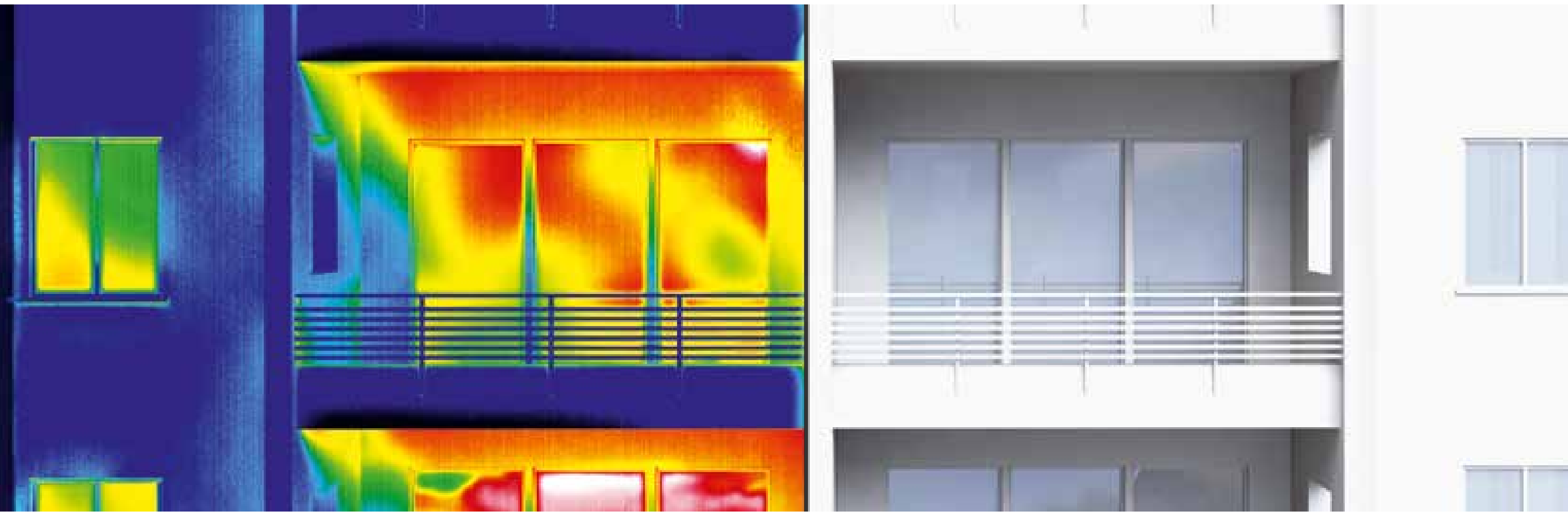

Thermal Bridging Guide

June 2015

Foreword

This publication presents information on the nature and significance of structural thermal bridges in buildings constructed of concrete and steel. It uses results from thermal modelling carried out by Oxford Brookes University employing methodology in accordance with BS EN ISO 10211: Thermal bridges in building construction - Heat flows and surface temperatures.
The information provides general guidance on methods of calculating the impact of structural thermal bridges and offers effective solutions to mitigate that impact.
The publication was prepared in cooperation with Oxford Brookes University.

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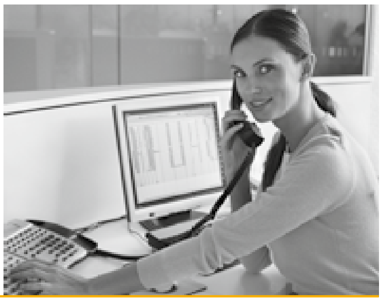

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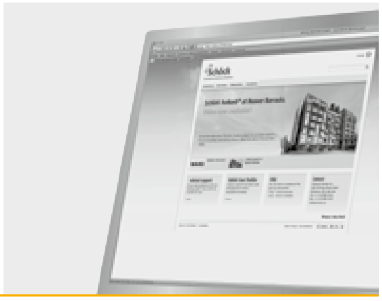

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Schöck Isokorb®
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1. Summary

Minimizing energy use in buildings, and therefore improving the thermal performance of building envelopes, has become increasingly important in the drive for sustainability and energy efficiency. We have seen the adoption of more stringent envelope thermal performance requirements in Building Regulations (Part L in the England and Wales), and voluntary certification schemes such as BREEAM and Passivhaus. These include requirements to reduce heat flow through the walls, roofs and floors. Adding insulation to the building is one obvious way to do this, but insulation is not effective if there are easy heat flow paths around it. This is why codes and standards are progressively moving to requirements based on Effective Thermal Resistance, in order to identify and minimize thermal bridges in the building envelope.

Thermal bridges can be defined as localized areas with higher thermal conductivity than the adjacent areas. A typical thermal bridge in a building envelope would be where a material of high conductivity, such as a structural attachment or metal flashing, penetrates the insulation layer. The presence of a thermal bridge in a building assembly would result in:

- Higher heat transfer through the assembly
- Colder surface temperatures on the warm side of the assembly

The possible consequences of these conditions include:

- Higher energy use for heating
- Higher energy use for cooling
- Noncompliance with Building Regulations
- Discomfort due to cold surfaces
- Condensation on cold surfaces, which could lead to:
  - Corrosion of metal elements and structure
  - Decay of wood-based materials
  - Visible patterns on interior or exterior surfaces due to variations of surface temperature and drying potential
  - Degradation of insulation performance (if condensation occurs within the structure)
- Mould growth and associated health concerns

A primary design goal for the construction of any building envelope in cold climates is to have a continuous and aligned layer of insulation, minimizing the number, size and impact of thermal bridges. Many designers are not fully aware of how significantly some common thermal bridges compromise the value of the installed insulation.

As shown later in this document, the heat transfer through common thermal bridges in a well-insulated building can equal the heat transfer through the insulated envelope (according to research by Oxford Brookes University). If designers do not consider the impact of thermal bridging, they will not meet the carbon emission targets in the Building Regulation Part L models used to establish compliance (SBEM and SAP).

Schöck provides product solutions specifically designed to mitigate or eliminate structural thermal bridges in commercial and multi-residential building construction. Schöck has over thirty years research experience, developing expertise both in the building physics of thermal bridging and bringing effective solutions to market.

The intent of this manual is to provide designers with:

- A better understanding of how heat moves through building assemblies and how this affects the surface temperatures and condensation control
- A confirmation of the minimum Standards and Code Requirements to ensure absence of damage
- Examples showing how the impact of thermal bridges can be mitigated during design, both in general and using Schöck Isokorb® thermal breaks
- Design guidance on how best to integrate Schöck Isokorb® thermal breaks for performance and code compliance
- Methods to calculate the impact of thermal bridges on the energy flows, temperature and moisture performance of building envelopes

2. Introduction to Thermal Bridging
2.1 What is a thermal bridge?

The thermal efficiency of a building is a function of the thermal performance of the planar elements (e.g. wall, roofs, windows) and the local heat losses that can occur around the planar elements and where they are penetrated by the building components that conduct heat. These areas of high local heat flow, commonly known as thermal bridges, can have a significant impact on the thermal performance of the building envelope and the building energy consumption.

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

Thermal bridges can be identified using thermal imaging cameras. The thermal bridges will appear as areas of higher temperature when viewed from the exterior of a building, typically these areas appearing as red or orange in colour. This is shown in Figure 1 where higher temperatures (i.e. thermal bridges) around the door, window and balcony slab can be seen due to higher heat transfer through the assemblies. Low outside surface temperatures show that this area is well insulated, so there is much less heat flow from inside to outside. Areas with low temperatures typically appear as blue or green in colour.

Figure 2 shows a well-insulated balcony with a low outside surface temperature (blue) resulting from minimized heat transfer through the assembly.

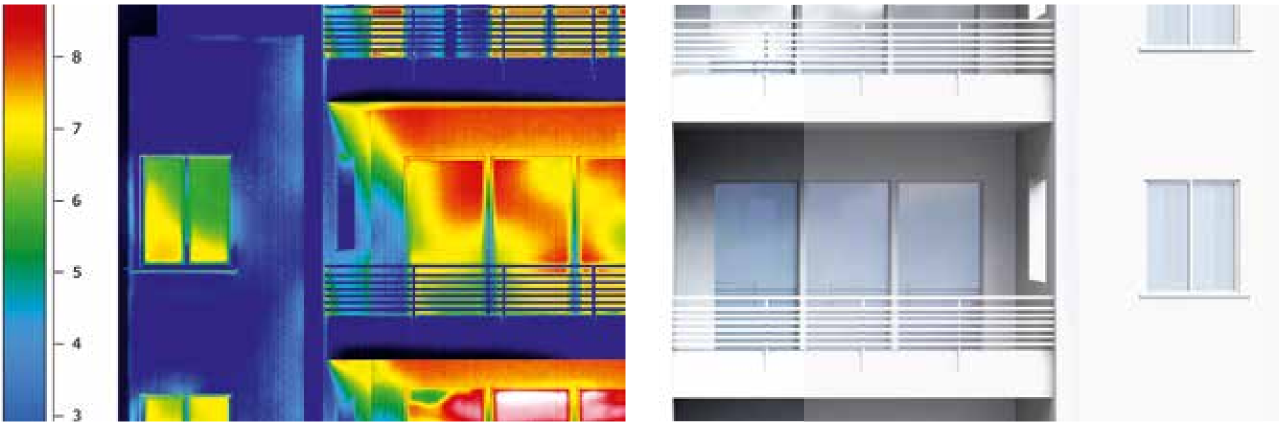

Figure 1: Thermal image of a residential building with higher temperatures at the windows, doors and balcony slabs.

