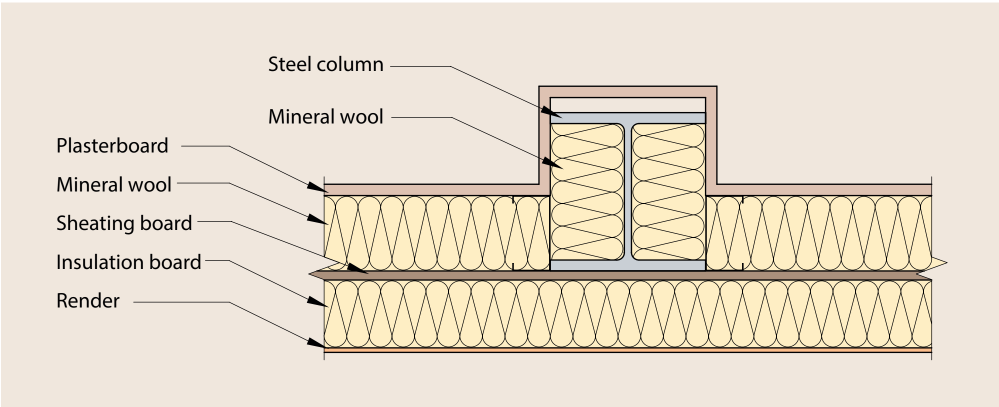


Figure 3.35 Open section steel column within an external wall with insulated render cladding

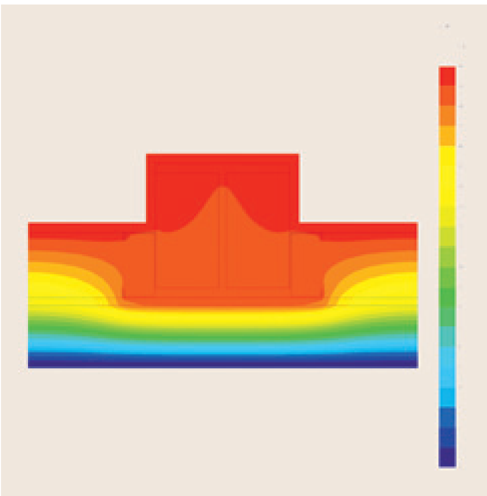


Figure 3.36 Temperature distribution for open section column with insulated render cladding

The larger HE 200 column section results in a larger linear thermal transmittance value and the temperature factor is reduced compared to the HE 150 column. However, even for the larger column the temperature factors are greater than the minimum level of 0.90 recommended for swimming pools and the linear thermal transmittance values are lower than the *Accredited Construction Details* approved Ψ-value of 0.07 W/mK for intermediate floors between dwellings.

Table 3.13 TResults of linear thermal transmission for HE columns within an external wall with insulated render and brickwork cladding

HE column	Cladding	PUR insulation thickness (mm)	f_{RSi}	Linear thermal transmittance (W/mK)
HE 150	Insulated render	100	0.965	0.018
		50	0.941	0.045
HE 200	Insulated render	100	0.968	0.024
		50	0.949	0.059
HE 150	Brickwork	100	0.968	0.016
		50	0.947	0.038
HE 200	Brickwork	100	0.972	0.020
		50	0.954	0.049

Note: All cases PUR insulation is used externally and mineral wool is placed between the C sections.

3.5.2 Hollow section column contained within a wall with insulated render and brickwork cladding

A square Structural Hollow Section (SHS) contained within a façade wall with insulated render cladding is shown in Figure 3.37. The results of thermal modelling of the detail are presented in Table 3.14.

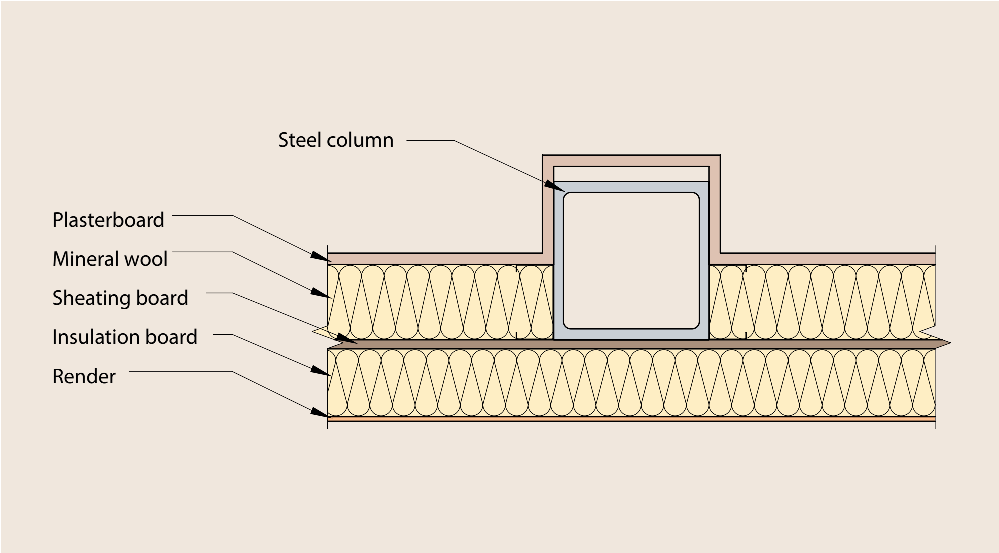


Figure 3.37 Hollow section column within an external wall with insulated render cladding

