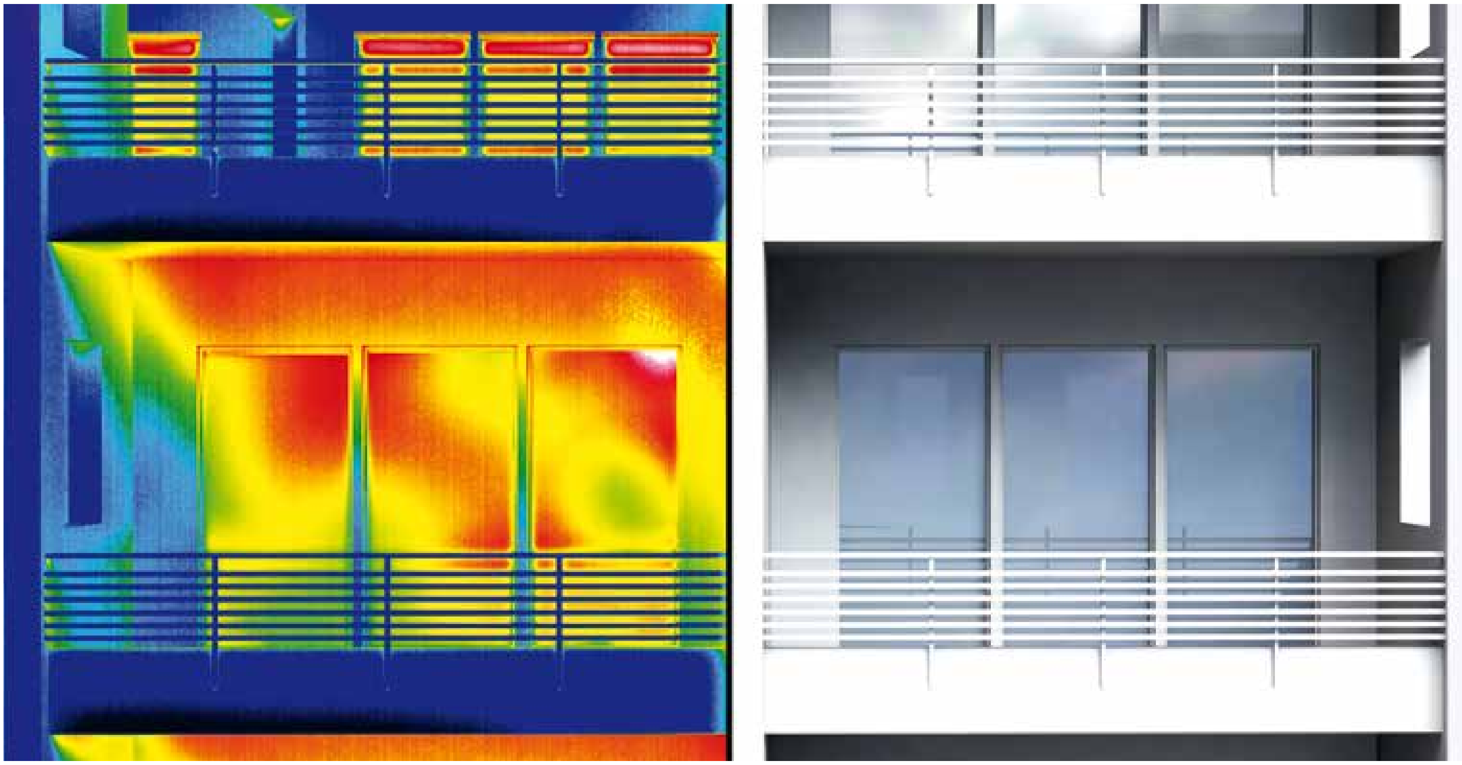

Design Guide

Solutions to Prevent Thermal Bridging

September 2018

Foreword

This publication presents information on the nature and significance of structural thermal bridges in buildings constructed of concrete and steel. It draws from the methods and results of thermal modeling carried out under and ASHRAE sponsored research project, ASHRAE 1365 RP Thermal Performance of Building Envelope Details for Mid and High Rise Buildings, and additional analysis undertaken by the authors of that report, Morrison Hershfield Limited.

This information provides general guidance on methods of calculating the impact of structural thermal bridges and effective solutions of mitigating that impact. In practice, additional analysis would be required to assess and address specific situations.

Morrison Hershfield

This Design Guide was prepared in cooperation with Mark Lawton and Patrick Roppel of Morrison Hershfield Limited. With Schöck's expertise in solving thermal bridging issues, combined with years of research and devlopment, we teamed together with Morrison Hershfield to provide a first step in educating the market on best practice and solutions to thermal bridging.