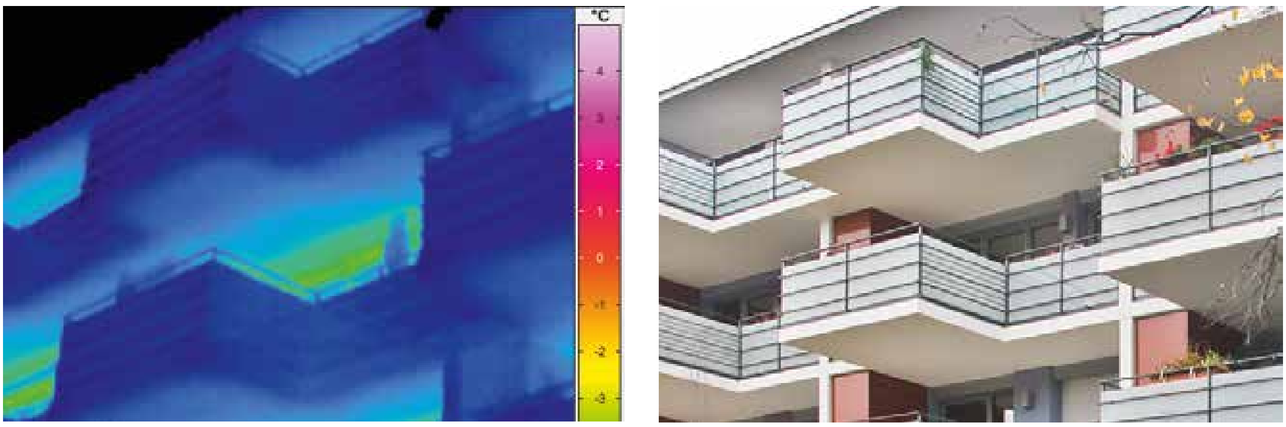

Figure 2: Thermal image of a residential building with minimized thermal bridges and an even temperature distribution along the envelope.

2.2 The causes of thermal bridging

Thermal bridges are localized areas of low thermal resistance. The rate of heat flow though a thermal bridge depends on a number of factors:

- The temperature difference across the thermal bridge
- The thermal conductivity of the materials passing through the insulation layer
- The cross sectional area of the thermal bridge
- How easily heat can get into and out of the thermal bridge which, in turn, depends on:
  - The relative area and surface resistance of the surfaces of the thermal bridge facing the source of heat and those facing the heat sink
  - The lateral heat flow paths in the assembly that can bring heat to and from the thermal bridge

It is easy to say that “heat flow takes the easiest path,” but it is sometimes very difficult to analyze what those three-dimensional paths are, how much heat flows through them, and what actually happens when you block one path. In fact, this analysis was almost impossible before the availability of 2D and 3D computer models. The recognition of how significant thermal bridges can be – and what the best ways to mitigate them are – has grown in direct relation to the availability of such tools. One still needs to understand the basic principles of heat flow through thermal bridges in order to effectively mitigate them.

Material Thermal Bridges

The most obvious kind of thermal bridge occurs when a thermally conductive element passes through an insulating layer. A typical example would be anchor bolts penetrating a layer of insulation, see Figure 3. These steel anchor bolts allow more heat flow than the surrounding insulation. Structural thermal bridges such as this are described in more detail in the next section.

Geometric Thermal Bridges

Another kind of thermal bridge depends on geometry, rather than on materials with different conductivities. Geometric thermal bridges can occur when the heat-emitting surface is larger than the heat absorbing surface. Building corners are a typical example, see Figure 4. Interior surfaces in the corner can be colder than other interior surfaces because more heat can flow due to the larger emitting surfaces.

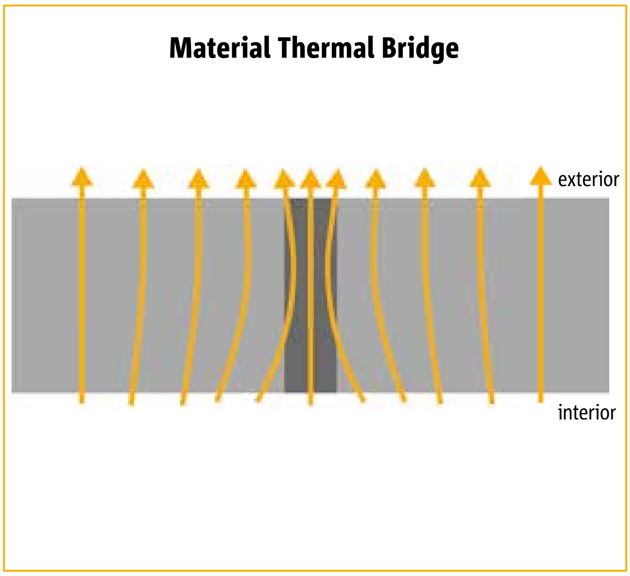

Figure 3: Cross-section through two materials, shows dark grey with high conductivity (steel) and grey with medium conductivity (concrete). The direction of heat flow is shown by the arrows. The heat flows from the warm room (bottom edge of the image) to the colder area (top edge of the image) through the material.

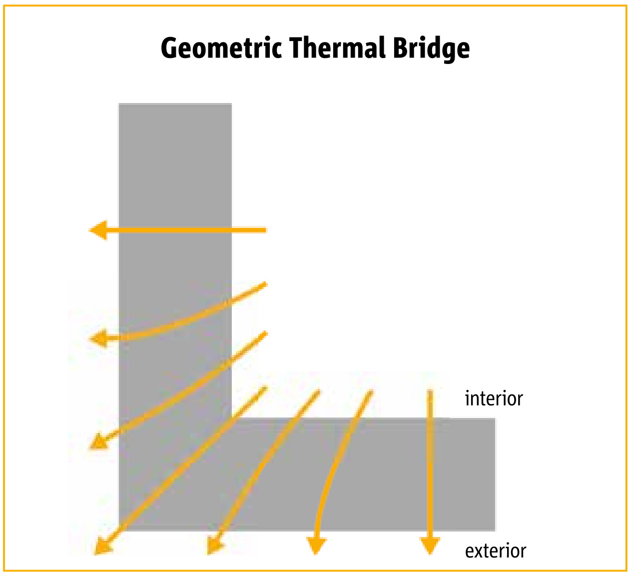

Figure 4: Cross-section of a building corner. The lines show the direction of heat flow from the warm to the cold area. The linear heat flow from an undisturbed wall is affected significantly by the geometric conditions.

2.3 Examples of structural thermal bridges

A structural thermal bridge may occur whenever you have a structural connection. In practice, structural connections often lead to high heat loss and low surface temperatures in the room. **Condensation** and **mould formation** can be caused by structural thermal bridges. The following images and examples show typical thermal bridges occurring in building envelopes.

In non-insulated cantilevered elements, such as balconies, the interaction between the **geometric thermal bridge** (cooling fin effect of the cantilever) and the **material thermal bridge** (penetrating the thermal insulation layer with reinforced concrete or steel) leads to significant heat loss, see Figure 5. Cantilevered balconies and exposed slab edges are considered the most critical thermal bridges in a building envelope. Non-insulated cantilevers cause severe heat loss and significantly reduce the internal surface temperature. As a result, the risk of mould growth greatly increases around the intersection of the interior slab and the exterior wall assembly, see Figure 6.

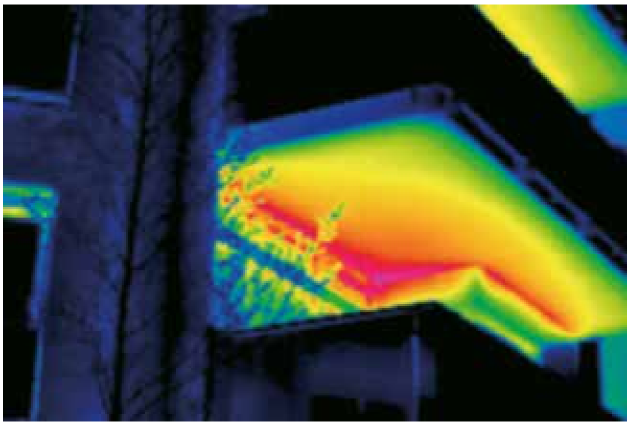

Figure 5: Infrared scan of a balcony thermal bridge with higher temperatures at the exterior slab.

Figure 6: Photograph showing mould growth on the ceiling of a concrete slab adjacent to an exposed slab edge thermal bridge. Condensation forms here frequently as a result of colder interior surface temperatures.

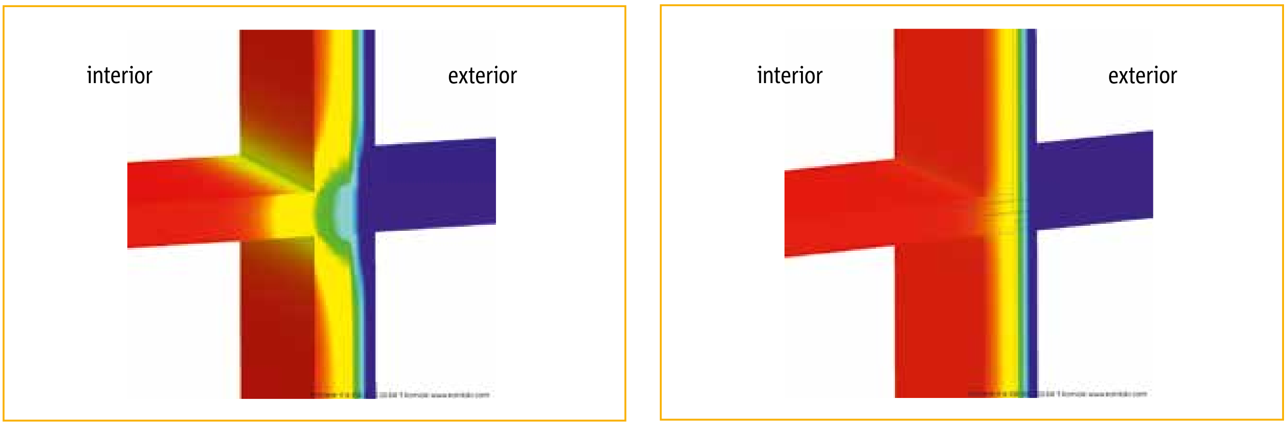

Figure 7: Continuous balcony slab compared with a solution with Schöck Isokorb®; Left: continuous balcony slab without thermal break, Right: Balcony slab thermally broken with Schöck Isokorb® providing a continuous insulation layer.

Figure 7 shows the modelled temperature distribution through a reinforced concrete balcony with and without a thermal break. The image on the left shows an unmitigated thermal bridge. The colour gradient shows how the heat flows to the outside through the balcony slab, from the warm red to the cold blue area. The image on the right depicts a thermally broken balcony connection. As the illustration shows, a load-bearing thermal insulation element significantly reduces heat loss and provides continuity in the insulation layer.