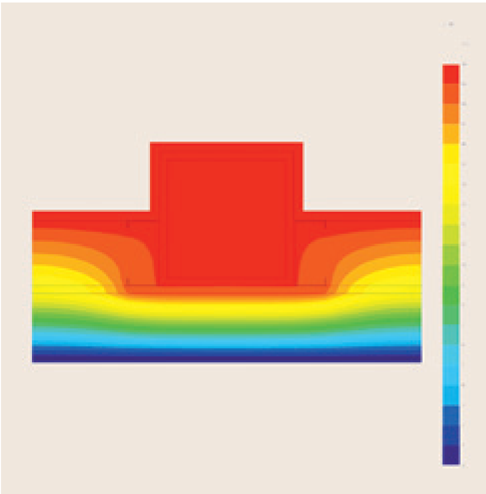


Figure 3.38 Temperature distribution for hollow section column with insulated render cladding

Linear thermal bridge results for two SHS column sizes, with two cladding systems and two thicknesses of external insulation are presented. In all cases PUR insulation is used externally and mineral wool is placed between the C sections. The differences between the results for insulated render and brickwork cladding are relatively small. The temperature distribution for the detail with insulated render is shown in Figure 3.38.

Table 3.14 Results of linear thermal transmission for SHS columns within an external wall with insulated render and brickwork cladding

SHS column	Cladding	PUR insulation thickness (mm)	f_{RSi}	Linear thermal transmittance (W/mK)
150 x150 SHS	Insulated render	100	0.957	0.014
		50	0.928	0.036
200 x 200 SHS	Insulated render	100	0.969	0.025
		50	0.946	0.065
150 x 150 SHS	Brickwork	100	0.959	0.016
		50	0.932	0.037
200 x 200 SHS	Brickwork	100	0.971	0.026
		50	0.950	0.065

Note: All cases PUR insulation is used externally and mineral wool is placed between the C sections.

As for the case with open sections, the larger column section results in a larger linear thermal transmittance value and the temperature factor is reduced. However, even for the larger column the temperature factors are greater than the minimum level of 0.90 recommended for swimming pools and the linear thermal transmittance values are lower than the Accredited Construction Details approved Ψ-value of 0.07 W/mK for intermediate floors between dwellings.


RIVERSIDE

RELATIVE IMPORTANCE OF THERMAL BRIDGING ON HEAT LOSS FROM AN APARTMENT

4.1 Introduction

It was explained in Section 1.5.1 that the heat transfer coefficient associated with non-repeating thermal bridges (H_{TB}) is calculated (in SAP) as:

$$H_{TB} = \Sigma (L \times \Psi)$$

Alternatively, HTB can also be expressed as:

$$H_{TB} = y.\Sigma A_{exp}$$

Where:

A_{exp} is the total exposed fabric area.

y is the term used to describe the sum of all non-repeating thermal bridges divided by the total heat loss area of the building (also known as y-value).

The units of the y-value are W/m^{2}K, i.e. the same as for U-values. The y-value therefore quantifies the aggregate thermal bridging heat loss for the building and can be used to compare the impact of thermal bridging relative to heat loss through the planar elements in the building envelope.

This section illustrates the relative importance of thermal bridging in a multi-storey steel framed apartment building. Two generic cladding systems are considered:

1. Insulated render bonded to rigid insulation and with an external sheathing board attached to the infill walls.
2. Brickwork supported by stainless steel angles and brackets connected to the perimeter steel beams at 600 mm spacing. A suitable sheathing board may be required for fire resistance and air-tightness purposes.

In this simplified example an apartment is taken as having a single aspect and its façade width is equal to the distance between the perimeter columns and it is one storey high. It is assumed that the building is sufficiently large that for a middle apartment on an intermediate floor, the roof, ground floor and corner effects can be neglected.

The steel structure consists of 305 mm deep UB edge beams supporting a 140 mm deep composite slab and the beams span between 203 mm UC columns at the periphery of the building. The infill walls use 100 mm × 1.5 mm thick C sections placed at 600 mm centres that span over a height of 3.15 m between the perimeter beams. Mineral wool is placed between the C sections and insulation boards are attached to the outside of the infill wall. For multi-storey buildings, sheathing boards are often used, in which case, the insulation is fixed to the sheathing boards. A balcony which is supported from the structure is included.

The following geometric data is used to define the façade area and its boundaries (see Figure 4.1):

- Floor-to-floor height is 3.3 m.
- Column spacing is 6.0 m.
- Window is 1.5 m square.
- Patio door is 2.1 m wide by 2.4 m high.
- Balcony is 2.4 m wide with two structural connections of the balcony to the internal steel structure.