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1. Summary

Improving the thermal performance of a building enclosure and minimizing the energy use of buildings has received increasing focus in the drive for sustainability and energy security. We have seen the adoption of increasingly stringent enclosure thermal performance requirements in building codes, ASHRAE and voluntary programs such as LEED. These include requirements aimed at controlling heat flow through the opaque portions of the building enclosure. Adding insulating materials to the enclosure assemblies 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; which requires identifying and mitigating thermal bridges.

Thermal bridges in building enclosures can be defined as localized areas with higher thermal conductivity than the adjacent areas. A typical thermal bridge in a building enclosure 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 could result in:

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

The possible consequences of these conditions include:

- Higher energy use for heating
- Higher energy use for cooling
- Noncompliance with energy code requirements
- Discomfort due to cold surfaces
- Condensation or frosting on chilled 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
- Mold growth and associated health concerns

A primary design goal for any building enclosure assembly 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 Design Guide, the heat transfer through common thermal bridges in a building can easily exceed the heat transfer through the insulated opaque enclosure assembles (reference ASHRAE RP-1365). If designers do not consider the impact of thermal bridging, they will not meet the intent of energy standards such as ASHRAE 90.1 and ASHRAE 189.1, and voluntary sustainability programs such as LEED, Green Globes and Passive House.

Schöck provides product solutions specifically designed to mitigate or eliminate structural thermal bridges in commercial building construction. For over 30 years, Schöck has developed research and expertise in building physics and understanding the problems of thermal bridging to provide the most effective solutions.

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 of building assemblies
- Methods to calculate the impact of thermal bridges on the energy flows, temperature and moisture performance of building enclosures
- Examples showing how the impact of thermal bridges can be mitigated during design, both in general and using Schöck Isokorb® thermal breaks
- Example procedures to evaluate energy benefit using whole building energy modeling
- Design guidance on how best to integrate Schöck Isokorb® thermal breaks for performance and code compliance

2. Introduction to Thermal Bridging

2.1 Thermal Performance of Building Envelopes

The thermal efficiency of a building is a function of the thermal performance of the planar elements (e.g. wall, roofs, windows), the local heat losses that can occur around the planar elements and where the planar elements 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, it is recognized that the local 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. 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.

Figure 2 shows a well insulated balcony, as there is a low outside surface temperature at the slab, coloured in blue, due to minimized heat transfer through the assembly.

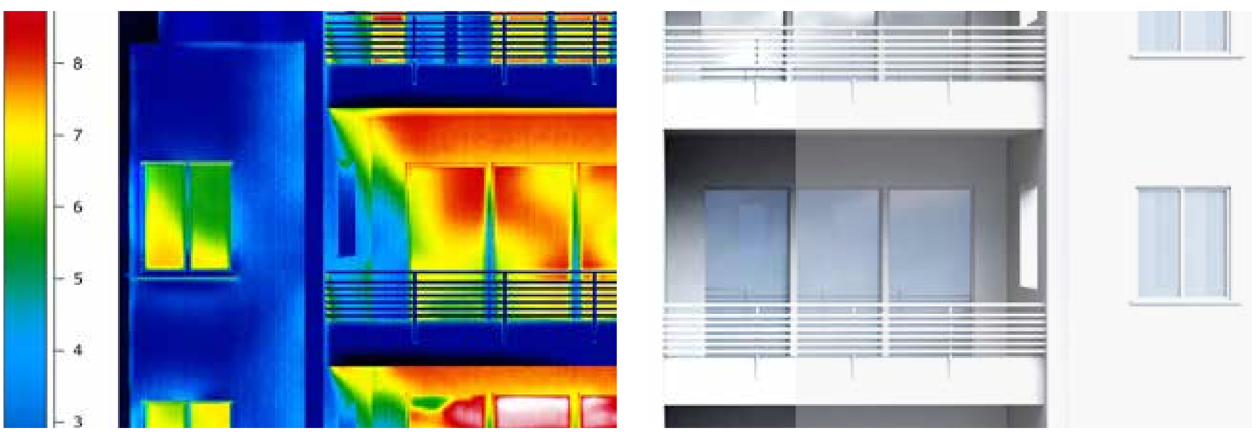


Figure 1: Thermal image of a residential building with higher temperatures at the windows, doors and balcony slabs