Linear Thermal Bridges

Linear thermal bridges are disturbances in the continuity of the thermal envelope that can occur along a certain length of the envelope. Typical examples of this include concrete balcony connections with the floor slab going through the wall, outer wall edges, floor supports and window to wall junctions. The energy losses incurred by a linear thermal bridge are quantified by the **linear thermal transmittance** ψ.

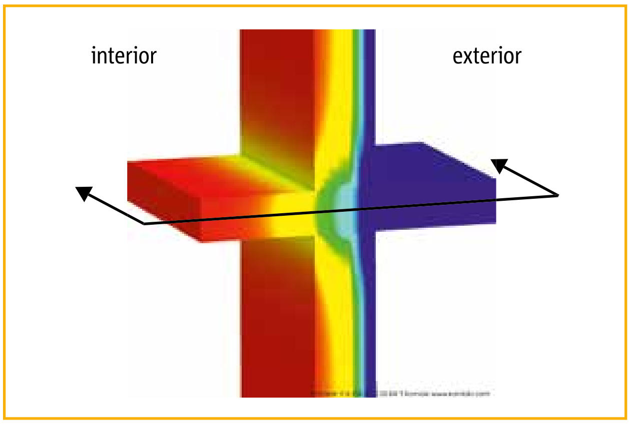

Figure 8a: Illustration of a linear thermal bridge on a linear balcony connection. The left side shows the warm interior with a red surface, while the cold exterior is shown in blue on the right. As the yellow and green spots in the interior corners show, the surface temperatures can drop quite significantly in these areas.

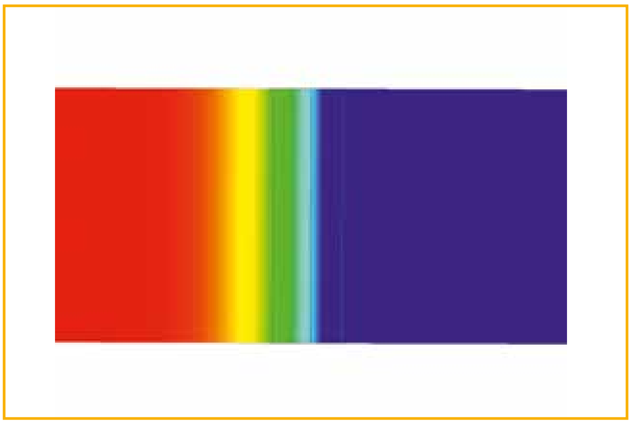

Figure 8b: Top view; this shows a cross-section through the balcony slab presented in 8a. You can clearly see that the heat loss is linear, meaning it remains the same across the entire connection length of the balcony.

Point Thermal Bridges

Some thermal bridges can be characterized as singular or point thermal bridges. They only occur in one spot. Typical examples include steel balconies, canopies, roof extensions, fastening elements, such as dowels or curtain wall supports and anchor bolts that penetrate the insulating layer. The energy losses incurred by point thermal bridges are quantified by the **Point thermal transmittance** χ.

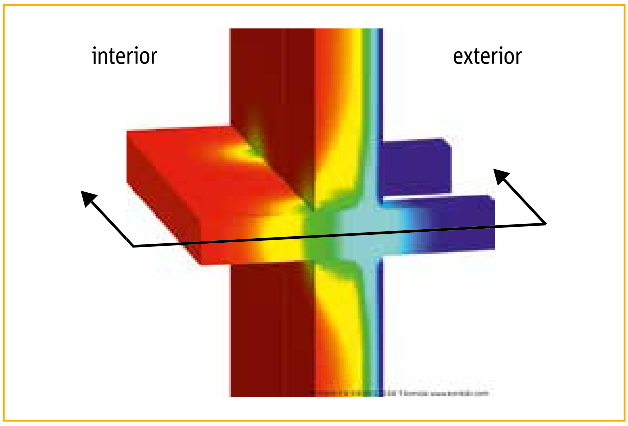

Figure 9a: Illustration of a local thermal bridge on a point balcony connection. In this case, steel beams are connected to a concrete floor from the outside. The left side shows the warm interior with a red surface, while the cold exterior is shown in blue on the right. As the yellow and green spots in the interior corners show, the surface temperatures can drop quite significantly.

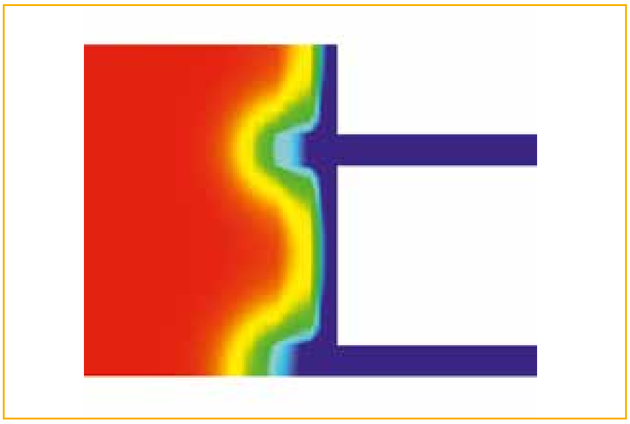

Figure 9b: Top view; this shows a cross-section through the balcony slab presented in 9a. You can clearly see that the heat loss is caused by the two continuous beams. The heat loss is also localised, meaning it is limited to specific spots.

Figure 10 shows typical thermal bridging occuring in steel structures, such as canopies or roof extensions. The image on the left shows a steel beam penetrating the insulation layer. On the right is an infrared scan of this location revealing areas of higher temperatures and heat loss around the area of penetration.

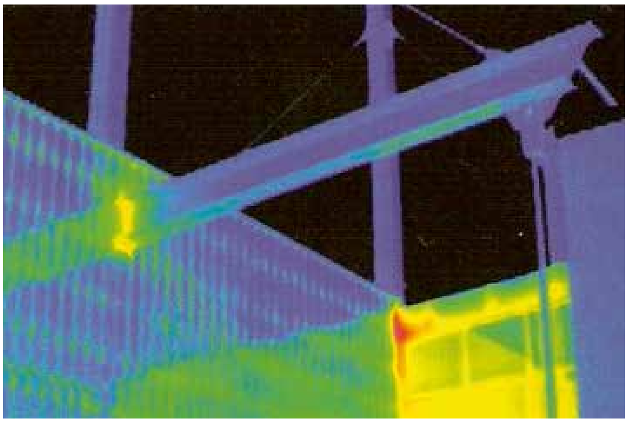

Figure 10: Structural thermal bridging in steel structures.

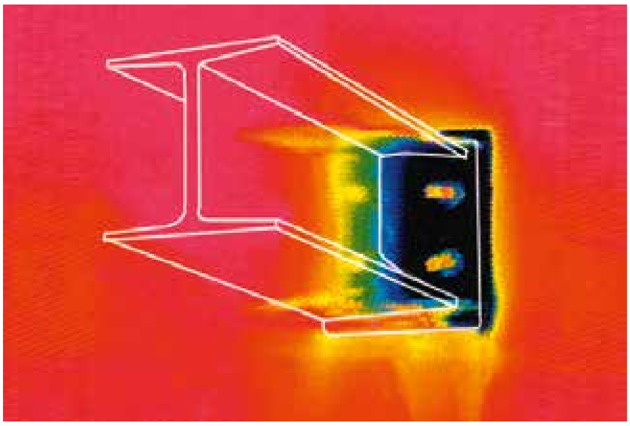

Figure 11: Thermal bridging occuring at continuous steel beams.

Figure 11 shows the effects of thermal bridging occurring at a continuous steel beam. The picture on the left shows the potential damage of the adjacent assemblies created by cold interior surfaces and resultant condensation, while the image on the right shows the temperature distribution by an infrared scan.

2.4 Condensation in buildings

Condensation control

Moisture in buildings accumulates from occupancy and everyday activities, such as cooking or bathing. However, it can also be caused by moisture rising from the soil beneath the building.

As a result, mould growth may occur when moisture condenses onto cold surfaces such as those in evidence at a thermal bridge. This can lead to damage to the structure through frost or corrosion. Furthermore thermal insulation performance is significantly reduced by moisture, thus resulting in a higher level of heat loss, with possible catastrophic results on the structure.

In order to prevent these negative effects, it is essential that the requirements for condensation control are met. For the building fabric, the main parameter that indicates surface condensation risk is the **Temperature factor,** which is governed by values contained within Part L.

Mould growth

When air cools, part of the resulting water vapour turns into condensation. This is a typical problem on cold surfaces in heated rooms. When the relative humidity is high, cold surfaces are also prone to **mould formation**, even before **condensation occurs**.

Mould growth can occur with moisture levels as low as 80% humidity. This means that mould begins to grow on cold surfaces if the surface is at least cold enough for a moisture level of 80% to be reached in the layer of air directly adjacent to the surface. The temperature at which this occurs is the so-called **mould temperature** θ_S. Mould formation therefore already begins at temperatures above the **dew point temperature**.

2.5 Heat Loss in Buildings

Buildings lose heat to the surroundings by a combination of air leakage and thermal conduction through the building envelope, including through the ground floor. Air leakage or infiltration has been addressed over the past decade by the introduction of pressure testing which ensures that ever more stringent air tightness standards are met by paying attention to sealing details at junctions and across porous wall constructions. Conductive heat losses have been subject to the same tightening of standards, primarily by the progressive lowering of U-values.

Conductive losses through the building fabric can be split into two categories:

a) Plane heat losses: through the main elements of the building fabric (roof, walls, windows and floor). The U-value (W/m^2K) of a construction multiplied by the area of that construction gives the heat loss in (W/K).

b) Thermal bridge heat losses: through corners, junctions, and structural elements penetrating the insulation layer.

The relative importance of each mode of heat loss for current new build properties in the UK very much depends upon the type of building under consideration and the level of performance being aimed at. In all cases, thermal bridge heat losses are responsible for an increasing percentage of the overall building heat loss as airtightness and fabric U-values have been improved in UK Building Regulations. For detached housing, it is common for thermal bridges to account for 30-50% of conductive losses, as calculated by thermal modelling. For multi-residential projects (apartments) this figure could be 20-30%, and balcony connections can be a major contributor to the total thermal bridge heat loss if effective thermal isolation is not included in the design.

2.6 Building Regulations

Heat Losses

To pass Building Control requirements in England and Wales, it is necessary to demonstrate compliance with Building Regulations. The latest version of the Building Regulations Part L (2013) and associated guidance document for residential construction Approved Document L1A (ADL1A) require that thermal bridging be included in the fabric heat loss calculations.