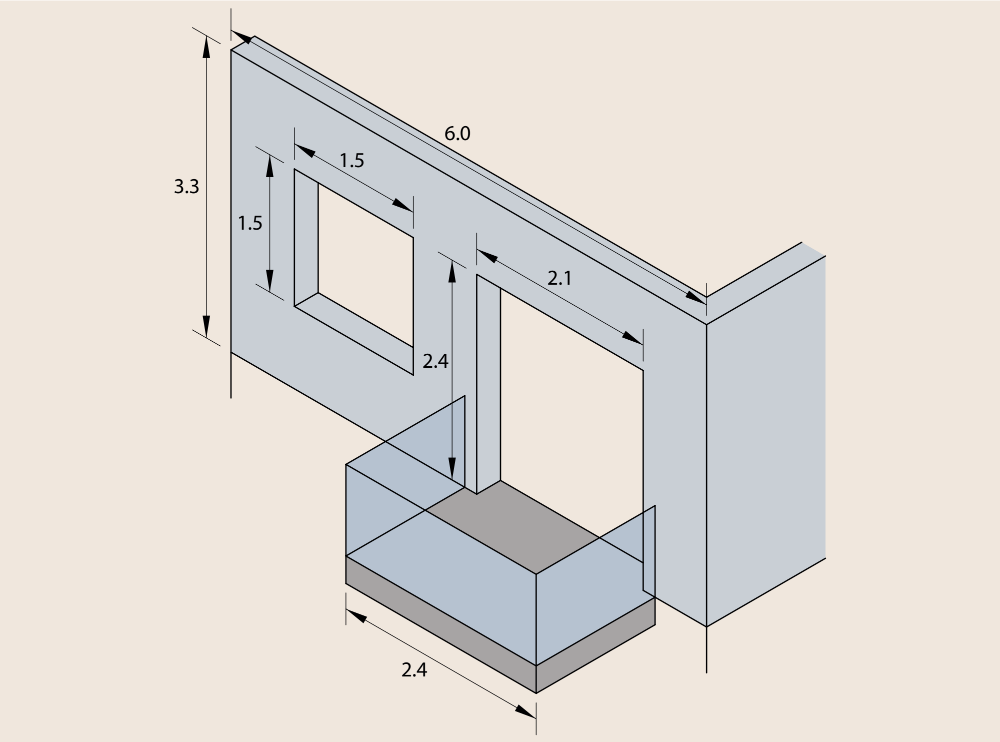


Figure 4.1 Example façade arrangement

The U-values of the elements of construction are:

- Wall build-up U-value = 0.2 W/m²K
- Glazing system U-value = 1.4 W/m²K (window and patio doors)

The U-value for the wall is calculated taking account of the repeating effects of the C sections within the infill wall.

Calculations are made of the additional linear heat loss through the:

- Edge beams.
- Columns embedded in the walls.

- Sill and jamb around the windows and patio door.
- Point thermal bridge due to the brickwork supports (expressed as a linear thermal bridge for brackets at 600 mm spacing).
- Minimised point thermal bridge due to the thermally broken balcony connections using *Schöck Isokorb* (two connections for each balcony).

The overall heat loss is calculated assuming the internal façade area is 90% of the external area and that the thermal bridging effect at the perimeter beams and columns is divided equally between adjacent apartments, when calculating the additional thermal bridging heat loss per apartment.

The heat loss through the apartment façade without the thermal bridging losses is therefore:

- Heat loss through the wall

$$= [90\% \times (3.3 \times 6.0) - (1.5 \times 1.5 + 2.1 \times 2.4)] \times 0.2 = 2.11 \text{ W/K}$$

- Heat loss through glazed elements

$$= (1.5 \times 1.5 + 2.1 \times 2.4) \times 1.4 \qquad = 10.21 \text{ W/K}$$

- Total heat loss through apartment façade (excluding thermal bridges)

$$= 2.11 + 10.21 \qquad = 12.32 \text{ W/K}$$

This is equivalent to a heat loss of 0.69 W/m^{2}K through the net apartment façade area.

4.2 Lightweight insulated render cladding

The target U-value of the façade (0.2 W/m^{2}K) is achieved by using 100 mm of expanded polystyrene (EPS) connected to the sheathing board with 100 mm of mineral wool insulation placed between the C sections that form the infill wall.

The linear and point thermal transmittance values used for this example are given in Table 4.1, which are based on data provided in this publication and SCI publication P411 [2]. The thermal transmittance values are approximate because the precise details of the construction are not defined but the results demonstrate the principle of determining the y-value for this type of building.

Table 4.1 Effect of the thermal bridging for insulated render cladding

Element	Thermal transmittance	Length of element per apartment	Heat loss W/K
Edge beam supporting infill wall	0.05 W/mK	6.0 m	0.30
Column within the infill wall	0.04 W/mK	3.3 m	0.13
Window jamb, lintel and sill	0.05 W/mK	6.0 m	0.30
Patio door jamb, lintel and sill	0.05 W/mK	9.0 m	0.45
		$\Sigma =$	1.18
Balcony attachments with *Schöck Isokorb* considered as a minimised point thermal bridge	0.077 W/K	2 No. connections	0.15
		$\Sigma = H_{TB}$	1.33

The heat loss due to thermal bridging (HTB) is divided by the net façade area of the apartment to give an equivalent y-value of:

$$1.33 / (0.9 \times 6.0 \times 3.3) = 0.075 \text{ W/m}^2\text{K}.$$

The heat loss due to thermal bridging (H_{TB} = 1.33 W/K) is 11% of the heat loss through apartment façade (12.32 W/K). Therefore, thermal bridging adds 11% to the heat loss which is calculated based on U-values of the planar façade elements, i.e. the insulated render infill wall and the window and patio doors. The balcony attachments, employing the *Schöck Isokorb* thermal break, contribute only 1.1% to the total heat loss.