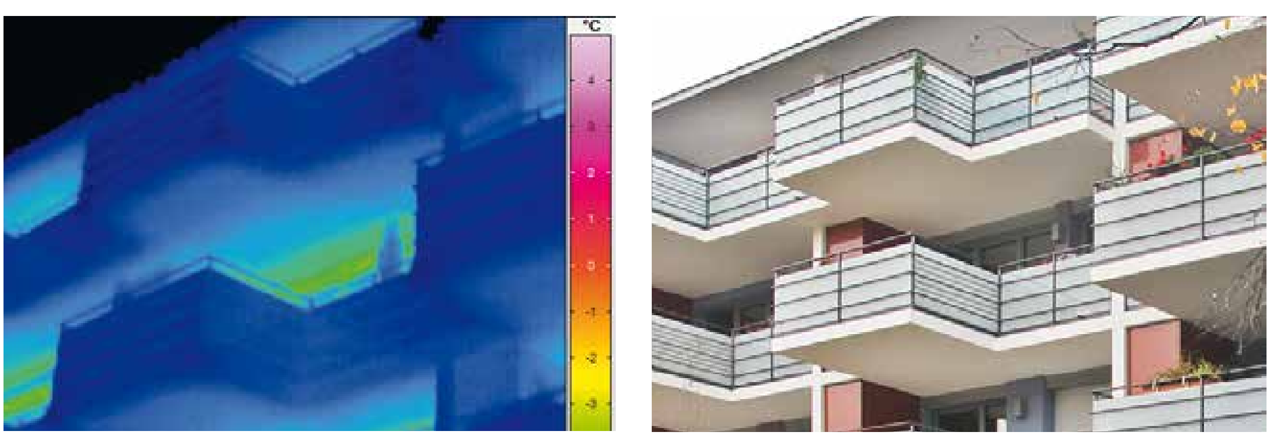


Figure 2: Thermal image of a residential building with minimized thermal bridges and an even temperature distribution along the envelope

2.2 What is a Thermal Bridge?

Thermal bridges are localized areas with higher thermal conductivity than their neighbouring areas. The rate of heat flow though a thermal bridge depends on a number of factors:

- The temperature difference between the heat source and heat "sink"
- 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 conductivity 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 simple 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. Still, one 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 anchors penetrating a layer of insulation, see Figure 3. These metallic anchors allow more heat to flow than the surrounding insulation.

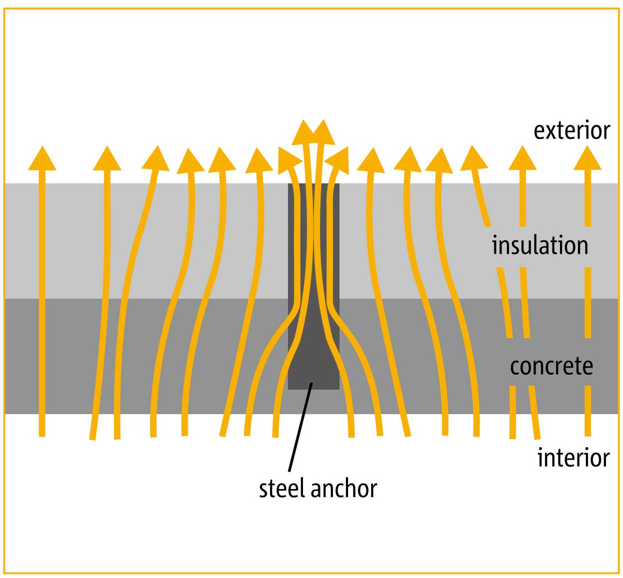


Figure 3: Cross-section through three materials (dark gray with high conductivity (steel), gray with medium conductivity (concrete), and light gray with low conductivity (insulation)); the direction of heat flow is shown by the arrows. The heat flows from the warm room (bottom edge of the image) to the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

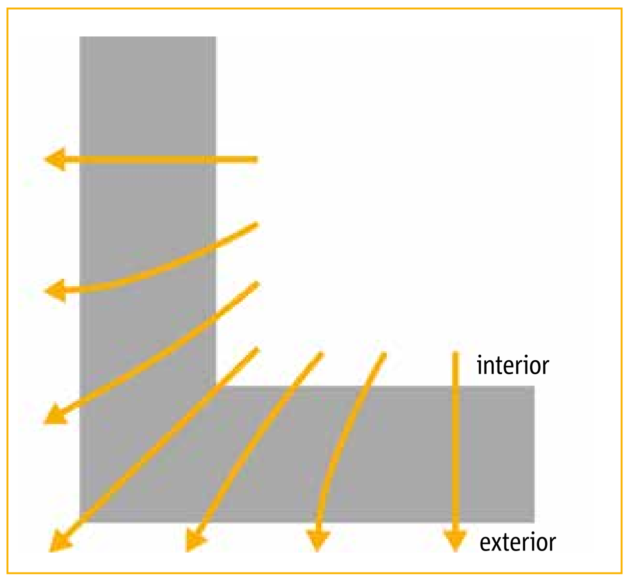


Figure 4: Cross-section of a building corner. The streamlines show the direction of heat flow from the warm to the cold area. The linear heat flow from an undisturbed wall is significantly affected by the geometric conditions.