The Government Standard Assessment Procedure (SAP 2012) is the simple energy use and carbon emissions model used to provide evidence that the carbon emissions target has been achieved. The SAP calculation includes the term HTB (heat loss due to thermal bridging) which is calculated or estimated as below:

a) The sum of all linear thermal transmittances (Ψ) x 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 in the equation below:

$H_{TB} = y\Sigma A_{exp}$ (where A_{exp} = total exposed fabric area)

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

- Approved Design Details if used (in ‘Approved’ column of SAP Appendix K Table K1)
- Uncalculated details (in ‘Default’ column of Appendix K Table K1)
- Modelled details, in which numerical modelling has been carried out by a person of suitable experience and expertise.

Method (a) is always preferable as it avoids the penalty imposed by (b) which can double the overall calculated heat loss in a well-insulated construction. 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.

One off calculations of Ψ can be carried out on request for all details using Schöck thermal breaks to obtain the optimal solution.

Condensation Control and temperature factor

Building Regulations Part L includes the requirement that minimum internal surface temperatures should be such that condensation risk is minimized and mould growth avoided. A measure of condensation risk is the temperature factor f_{Rsi}:

$$f_{Rsi} = \frac{\text{Lowest surface temperature at junction – outside air temperature}}{\text{Inside air temperature - outside air temperature}}$$

Approved Document L1A (L2A for non-residential buildings) cites the BRE Information Paper IP1/06 (Assessing the effects of thermal bridging at junctions and around openings) which includes some limiting values for f_{Rsi}:

Type of building	Minimum f_{Rsi}
Dwellings, residential buildings, schools	0.75
Offices, retail premises	0.50
Sports halls, kitchens, canteens; buildings heated with un-flued gas heaters	0.80

Details using Schöck thermal breaks show temperature factors far in excess of Part L requirements in all cases. Temperature factors can be calculated by Schöck on request to provide bespoke details that verify code compliance.

3. Best Practice Solutions and Details

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The most effective way to minimize the heat transmittance of structural components (balconies, parapets, canopies) penetrating the insulation layer is to thermally separate the exterior structure from the interior structure. With the aim of decreasing thermal losses at the connection, Schöck Isokorb® structural thermal breaks optimize the function and performance of each integral element at the junction. A primary goal for designing and selecting proper thermal bridging strategies is to comply with UK Building Regulations Part L where minimum requirements for the temperature are provided.

The general concept is that more conductive materials such as reinforced concrete (λ = 2.2 W/(mK)) or structural steel (λ = 50 W/(mK)) at the connection are replaced with expanded polystyrene (EPS, λ = 0.031 W/(mK)) with a minimum thickness of 80mm to give an effective thermal separation. This is non-structural and constitutes the main body and surface area of the thermal break. To conserve the structural integrity between the exterior elements (e.g. balconies, canopies) and the interior structure (e.g. floor slab), reinforcement bars are used to connect both sides and transfer loads (tension and shear). These traverse the insulation body of the thermal break and are made of high strength stainless steel (λ = 15 W/(mK)), instead of carbon steel (λ = 50 W/(mK)). This not only reduces thermal conductivity, but also guarantees longevity through its inherent corrosion resistance. To transfer the compression loads, the thermal break uses special compression modules made of high strength concrete (λ = 0.8 W/(mK)), as these offer better thermal performance in when compared with compression bars made of carbon steel or even stainless steel.

A thermal modelling study was undertaken by Oxford Brookes University to determine the effectiveness of Schöck Isokorb®. The following sections show the results for different applications with different solutions.

3.1 Concrete balconies

Typical residential buildings are supported by concrete frames, often implementing cantilevered balconies made of concrete. Schöck Isokorb® type K is the solution to thermally separate the exterior balcony from the interior slab.
Schöck Isokorb® type K offers high thermal resistance by using stainless bars to act as tension and shear reinforcement and high-strength concrete bearings (HTE, high thermal performance) to act as compression modules.

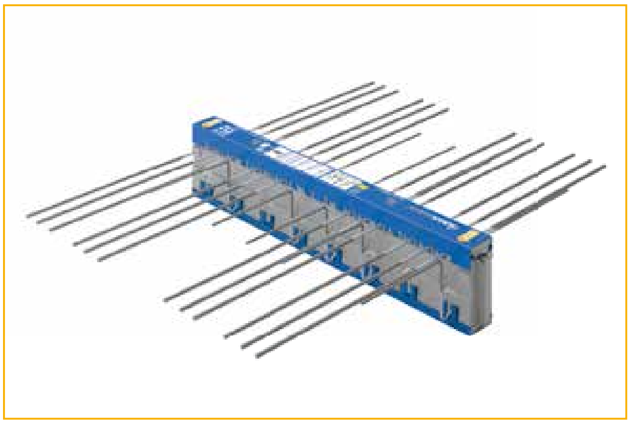

Figure 12a: Schöck Isokorb® type K for concrete balconies connected to interior slabs.

Figure 12b: Typical residential building, supporting structure made of concrete. Concrete balconies are thermally broken by Schöck Isokorb® type K.

A modelling study was undertaken by Oxford Brookes University to determine the effectiveness of Schöck Isokorb®. The aim of this investigation was to determine the heat loss, minimum surface temperature and hence temperature factor (f_{Rsi}) resulting from use of Schöck Isokorb® type K units, connecting a concrete balcony to a floor slab and to compare these values without the use of connectors (floor slab projecting straight through wall). Calculation was by means of finite difference analysis using BISCO and TRISCO software from Physibel.

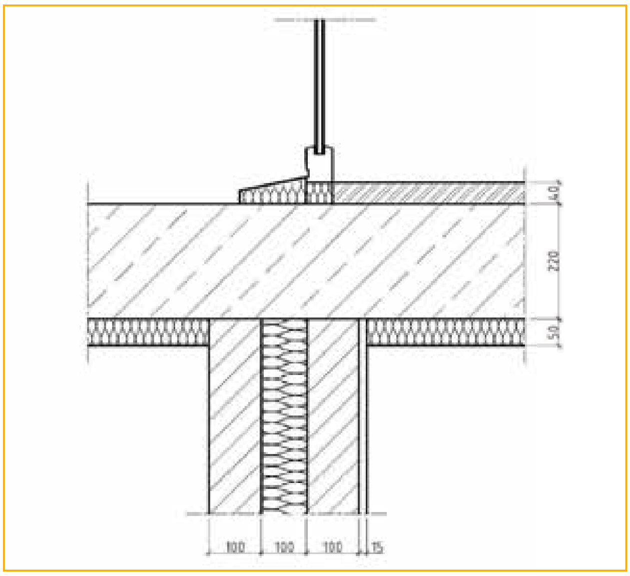

Figure 13a: Wall construction with balcony slab through.

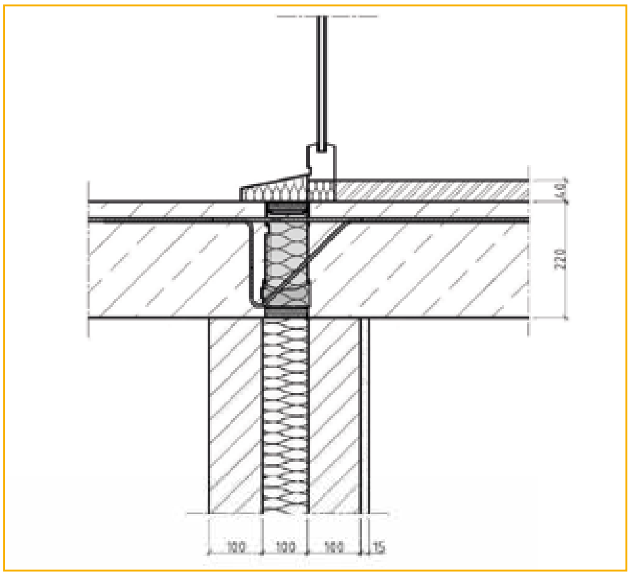

Figure 13b: Schöck Isokorb® type K50 installed in construction.

Further information about the boundary conditions and the thermal conductivity of the used components in can be found in Reference 2.

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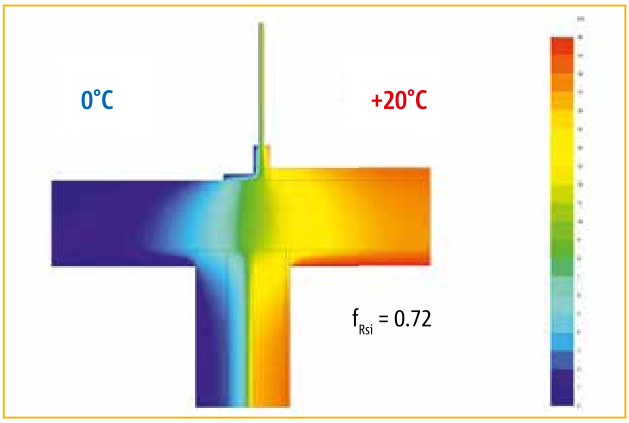

Figure 14a: Balcony connection without thermal breaks: temperature distribution (section). This detail does NOT conform to UK Building Regulations Part L requirements for minimum temperature factor in dwellings (f_{Rsi} = 0.75)

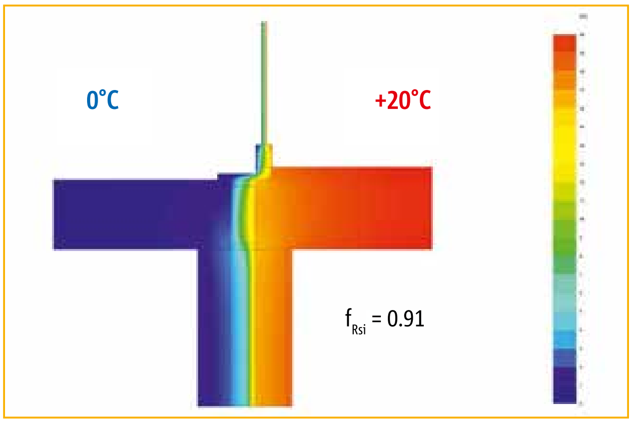

Figure 14b: Schöck Isokorb® type K50 connection: temperature distribution (section). This detail conforms with UK Building Regulations Part L requirements for minimum temperature factor in dwellings (f_{Rsi} = 0.75)

	Temperature factor (based on wall surface)	Linear thermal transmission Ψ (W/mK)
Without Isokorb	0.725	1.23
With Isokorb Type K50	0.91	0.71

Table 1: Thermal modelling results

Table 1 shows the temperature factor and linear thermal transmittance and equivalent thermal transmittance for the case without an Isokorb unit installed, versus using an Isokorb Type K50. In the UK, the temperature factor (f_{Rsi}) is used to indicate condensation and mould risk as described in BRE IP1/06, a document cited in Building Regulations Approved Documents Part L1 and L2. For dwellings, residential buildings and schools, f_{Rsi} must be greater than or equal to 0.75.
It can be seen from the results that the Schöck Isokorb® Type K50 unit, with f_{Rsi} = 0.91 exceeds these values and therefore meets the requirements of Building Regulations Approved Documents L1 and L2. The results for the case with no unit (f_{Rsi} = 0.72) is a failure for dwellings. The heat loss using the Isoborb is reduced by over 40%.