In comparison, if a direct connection had been used for the balcony attachments without any thermal break, the total heat loss due to thermal bridging (H_{TB}) would be 2.31 W/K (a 74% increase) and the equivalent y-value would be 0.130 W/m^{2}K. For this case the thermal transmittance for each balcony attachment is taken as 0.564 W/mK (see Table 3.4).

4.3 Brickwork cladding supported at every floor level

The target U-value of the façade (0.2 W/m^{2}K) is achieved by using 80 mm of closed cell insulation board (PUR) connected to an optional sheathing board with 100 mm of mineral wool insulation placed between the C sections. The brickwork is supported at each floor by stainless steel angles connected to support brackets that are connected to side plates welded to the edge beams every 600 mm. A 50 mm cavity is provided between the foil backed insulation board and the brickwork. The brickwork is laterally supported by stainless steel wall ties at every fifth course, located in vertical runners that are screw fixed through the insulation to each C section, with additional ties and runners around windows and patio doors.

The linear and point thermal transmittance values used for this example are given in Table 4.2, which are based on data provided in this publication and SCI publication P411 [2]. The thermal transmittance values are approximate because the precise details of the construction are not defined but the results demonstrate the principle of calculating the y-value.

Linear element	Thermal transmittance	Length of element per apartment	Heat Loss W/K
Edge beam supporting infill wall and connected to stainless steel brackets	0.23	6.0 m	1.38
Column within the infill wall	0.03	3.3 m	0.10
Window jamb, lintel and sill	0.05	6.0 m	0.30
Patio door jamb, lintel and sill	0.05	9.0 m	0.45
		Σ =	2.23
Balcony attachments with Schöck Isokorb considered as a minimised point thermal bridge	0.077 W/K	2 No. connections	0.15
		$\Sigma = H_{TB}$	2.38

Table 4.2 Effect of the thermal bridging for brickwork cladding

The heat loss due to thermal bridging (H_{TB}) is divided by the net façade area of the apartment to give an equivalent y-value of:

$$2.38 / (0.9 \times 6.0 \times 3.3) = 0.134 \text{ W/m}^2\text{K}.$$

The heat loss due to thermal bridging ($H_{TB} = 2.38$ W/K) is 19% of the heat loss through the apartment façade (12.32 W/K). Therefore, thermal bridging adds 19% to the heat loss which is calculated based on U-values of the planar façade elements. The balcony attachments, employing the *Schöck Isokorb* thermal break, contribute only 1.0% to the total heat loss.

In comparison, if a direct connection had been used for the balcony attachments without any thermal break, the total heat loss due to thermal bridging (H_{TB}) would be 3.36 W/K (a 41% increase) and the equivalent y-value would be 0.189 W/m^{2}K. For this case the thermal transmittance for each balcony attachment is taken as 0.564 W/mK (see Table 3.4).

It should be noted, the edge beam with brickwork support detail contributes significantly (58%) to the total HTB value. For ground supported brickwork, which can be used up to three storeys height, the heat loss will be similar to that of the insulated render cladding case (see Section 4.2) because the brickwork support system would not be required.

STRUCTURAL DESIGN OF CONNECTIONS WITH THERMAL BREAKS

5.1 Introduction

Structural steelwork connections should be designed in accordance with the following SCI guidance:

- Simple Connections
  - SCI-P212: Joints in steel construction. Simple connections (BS 5950-1) [22]
  - SCI-P358: Joints in steel construction. Simple joints to Eurocode 3 [23]
- Moment Connections
  - SCI-P207: Joints in steel construction. Moment connections (BS 5950-1) [24]
  - SCI-P398: Joints in steel construction. Moment joints to Eurocode 3 [25]

However, where connections incorporate thermal breaks, additional design checks may be required to ensure that the structural performance of the connection is acceptable.

The following sections explain the structural design considerations that are required for different types of thermal break products.

5.2 Proprietary structural thermal break products

For structural thermal break products, such as the Schöck Isokorb, the product manufacturer should provide data relating to the structural performance of the product. Generally, it is not possible for the structural engineer to calculate the resistance of connections incorporating proprietary structural thermal breaks without significant input from the product supplier.

5.2.1 Structural resistance

The Schöck Isokorb product is composed of several elements which can be configured in various combinations to suit the structural requirements of each connection. The components of the *Schöck Isokorb* product are shown in Figure 5.1; the ZST modules provide tension resistance and the QST modules provide compression and shear resistance. A special ZQST module is also available which combines the technical features of the ZST and QST modules. Figure 5.2 shows the transfer of loads in the Isokorb product.

Structural performance data for the *Schöck Isokorb KST* is presented in Table 5.1. Further information on the technical performance of Isokorb and the structural design requirements are available from *Schöck* [26].