Geometric Thermal Bridges

There is another kind of thermal bridge that depends on geometry, rather than on materials with different conductivities. Geometric thermal bridges can occur when the heat-emitting surface is smaller 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.

2.3 Types and Characteristics of Thermal Bridges

There are different characteristic values used to determine and limit the effects of thermal bridges. They describe different characteristics of thermal bridges. While the **thermal transmittances ψ (Psi) and χ** provide insight into the thermal energy losses, the **temperature index TI** and the **minimum surface temperature** assess the risk for mold growth and accumulation of condensate, find more detailed information in part 2.5 (Calculating Heat Flow) and part 2.6 (Humidity, Temperature and Condensation Control).

Linear Thermal Bridges

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

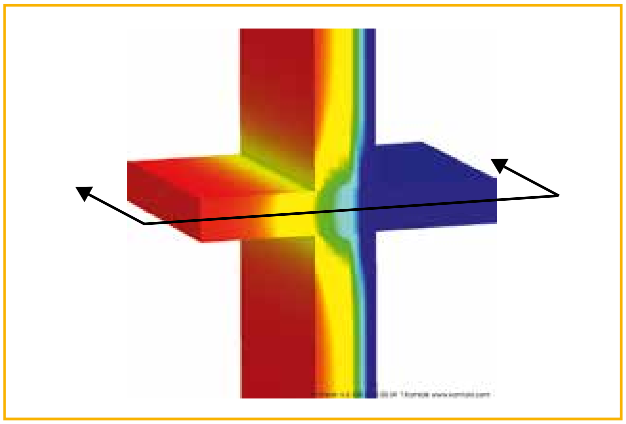


Figure 5A: Illustration of a linear thermal bridge on a linear balcony connection. The left side shows the warm interior with a red surface, while the cold exterior is shown in blue on the right. As the yellow and green spots in the interior corners show, the surface temperatures can drop quite significantly in these areas.

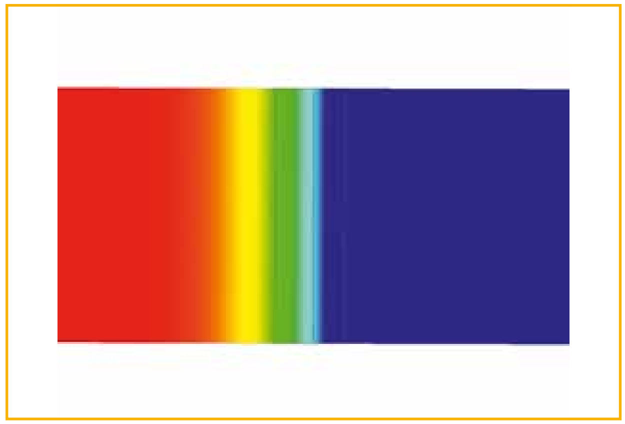


Figure 5B: Top view; this shows a cross-section through the balcony slab presented in 5A. You can clearly see that the heat loss is linear, meaning it remains the same across the entire connection length of the balcony.

Point Thermal Bridges

Some thermal bridges can be characterized as singular or Point thermal bridges. They only occur in one spot. Typical examples include fastening elements, such as dowels or curtain wall supports and anchors that penetrate the insulating layer. The energy losses incurred by punctiform thermal bridges are described by the **Point thermal transmittance χ**.

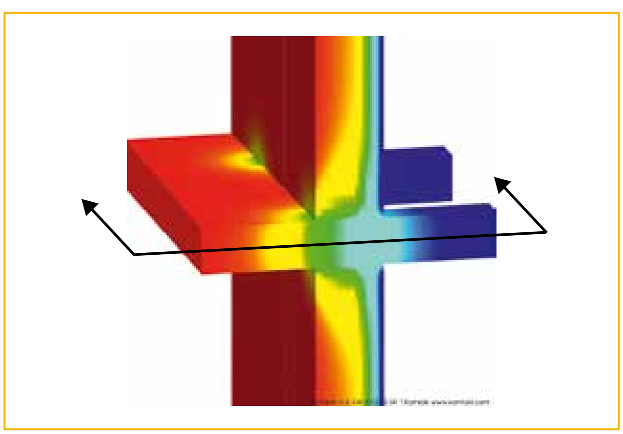


Figure 6A: Illustration of a local thermal bridge on a punctiform balcony connection. In this case, steel beams are connected to a concrete floor from the outside. The left side shows the warm interior with a red surface, while the cold exterior is shown in blue on the right. As the yellow and green spots in the interior corners show, the surface temperatures can drop quite significantly.