Figure 15: Schöck Isokorb® type K incorporated between the exterior balcony and the interior slab.

3.2 Steel balconies

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A common design feature in the UK is to connect a steel balcony to an interior concrete slab.
Schöck Isokorb® type KS is the solution which thermally separates the exterior balcony from the interior slab.
The main body of Schöck Isokorb® type KS consists of 80 mm thick EPS insulation. It offers high thermal resistance by using stainless bars to act as tension, shear and compression reinforcement.

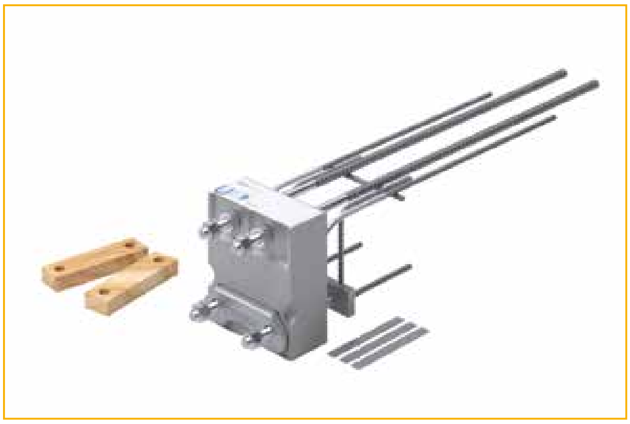

Figure 16: Schöck Isokorb® type KS for steel balconies.

Figure 17: Typical residential building, supporting structure made of concrete. Steel balconies are thermally broken by Schöck Isokorb® type KS.

A modelling study was undertaken by Oxford Brookes University to determine the effectiveness of Schöck Isokorb®. The aims of this investigation were to determine the heat loss, minimum surface temperature and hence temperature factor (f_{Rsi}) resulting from use of Schöck Isokorb® type KS14 units connecting a steel balcony support to a concrete floor slab. To simulate the real life situation for a balcony, the study included the glazing element as part of the building envelope.

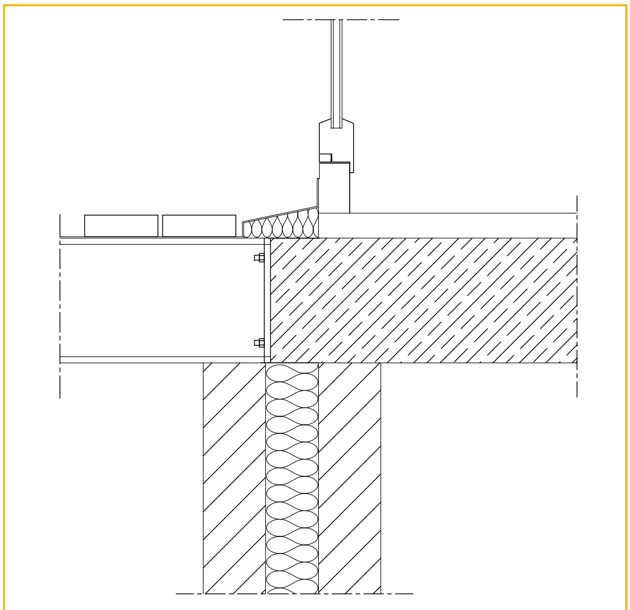

Figure 18a: Wall construction with a direct steel balcony connection.

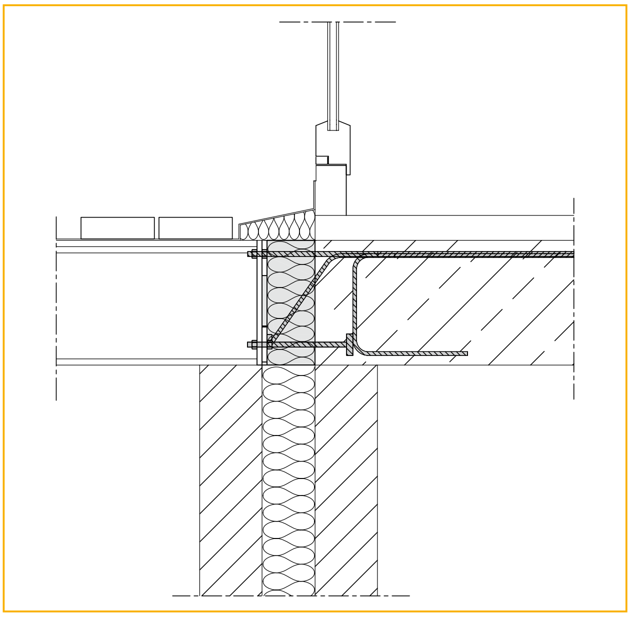

Figure 18b: Schöck Isokorb® type KS14 installed in construction.

Further information about the boundary conditions and the thermal conductivity of the used components can be found in reference 3.

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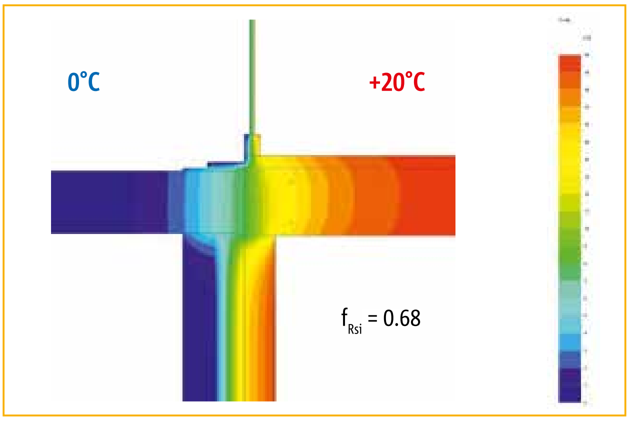

Figure 19a: Direct connection (Case 1): temperature distribution (section)This detail does NOT conform to UK Building Regulations Part L requirements for minimum temperature factor in dwellings (f_{Rsi} = 0.75)

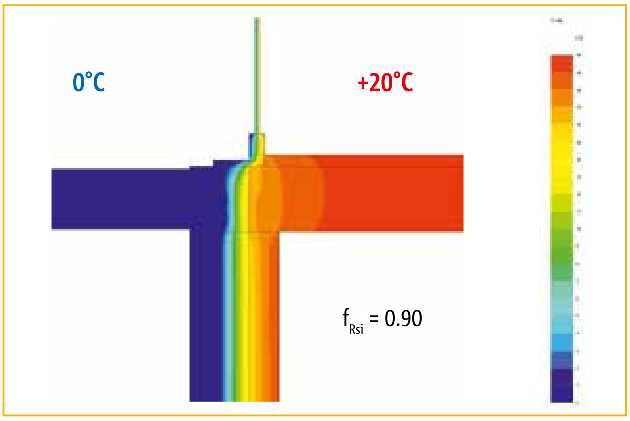

Figure 19b: KS14 H200 connection (Case 4): temperature distribution (section). This detail conforms with UK Building Regulations Part L requirements for minimum temperature factor in dwellings (f_{Rsi} = 0.75)

	Linear thermal transmission Ψ (W/mK)	Minimum Temperature factor f_{Rsi}
Constuction without thermal break	0.98	0.68
With Isokorb® type KS14 H200	0.287	0.90

Table 2: Thermal modelling results

From table 2 it can be seen that the KS14 unit, with f_{Rsi} = 0.90, exceeds the minimum temperature factor value cited in IP1/06 (f_{Rsi} = 0.75) and will therefore meet the requirements of Building Regulations Approved Documents L1 and L2. The construction without a thermal break does not meet the temperature factor value required for dwellings. The heat loss by incorporating Schöck Isokorb® KS is reduced by almost 70%.

Figure 20: Schöck Isokorb® type KS incorporated into the interior slab. Steel balcony to be installed afterwards.

3.3 Steel canopies

Exterior canopies penetrating the envelope typically occuring in schools, universities etc. are another critical thermal bridge which leads to significant heat loss.
Schöck Isokorb® type KST is the solution to thermally separate the exterior steel structures from interior steel strcutures.

Figure 21: Schöck Isokorb® type KST for steel beams

Figure 22: Typical building with supporting structure made of steel. Steel canopies are thermally broken by Schöck Isokorb® type KST.

The highly conductive structural steel (λ = 50 W/(mK)) at the connection is replaced with expanded polystyrene (EPS, λ = 0.031 W/(mK)) with a thickness of 80 mm to give an effective thermal separation of the steel beam. This is non-structural and constitutes the main body and surface area of the thermal break.
Stainless steel is used within the Isokorb® module for the structural elements (bolts and a hollow section) to transfer the loadings, while further reducing the thermal conductivity, since stainless steel λ = 15W/(mK) has a thermal conductivity 30% that of carbon steel carbon steel 50W/(mK).

Typically two Isokorb® type KST/QST are used per beam connection. Appendix chapter 4.2 shows the equivalent thermal conductivity λ_{eq} and the equivalent thermal resistance R_{eq} respectively. Note that heat transfer through the connection is reduced by about 85% compared to the heat transfer through a continuous steel beam.

The following 3D thermal models have used Schöck Isokorb® for concrete structures and steel structures.

A modelling study was undertaken by Oxford Brookes University to determine the effectiveness of Schöck Isokorb®. The aim of this investigation was to determine the heat loss, minimum surface temperature and temperature factor (f_{Rsi}), and equivalent conductivity resulting from use of Schöck Isokorb® type KST units connecting a steel beam, and to compare these values with alternative connection methods and with a continuous beam. Calculation was by means of three dimensional finite difference analysis.