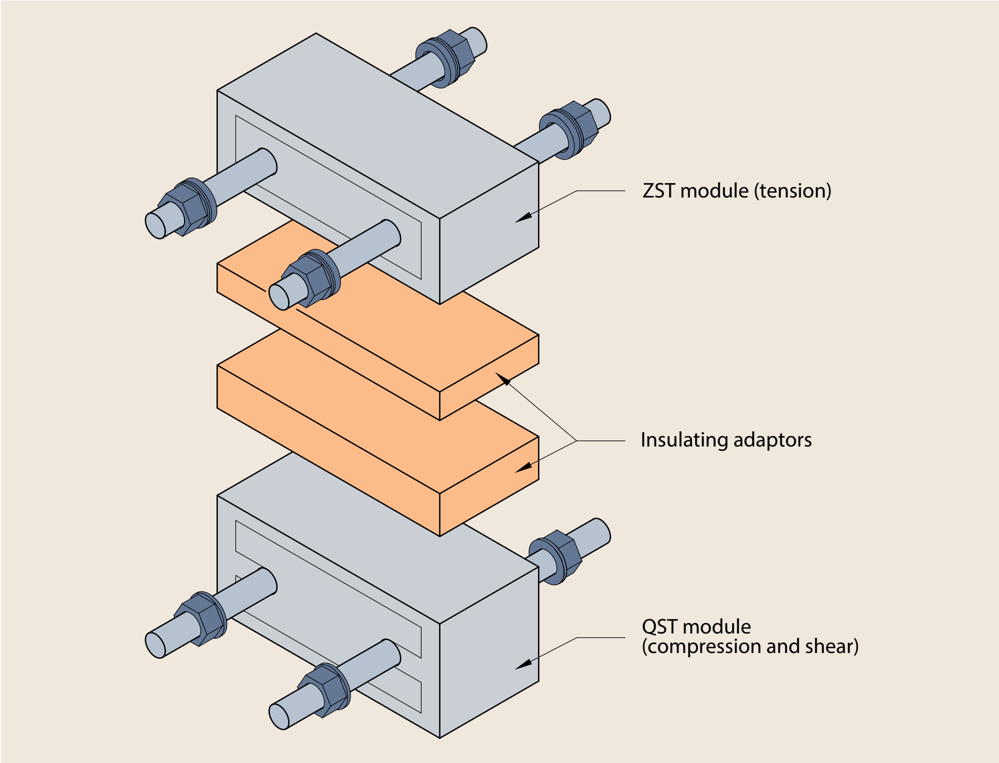


Figure 5.1 Components of the Schöck Isokorb KST thermal break

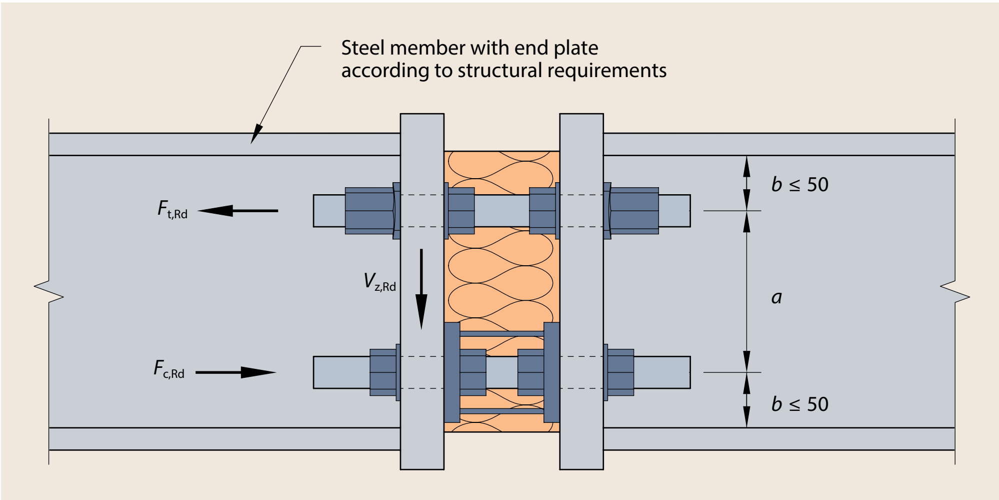


Figure 5.2 Side elevation of Schöck Isokorb KST thermal break

Table 5.1 Structural performance data for the Schöck Isokorb KST

Structural resistance	Complete unit		Compression and shear module		Tension module	
	KST 16	KST 22	QST 16	QST 22	ZST 16	ZST 22
Vertical shear resistance, $V_{z,Rd}$	30 kN	36 kN	30 kN	36 kN	0 kN	0 kN
Tensile resistance of bolt row, $F_{t,Rd}$	116.8 kN	225.4 kN	0 kN	0 kN	116.8 kN	225.4 kN
Compression resistance of bolt row, $F_{c,Rd}$	116.8 kN	225.4 kN	116.8 kN	225.4 kN	0 kN	0 kN
Moment resistance of complete KST unit, $M_{y,Rd}$	$a \times F_{t,Rd}$		N/A	N/A	N/A	N/A

Note: Dimension a is defined in Figure 5.2

5.2.2 Thermal expansion

Differential temperatures between internal and external steel will lead to differential movement due to thermal expansion and contraction. Provisions to allow for differential movements should be incorporated into thermal break connection details or the external steelwork. This may include the use of slotted holes.

The *Isokorb* connection incorporates an allowance for thermal movement which is designed to be suitable for construction lengths of 6 m between connections without the need for additional expansion joints. See Reference 26 for further information.