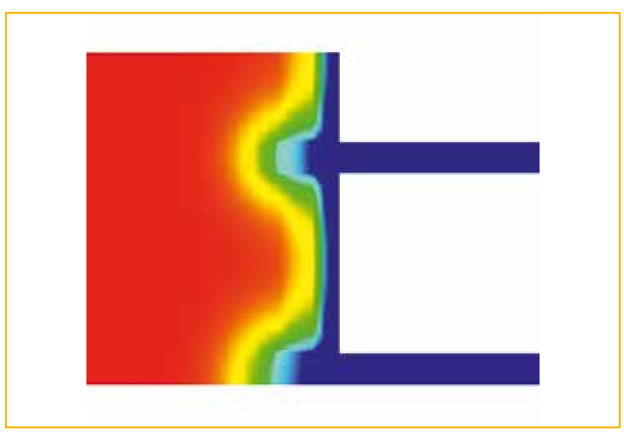


Figure 6B: Top view; this shows a cross-section through the balcony slab presented in 6A. You can clearly see that the heat loss is caused by the two continuous beams. The heat loss is also punctiform, meaning it is limited to specific spots.

2.4 Examples of Structural Thermal Bridges in Buildings

The connections of structural elements are typical structural thermal bridges, which must be considered with particular care. In practice, structural connections often lead to high heat loss and low surface temperatures in the room. **Condensation** and **mold formation** can be caused by structural thermal bridges. The following images and examples show typical thermal bridges occuring 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 7. 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 surface temperature. As a result, the heating costs and the risk of mold growth significantly increase around the intersection of the interior slab and the exterior wall assembly, see Figure 8.

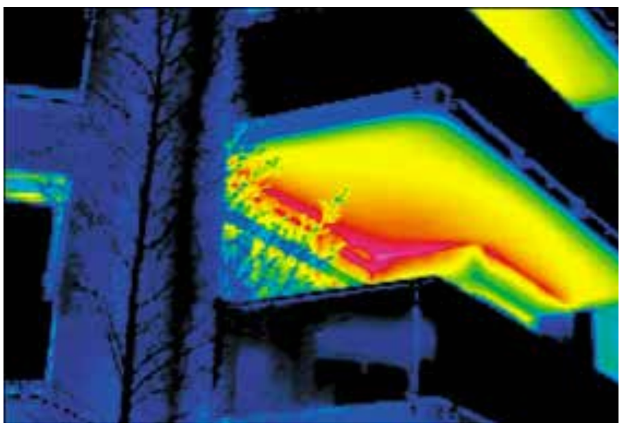


Figure 7: Infrared scan of a balcony thermal bridge with higher temperatures at the exterior slab

Figure 8: Photograph showing condensation and organic growth on the ceiling of a concrete slab adjacent to an exposed slab edge thermal bridge. Condensation has formed here frequently as a result of colder interior surface temperatures.

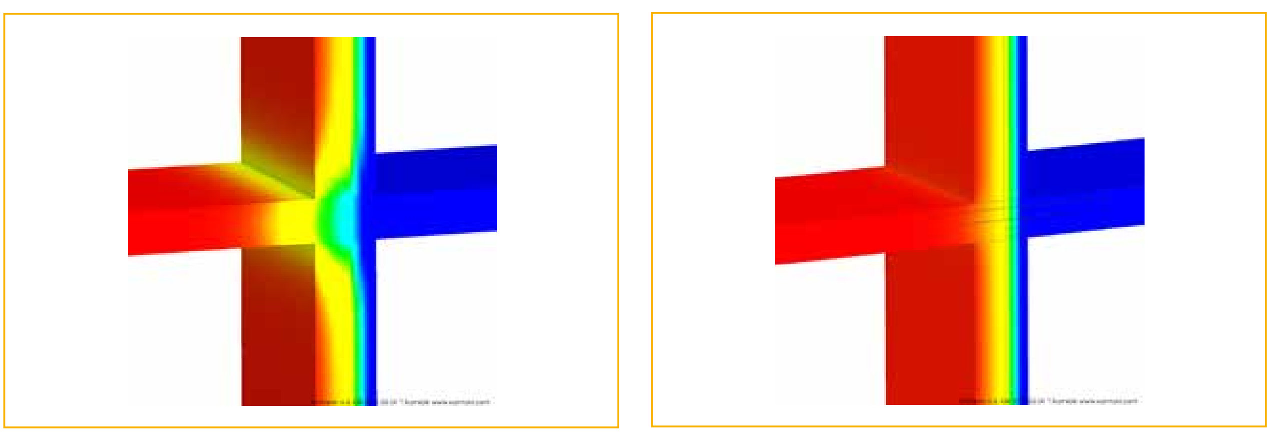


Figure 9: Continuous balcony slab versus a solution with Schöck Isokorb®; Left: continuous balcony slab without thermal break, Right: Balcony slab thermally broken with Schöck Isokorb® providing a continuous insulation layer

Figure 9 shows a thermographic illustration of a reinforced concrete balcony with and without a thermal break provided by a 3D thermal analyses. The image on the left shows a unmitigated thermal bridge. The color 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.