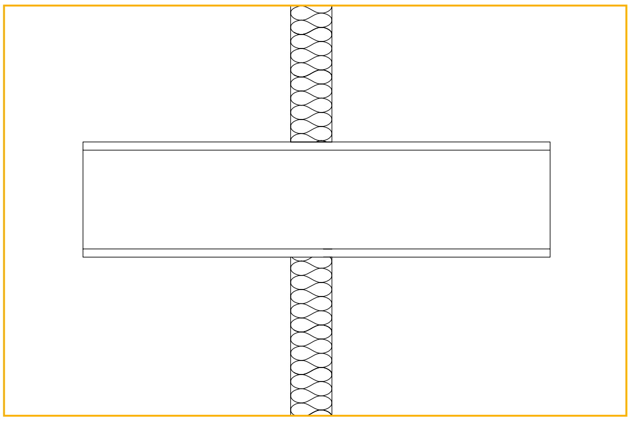

Figure 23a: HEA200 beam passing through 80mm insulation

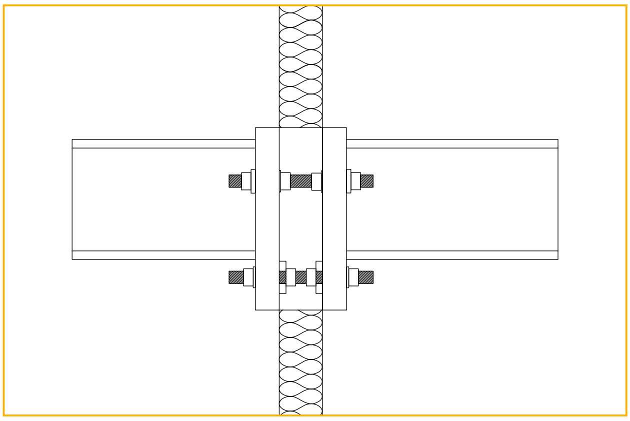

Figure 23b: Thermally broken steel beam with KST22

Further information about the boundary conditions and the thermal conductivity of the used components can be found in Reference 1.

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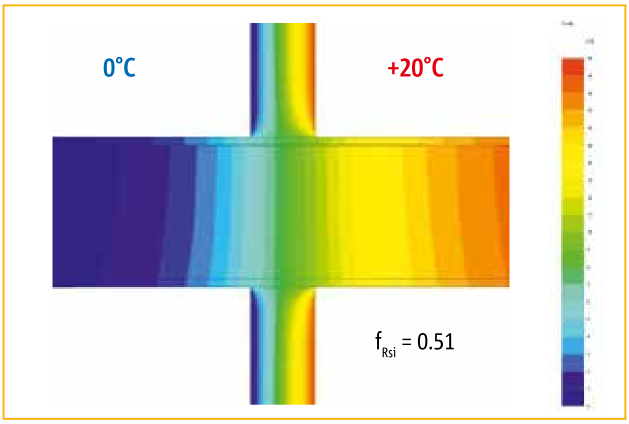

Figure 24a: Direct connection (Case 1): temperature distribution (section) This detail does NOT conform to UK Building Regulations Part L requirements for minimum temperature factor in dwellings (f_{Rsi} = 0.75)

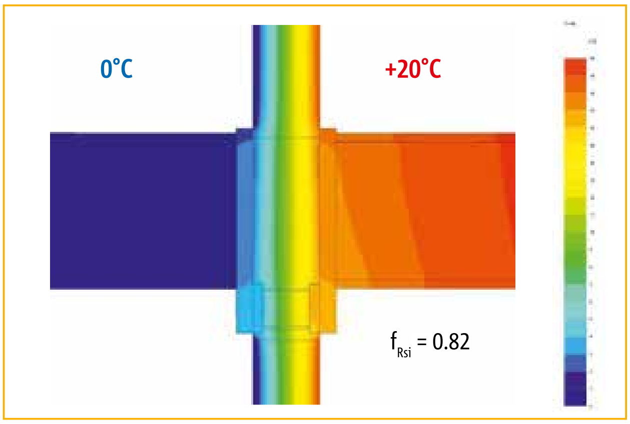

Figure 24b: KST16 connection: temperature distribution (section). This detail conforms with UK Building Regulations Part L requirements for minimum temperature factor in dwellings (f_{Rsi} = 0.75)

	Minimum Surface Temperature °C	χ (W/K)	Minimum Temperature factor f_{Rsi}
Continuous Beam	5.7	0.77	0.51
With Isokorb® type KST 16	13.8	0.26	0.82

Table 3: Thermal modelling results

It can be seen from the results that the KST16 units, with f_{Rsi} = 0.75 respectively, exceed the minimum value of 0.75 and will therefore meet the requirements of Building Regulations Approved Documents L1 and L2. whereas the continuous beam falls far short of the requirements. The heat loss by incorporating Schöck Isokorb® type KST is reduced by almost 65%.

Figure 25: Schöck Isokorb type KST installed between the interior and the exterior beam.

4. Appendix
4.1 Calculating Heat Flow and Thermal Bridges

Basic Definitions
Thermal conductivity quantifies the ability of a material to transmit heat in terms of energy by unit thickness and by degree of temperature difference, see Table 4.

Material	Thermal Conductivity λ in W/(mK)
Insulation Material	0.035
Reinforcement steel	50
Stainless steel	15
Concrete	1.8

Table 4: thermal conductivity of a range of materials

Thermal resistance
The thermal resistance R is the resistance to heat flow with K temperature difference across one m² and is based on the conductivity λ. R is calculated as the thickness (t) of the material divided by its thermal conductivity:

$$R = \frac{t}{\lambda}$$

λ: Thermal conductivity in W/(mK)
t: Material thickness in m

This calculation of the R-value can also be performed for multilayer components:

$$R = \frac{t_1}{\lambda_1} + \frac{t_2}{\lambda_2} + \dots + \frac{t_n}{\lambda_n}$$

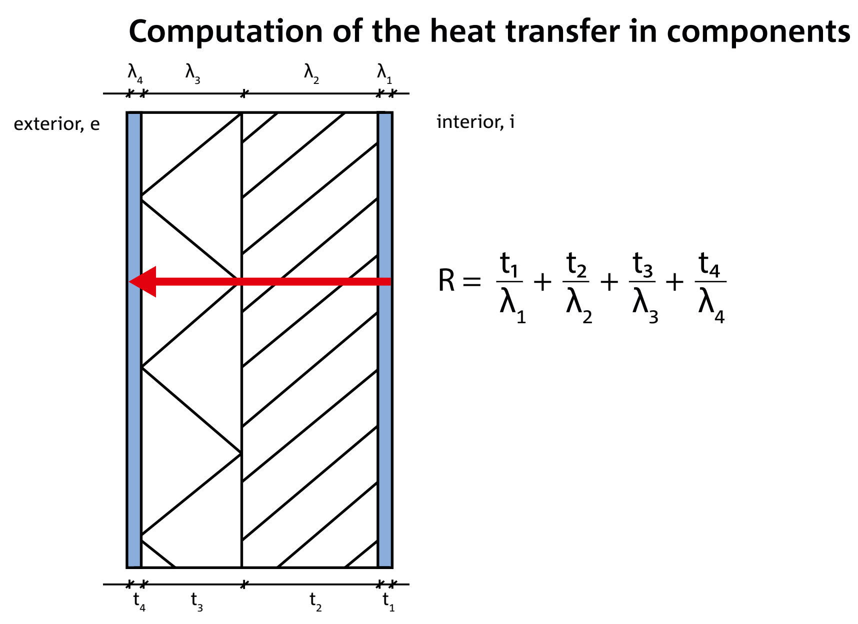

Figure 26: A representation of a wall construction, to define the R value by the thickness of the layers and the corresponding λ value.

The U-value, or thermal transmission coefficient, quantifies the heat flow through a building construction by the degree temperature difference across it. It is calculated as the reciprocal value of the sum of the thermal resistances and the surface resistances R_{si} and R_{se}:

$$U = \frac{1}{R_{si} + R + R_{se}}$$

The U-value describes one dimensional heat flow per square metre of component per degree temperature differential across it, which is needed to calculate the energy loss of areas of the same assembly. U-value is not applicable to areas of thermal bridges, such as that shown in Figure 27. For more information about Basic Definitions, see Apendix 4.3.

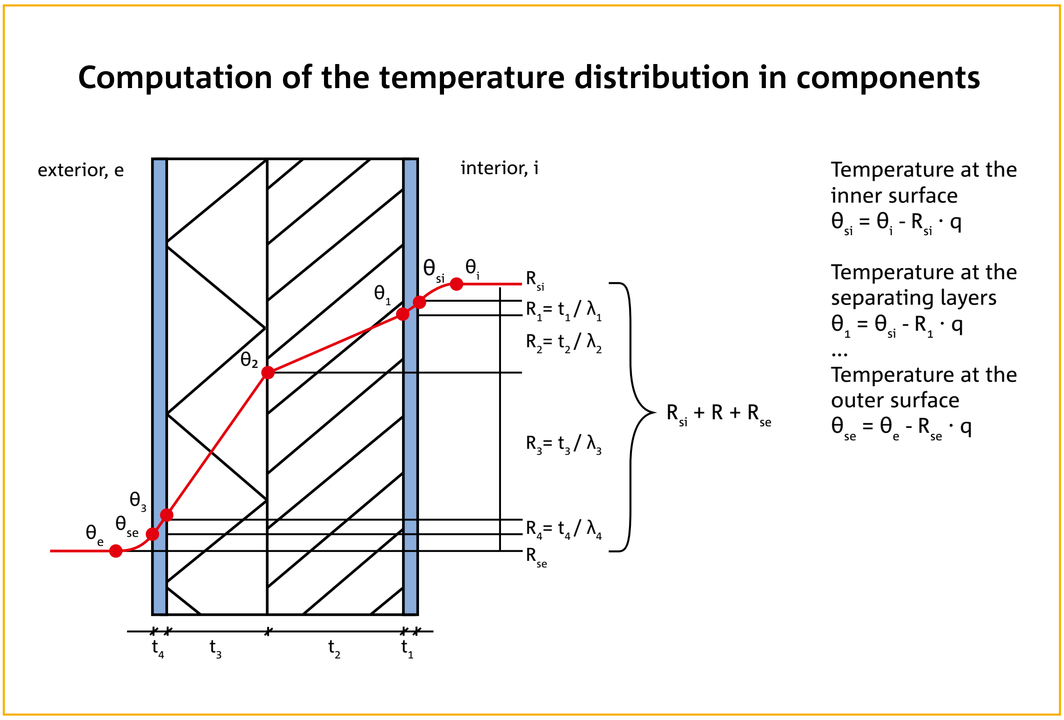

Figure 27: Representation of a temperature profile through a wall. The slope of the temperature profile is defined by the thickness of the layers and the corresponding R value. At the surfaces the surface resistances R_{si} and R_{se} also take effect. On the right hand side you can see how the temperature profile between the different layers is calculated.