5.3 Thermal break pads

For connections with thermal break pads between the steel elements additional design checks should be carried out. These additional checks are explained in the following sections. For the structural engineer to be able to carry out these design checks, the thermal break manufacturer will need to supply design values of the material properties for the thermal break material.

5.3.1 Compression resistance

Nominally pinned connections

Nominally pinned connections (also referred to as simple connections) are designed to only transmit shear forces and tying forces, as shown in Figure 5.3. Therefore, the thermal break pad is not required to resist compression forces and so for nominally pinned connections there is generally no requirement to check the compression resistance of the thermal break pad within the connection.

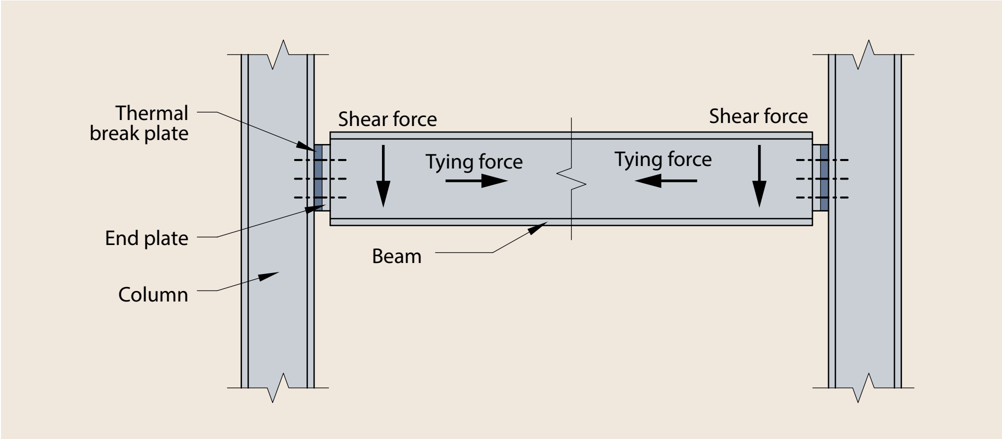


Figure 5.3 Nominally pinned connection with Farrat thermal break pad

However, there may be situations where beams are also subject to axial load, and so the thermal break pad is required to resist compression forces and it should be designed accordingly. The design procedure presented in Section 5.3.1 can be adapted to suit thermal break pads subject to compression. Alternatively, the thermal break pad can be treated in a similar way to the concrete under a column base plate (see Section 7 of SCI publication P358).

Moment connections

Many applications where thermal break pads are required in connections will be moment resisting connections, e.g. steel beams supporting balconies or canopies.

In moment resisting connections one part of the connection is in tension and the other part of the connection is in compression, as shown in Figure 5.4. Therefore, a thermal break pad within the connection is required to resist compression forces. Hence, for moment connections there is a requirement for the designer to check the compression resistance of the thermal break pad within the connection.

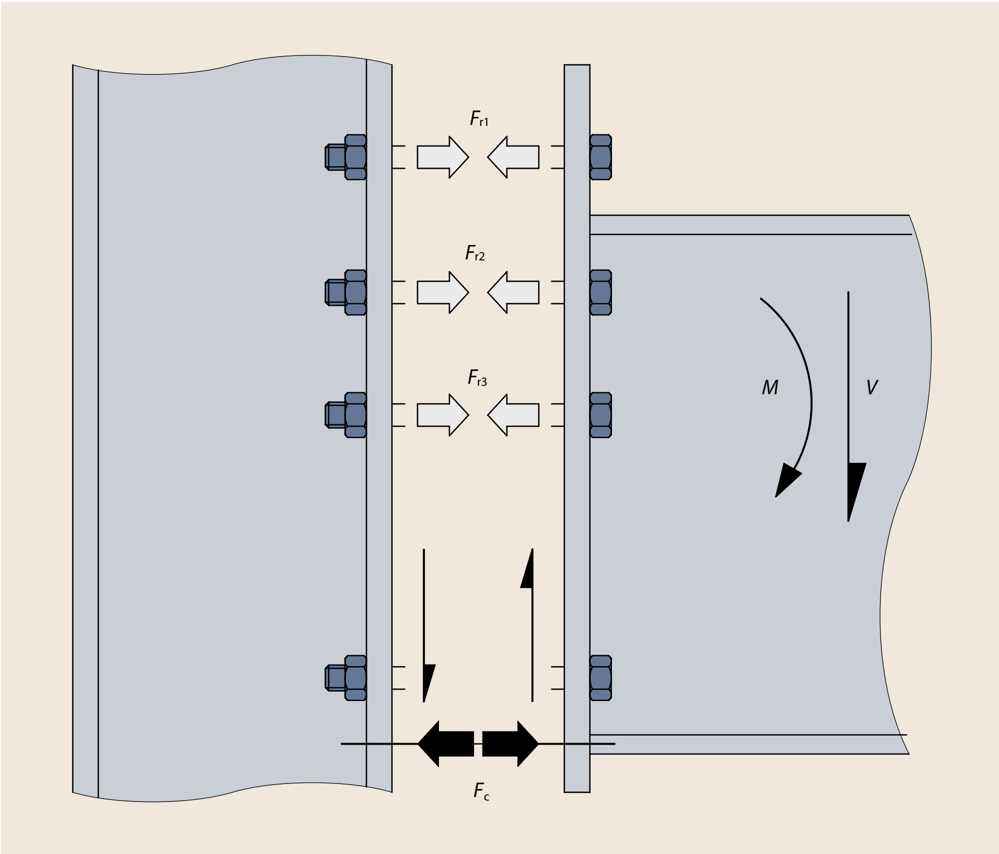


Figure 5.4 Forces in a typical moment connection

The designer must check that the compressive stress applied to the thermal break pad is less than the design compression strength of the thermal break material. This is achieved by satisfying the Expression (1), given below.