There are various further structural elements penetrating the building envelope like parapets in concrete structures or steel beams used for canopies or roof overhangs.

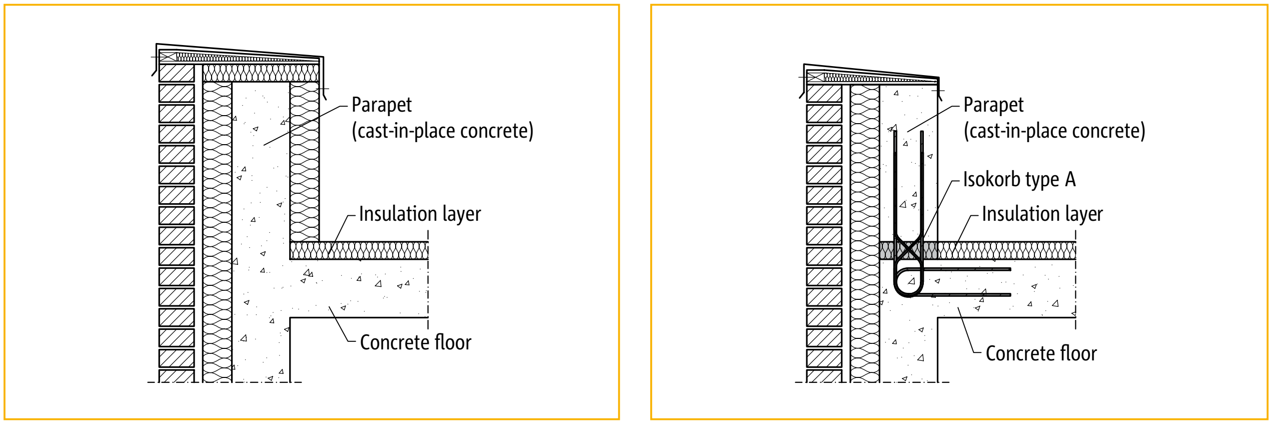


Figure 10: The illustration on the Left shows a parapet with insulation wrapping causing a thermal bridge in the insulation layer.

The illustration in Figure 10 on the left shows a traditional design approach, wrapping the parapet with insulation. The illustration on the right shows an integrated design approach considering a thermal break element, providing continuous insulation along the insulation layer. This solution results in reduced heat transmittance and therefore reduced energy costs.

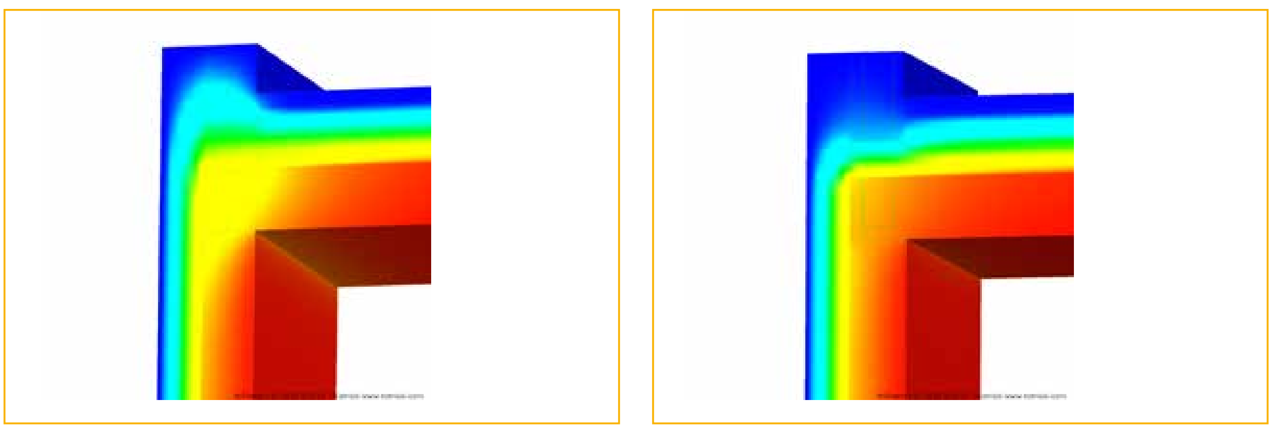


Figure 11: Left: Continuous parapet connection without thermal break, right: Parapet connection thermally broken with Schöck Isokorb®

Figure 11 shows the heat flows through a parapet connection without a thermal break (left) and with a thermal break (right). The color gradient illustrates the temperatures in the component. The heat flows from the warm (red) area to the cold (blue) area. The parapet connection without thermal break (left) suffers high heat loss through the assembly, which causes low interior surface temperatures. In the thermally broken connection (right), the heat rarely escapes through the load-bearing thermal insulation element. This is indicated by the low temperatures above the thermal break element, which is shown in dark blue.