Consideration of lateral Heat Flow

Figure 28 illustrates several important concepts using the example of a slab, such as a balcony, penetrating a wall and therefore the insulation layer:

- Heat will flow laterally to the easiest path through the assembly (i.e. the slab).
- The planar heat flow (U) is the heat flow through an assembly without thermal anomalies. The linear thermal transmittance is the additional heat flow with the thermal anomaly due to lateral heat flow as shown in Figure 28.
- One can view the influence of the thermal bridge as being an additional heat loss due to the slab (the yellow area under curve on the graph) that is added to the heat loss of the wall without the slab (the blue area of the graph).

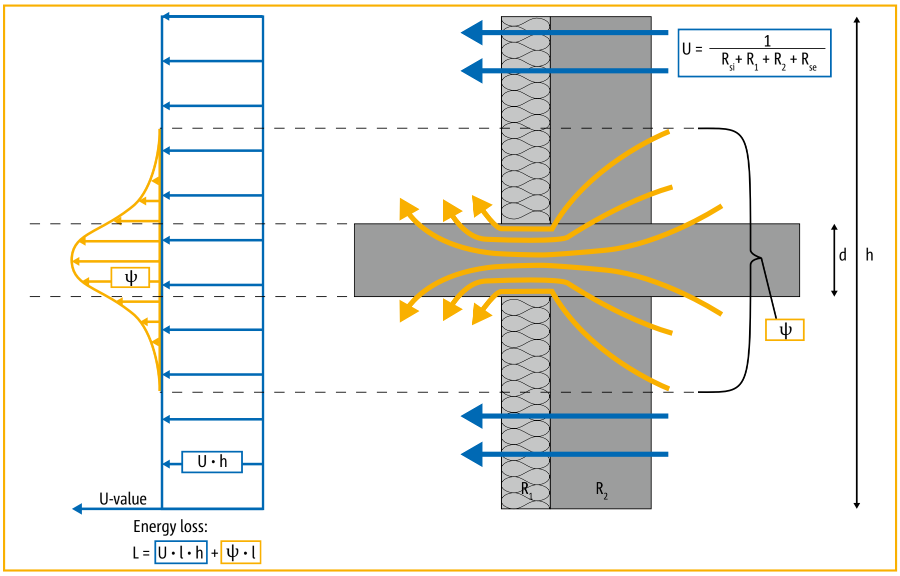

Figure 28: Pattern of heat flow through a building envelope with materials that allow lateral heat flow to a thermal bridge.

Recognizing that the heat flow through a thermal bridge can be added to the heat flow through a planar building assembly provides a method of accounting for thermal bridges that cannot really be addressed by the "parallel path" method of the equations in Chapter 4.3. This is particularly true when the power of computer modelling can be used to determine the heat flow attributable to specific types of thermal bridges. It has proven useful to classify thermal bridges by how one would add them up: Figure 29 illustrates an example of using computer modelling to determine the Ψ value of a linear thermal bridge, in this example a slab penetrating a wall. One creates two "models" with the same width and height:

- The impact of small, frequent and distributed bridging elements (e.g. brick ties or Z-spacers carrying cladding as seen in Figure 29 on the following page) are generally best handled by adding their thermal influence to **U-value** (W/(m²K) for the assembly. These are repeating thermal bridges, and they are included in the U-value calculation.
- The heat transfer associated with **linear elements** (e.g. slab edges, corners, roof/wall intersections, window wall interfaces etc.) can be handled by determining the **Linear Heat Transmittance coefficient** W/(mK). The Greek letter Psi (Ψ) is conventionally used to represent a linear transmittance.
- The heat transfer associated with **intermittent or singular** elements (e.g. beams or other projecting structural elements) can be handled by determining the **Point Heat Transmission coefficient** (W/K)). The Greek letter Chi (χ) is conventionally used to represent a point transmittance.

1. The wall without the slab but with the frequent and distributed bridging elements (the Z-spacers in this case) that you would want to include in the U-value. The program provides the steady state heat flow for the assembly (Q).

2. The assembly including the slab. The program provides the steady state heat flow for the combined assembly (Q).

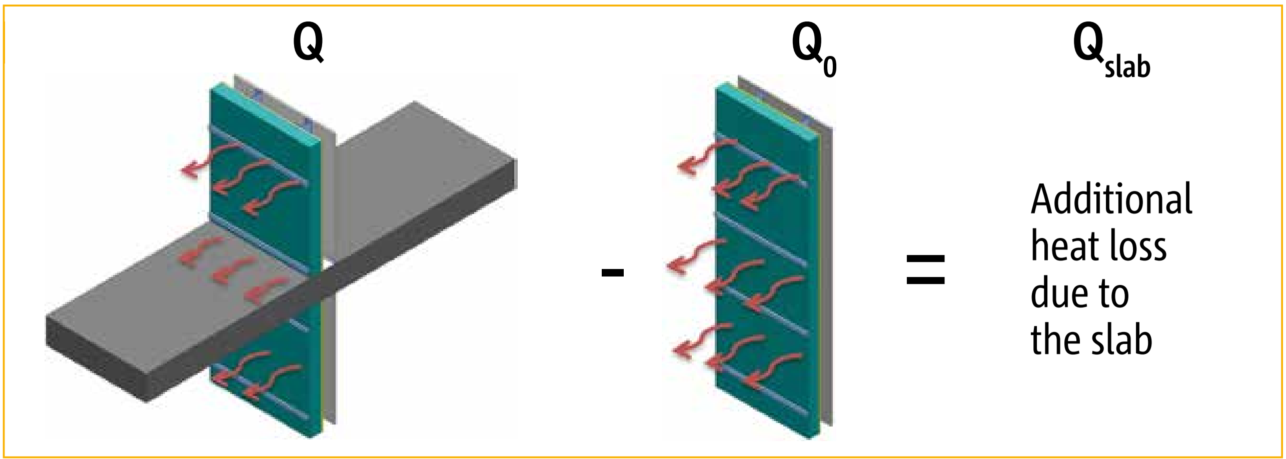

Figure 29: Example of process of determining the linear transmittance of a slab penetrating a wall.

The difference in heat flow between the two models divided by the width of the modelled sections is the linear transmittance or Ψ for slab. This value is effectively the area under the yellow curve in Figure 28.

A similar process can be used to calculate the point transmittance of a beam penetrating a wall.

Linear and point transmittances can be determined by two or three dimensional thermal modelling for specific details.
Using this concept, the total heat flow through a wall, roof or floor with linear and point thermal bridges is calculated by adding the heat flow through the thermal bridges to that through the clear field of the assembly.

$Q = [U \cdot A + \Sigma(\Psi_i \cdot L_i) + \Sigma(\chi_j \cdot n_j)]\ \Delta T$

where

U is the “clear wall” assembly heat transmittance (including the impact of frequent and distributed bridging elements)
A is the area of the assembly, including all details in the analysis area
Ψ_i is the linear thermal transmittance value of detail “i”
L_i is the total length of the linear detail “i” in the analysis area
χ_j is the point heat transmittance value of detail “j”
n is the number of point thermal bridges of type “j” in the analysis area

The examples in Chapter 3 and 4 use this method of calculation.

4.2 Humidity, Temperature and Condensation Control

One consequence of thermal bridging is that some surfaces can become cold enough to allow condensation of water vapour from the indoor air. The collected moisture can corrode steel, rot wood and allow mould growth. Condensation control is an important factor in the integrity and durability of buildings.

The term "humidity" refers to water vapour in the air. The amount of water vapour that air can hold depends on its temperature. **Relative Humidity** (RH) defines the ratio of actual vapour in the air to the maximum amount the air could hold at that temperature.

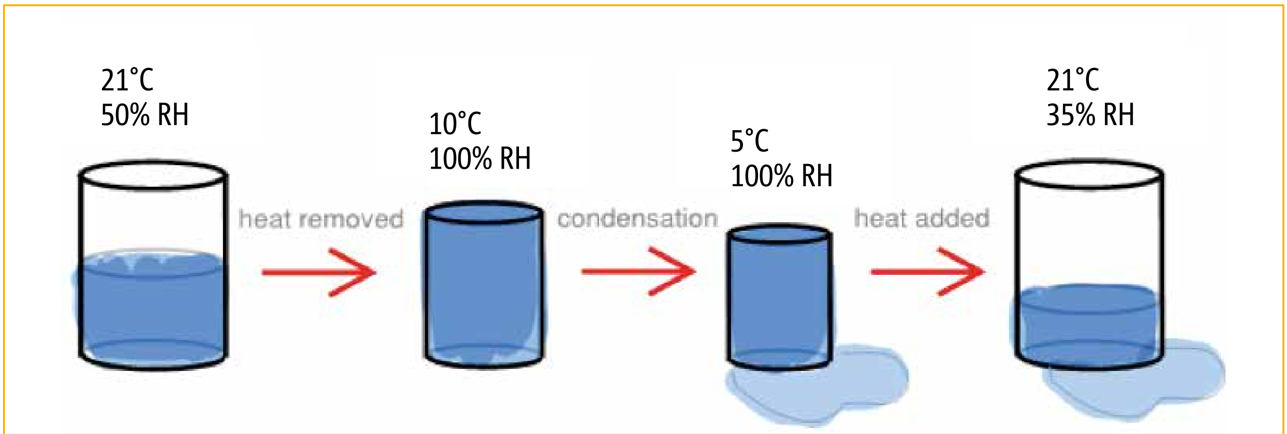

Figure 30: Illustration of condensation process.