$$F_c \leq \frac{B \times L \times f_{ck}}{\gamma_{M2}} \tag{1}$$

where:

F_c	is applied design compression force
B	is the depth of the compression zone on the thermal break pad
L	is the width of the compression zone on the thermal break pad
f_{ck}	is the characteristic compression strength of the thermal break pad
γ_{M2}	is a partial safety factor.

The compression force F_c can be obtained from published data for standard moment connections (see SCI-P207 and SCI-P398). Alternatively, F_c is calculated as part of the normal connection design process if standard moment connections are not used.

The value to be used for the partial safety factor (γ_{M2}) will depend on the material and the nature of failure under loading. Independently verified design values for compression strength should be available from product manufacturers.

The dimensions B and L are calculated based on a dispersal of the compression force from the beam flange as shown in Figure 5.5 and Figure 5.6. Dimensions B and L are defined in expressions (2) and (3). However, it should be noted that B and L must be reduced if the beam end plate projection is insufficient for full dispersal of the force or if the column flange width is insufficient for full dispersal of the force.

$$B = t_{f,b} + 2\,(s + t_p) \quad (2)$$

where:

$t_{f,b}$ is the beam flange thickness

s is the weld leg length

t_p is the end plate thickness.

$$L = b_b + 2 \times t_p \quad (3)$$

where:

b_b is the beam flange width

t_p is the end plate thickness.