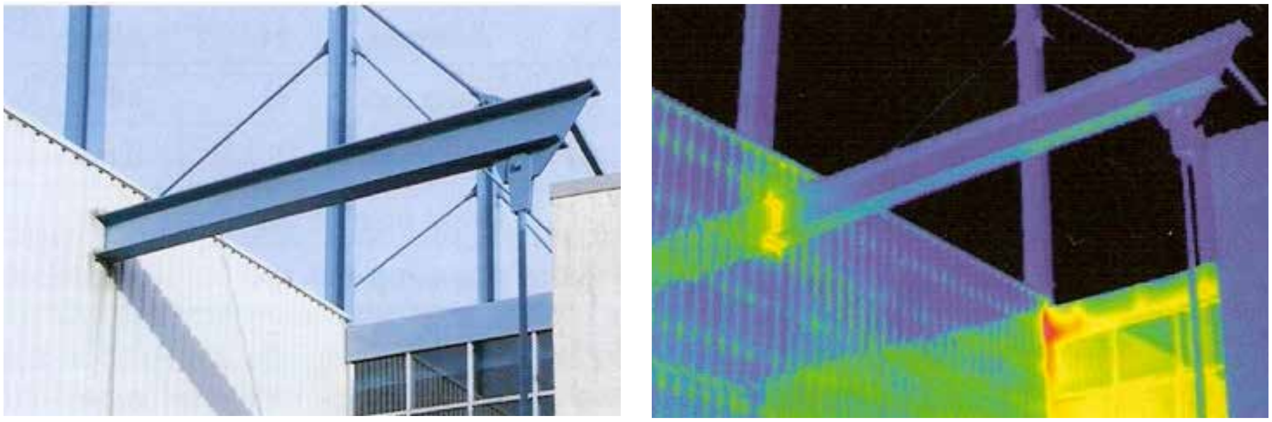


Figure 12 Structural thermal bridging in steel structures. The image on the left shows a steel beam penetrating the insulation layer. On the right, is an infra-red scan of this location revealing areas of higher temperatures and heat loss around the penetration.

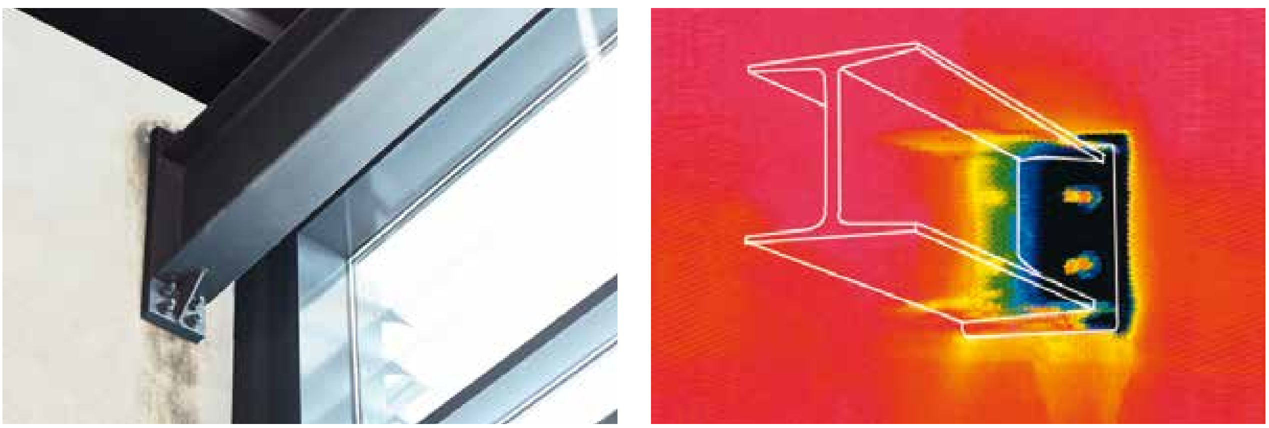


Figure 13: Thermal bridging occuring at continuous steel beams. The picture on the left shows the potential damages of the adjacent assemblies created by cold interior surfaces and condensation, while the image on the right shows the according temperature distribution by an infrared scan.

Impact of the alignment of the wall assemblies on the surface temperatures

Especially in wall systems including high conductive materials such as steel studs, the temperature of materials in an assembly can be less dependent on U-values or the magnitude of energy flow, and more dependent on the arrangement of materials and geometry.