Figure 30 is an illustration explaining some of the interactions between air, vapour, temperature and liquid water. It is based on the idea that air is like a container that changes size with temperature, representing air's ability to hold moisture. If you start with air at 21°C and 50% RH, and allow the air to cool so our imaginary container shrinks, the relative humidity will increase even though there is no water added or taken away. At some point, which happens to be about 10°C, the container is full to the top. This is the point where the air is **saturated** and is at 100% RH. This is also called the **dew point temperature**.

If further cooling occurs, the container shrinks and some water spills over the top. This is the same as moisture condensing from the air as a liquid. The air is still at 100% RH but a calculable volume of liquid water has been released.

If the air is now warmed (without adding back the condensed moisture) the RH would reduce, and when it reaches the same starting temperature, the air would be of a lower RH than at the beginning of the exercise.

All these relationships can be calculated using psychrometric charts and tables, but the important thing is to understand the relationships between cold surfaces, humidity and condensation:

- Air that has water vapour in it has a **Dew Point Temperature**: the temperature where the air is saturated.
- Condensation will form on a surface that is below the Dew Point Temperature of the air to which it is exposed.
- The more vapour in the indoor air, the higher its RH and dew point temperature. Therefore, the less cold a surface has to be to start condensing, and the more condensation forms on a surface of a given temperature below the dew point.
- The relative humidity of the air layer in contact with a cold surface will be at a higher value than the warmer air away from the surface.

A major concern with condensation or high local RH caused by cold surfaces is that it can lead to mould growth. Because mould spores and suitable nutrients (cellulose) are virtually always present in dust, all that is required to cause mould growth in a building is a sufficient amount of moisture in the microclimate in which the spores exist. Liquid water as formed by condensation is a particular concern, but some mould species can grow in high humidity conditions without actual liquid water. In Europe the concept of "Mould Temperature" is used which is similar to the Dew Point Temperature, but defines the temperature where air is at 75% RH. Figure 31 and 32 compare the Dew Point Temperature and Mould Temperature for a range of indoor conditions.

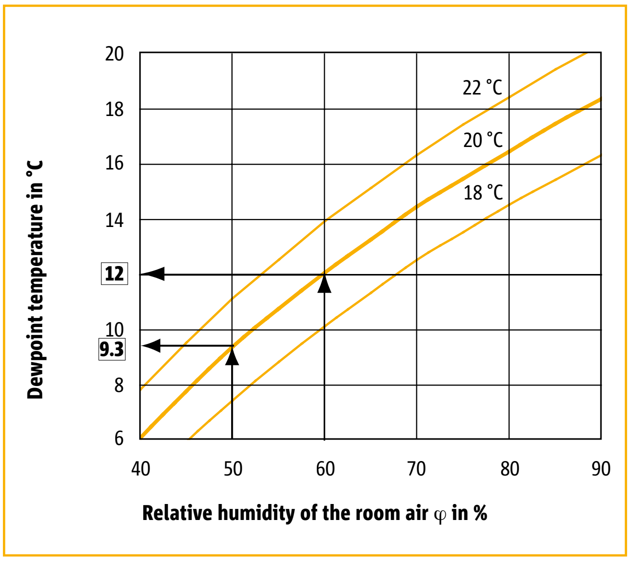

Figure 31: Dependency of the dewpoint temperature on the room air humidity and temperature.

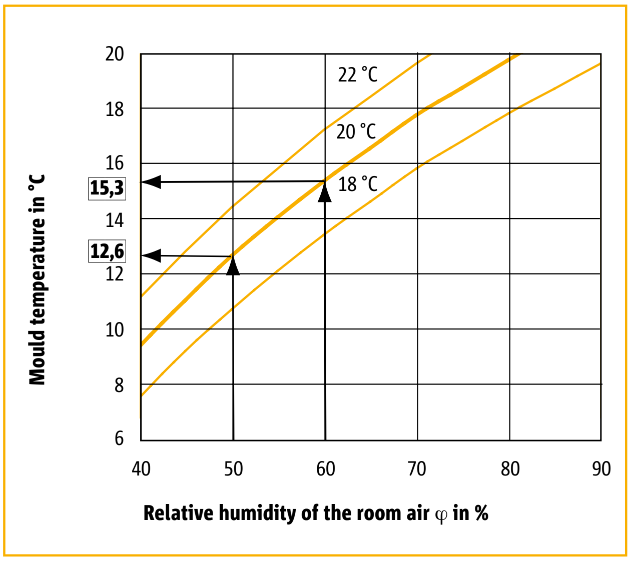

Figure 32: Dependency of the mould temperature on the room air humidity and temperature.

The **dew point temperature** is dependent upon the inside air temperature and humidity (see Figure 18). The higher the relative inside air humidity and temperature, the higher the dew point temperature becomes, - and the sooner condensation begins to form on cold surfaces.

The indoor air climate is typically an average of approx. 20 °C and 50% relative humidity. This puts the dew point temperature at 9.3 °C. Rooms frequently exposed to moisture, such as bathrooms, can easily reach higher humidity levels of 60% or more. This also raises the dew point temperature and increases the risk of condensation forming. At a humidity level of 60% in a room, the dew point temperature is already at 12.0 °C.

Mould growth on building component surfaces can occur with moisture levels as low as 80% humidity in the room.
This means that mould begins to grow on cold component surfaces if the surface is at least cold enough that a moisture level of 80% can be reached in the directly adjacent air layer. The temperature at which this occurs is the so called **mould temperature** θ_S.
Mould formation thus already begins at temperatures above the **dew point temperature**.

For an indoor climate of 20 °C and 50% relative humidity, the mould temperature is 12.6 °C (see Figure 32), which means it is 3.3 °C higher than the dew point temperature (see Figure 31). For this reason, the mould temperature is the decisive aspect of preventing structural damage due to mould formation. Surface temperatures must therefore be kept above the mould temperature.

Predicting Surface Temperature

The temperature factor is a parameter that helps evaluate the risk of mould growth and condensation on the inside surfaces of a construction.

The temperature factor f_{Rsi} is defined as the temperature difference between the inside surface temperature and the outside air temperature ($\theta_{si} - \theta_e$) divided by to the temperature difference between the inside and outside air ($\theta_i - \theta_e$):

$$f_{Rsi} = \frac{\theta_{si} - \theta_e}{\theta_i - \theta_e}$$

Minimum requirement according to IP1/06

The purpose of the minimum requirements for the f_{Rsi} value is to prevent damage to the structure from condensation. The general rule for dwellings is:

$$f_{Rsi} \geq 0.75$$

If Accredited Construction Details are used, there is no requirement to prove thermal performance. If another detail is used, numerical modelling must be carried out to prove that $f_{Rsi} > 0.75$

The f_{Rsi} is a relative value and thus provides the advantage that it depends only on the design of the thermal bridge and not on the external and internal air temperature like θ_{si}. The value of the temperature factor when f = 1 is if the minimum inside surface temperature θ_{min} is the same as the inside air temperature and when f = 0 is if it is the same as the outside air temperature (see Figure 33).

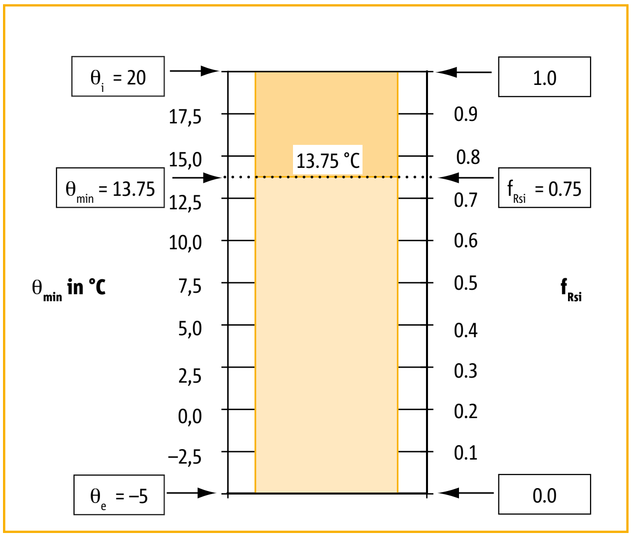

Figure 33: Definition of the f_{Rsi} value.

The minimum surface temperature is determined using three dimensional numerical analysis. With this number and with the air temperature inside and outside it can be calculated thus:

$$f_{Rsi} = \frac{15°C - 0°C}{20°C - 0°C} = 0.75$$

In this example the surface temperature is 15°C and the air temperatures are 20°C and 0°C, this results in an f_{Rsi} of 0.75.

4.3 Basic definitions of thermal characteristics

Term	Symbol	Units	Description
Conductivity	λ	$\frac{W}{(m \cdot K)}$	The ability of a material to transmit heat in terms of energy per unit area per unit thickness for each degree of temperature difference.
Equivalent Conductivity	λ_{eq}	$\frac{W}{(m \cdot K)}$	The averaged or equivalent thermal conductivity of a component consisting of several building materials, effectively treating the component as a homogeneous material that provides the same thermal characteristics.
Thermal resistance	R	$\frac{(m^2 \cdot K)}{W}$	The thermal resistance R is the resistance of a 1m length of material to heat flow per Kelvin temperature difference. $R= t/\lambda$ Thermal resistance of an assembly with uniform layers of materials, including air films, which can be added to get the total. $R = R_1 +R_2+R_3...$
Thermal Transmission Coefficient	U	$\frac{W}{(m^2 \cdot K)}$	Rate of Heat flow through a unit area of an assembly for a temperature difference of 1K $U=1/ R$
Heat Flow	Q	W	Rate of Heat flow through an assembly 1W = 1 J/s
Linear Heat Transmittance coefficient	Ψ	$\frac{W}{(m \cdot K)}$	A calculated value representing the added heat flow associated with a linear thermal bridge.
Point Heat Transmittance coefficient	χ	$\frac{W}{K}$	A calculated value representing the added heat flow associated with a point thermal bridge.

5. References

1. Report 060814SCH, Thermal Performance of Steel Beam Junctions using Different Connection Methods, Oxford Brookes University, updated 18th December 2012

2. Report 121212SCH, Thermal Performance of Concrete Balcony Connections using Different Connection Methods, Oxford Brookes University, 24th January 2014

3. Report 120927SCH, Steel balcony connections to concrete slabs using different connection methods, Oxford Brooks University, updated December 2012

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