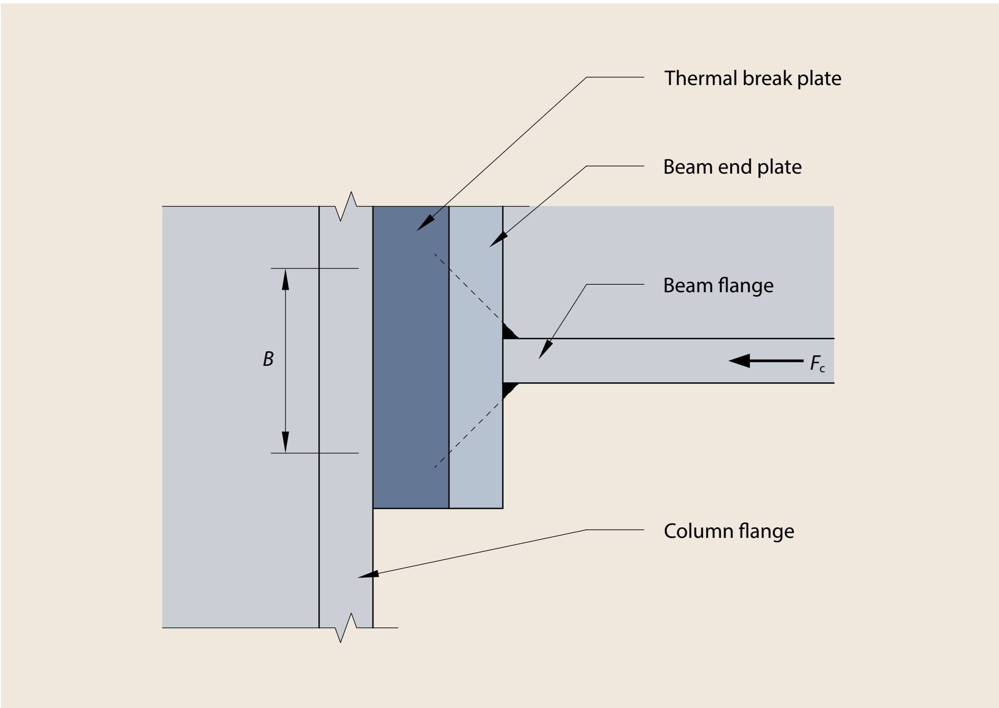


Figure 5.5 Dispersion of force through connection compression zone

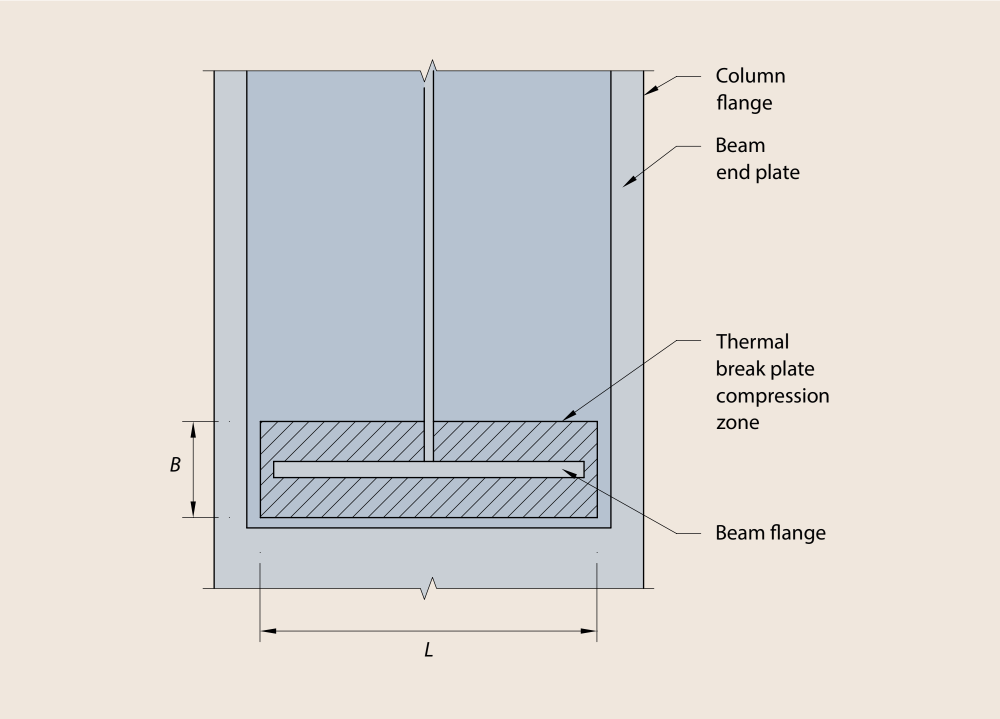


Figure 5.6
Thermal break pad compression zone

5.3.2 Additional rotation due to compression of thermal break

Nominally pinned connections

Nominally pinned connections are assumed to rotate and therefore any rotation due to the presence of a thermal break pad within the connection can generally be neglected.

Moment connections

For moment connections, such as those supporting balconies, the rotation of the connection under load is an important design consideration, typically for aesthetic and serviceability requirements.

The amount of compression deformation of the thermal break pad ΔT is calculated as given in expression (4).

$$\Delta T = \frac{t_{tb} \times \sigma_{tb}}{E_{tb}} \qquad (4)$$

where:

t_{tb} is the thickness of the thermal break pad
σ_{tb} is the stress in the compression zone of the thermal break pad
E_{tb} is the elastic modulus of the thermal break pad.

To ensure expression (4) remains valid, the stress in the compression zone of the thermal break pad should not exceed the elastic strength of the material.

The additional rotation of the connection (θ) due to the presence of a thermal break pad within the connection can be calculated using the expression (5).

$$\theta = \text{Sin}^{-1}\left(\frac{\Delta T_{\text{tb}}}{h_{\text{tb}}}\right) \quad (5)$$

where:

h_b is the depth of the beam.

All connections (with or without a thermal break pad) will rotate when loaded.

Long term creep

Some thermal break materials exhibit a degree of creep behaviour, where deformation continues over time under constant load. Therefore, in the consideration of additional rotation due to compression of the thermal break pads the designer should include an allowance for long term creep. Long term creep can often be expressed as a function of short term deformation. Data provided by the thermal pad manufacture should be used to determine the amount of long term creep.

5.3.3 Bolt shear resistance

Packs

A thermal break pad in a connection must be considered as a pack in terms of connection design. Where packs are used in connections there are detailing rules that should be followed and depending on the thickness of packs it may be necessary to reduce the shear resistance of the bolts within the connection. Design rules for bolts through packing are given in Clause 6.3.2.2 of BS 5950-1 [27] and Clause 3.6.1(12) of BS EN 1993-1-8 [28].

The number of packs should be kept to a minimum (less than four). BS 5950-1 states that the total thickness of packs t_{pa} should not exceed $4d/3$, where d is the nominal diameter of the bolt.

If t_{pa} exceeds $d/3$ then, the shear resistance of the bolts should be reduced by the factor β_p given in expression (6).

$$\beta_p = \frac{9d}{8d + 3t_{pa}} \quad (6)$$

where:

d is nominal bolt diameter

t_{pa} is the total thickness of packs.

5.3.4 Large grip lengths

A thermal break pad in a connection will increase the total grip length (T_g) of the bolts. The total grip length is the combined thickness of all the elements that the bolt is connecting together (e.g. end plate, thermal break pad, column flange, additional packs, etc.) Depending on the size of the grip length it may be necessary to reduce the shear resistance of the bolts within the connection. Design rules for bolts with large grip lengths are given in Clause 6.3.2.3 of BS 5950-1. BS EN 1993-1-8 does not include design rules for bolts with large grip lengths, however, it is recommended that the following design guidance is followed.

If T_g exceeds $5d$ then, the shear resistance of bolts with large grip lengths should be reduced by the factor β_g given in expression (7).

$$\beta_g = \frac{8d}{3d + T_g} \qquad (7)$$

where:

d is nominal bolt diameter

T_g is the total grip length of the bolt.

5.3.5 Thermal expansion

Differential temperatures between internal and external steel will lead to differential movement due to thermal expansion and contraction. Design of connections with thermal break pads should consider the need for allowance of movement due to differential temperatures. This may include the use of slotted holes or expansion joints in the external steelwork.

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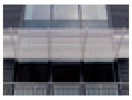

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