With a single layer of insulating material in a building assembly, one can expect that the inside surface of the insulation will be close to the indoor temperature, and the outside surface will be close to the outside temperature (though sun and air films will have an effect). If a highly conductive element, such as a steel stud, passes through the insulating layer, its temperature will be more uniform with less difference between inside and outside.

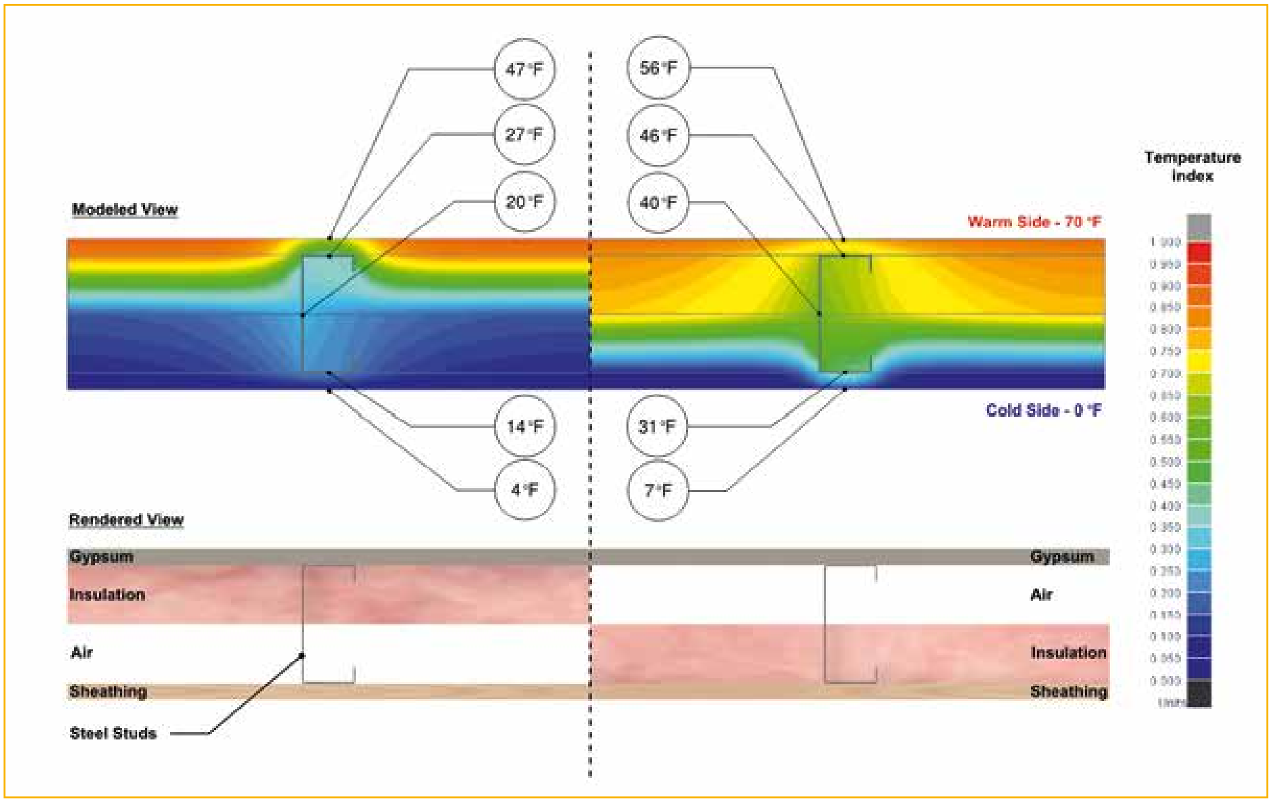


Figure 14: Thermal analysis of steel stud wall with different placement of insulation

The temperature of such a thermal bridge depends on how easily heat can enter the bridge compared with how easily it can leave. For example, in Figure 14 the assemblies on the left and right side are made of the same materials, have the same level of insulation and will allow about the same heat flow. However, the temperature of materials at critical locations is different. On the left side assembly, the steel stud has more area exposed to cold air and the right side assembly has more exposed to warm air. The temperature of the stud and the surface temperature of the interior wallboard at the stud on the left side assembly are significantly colder than the right. The colder surfaces result in an increased risk for condensation (See chapter 2.6).

This phenomenon is one reason building scientists are such advocates of having insulation outside the structure. It is essential to minimizing the potential for condensation in cold climates.

2.5 Calculating Heat Flow and thermal bridges

Basic Definitions

To understand the heat flow one needs to understand the definitions of k, R und U. Starting with k, the conductivity. It describes the ability of a material to transmit heat in terms of energy per unit area per unit thickness per degree of tempreature difference, see table 1.

Material	Conductivity k in W/(mK)	Conductivity k in BTU in/hr/ft²/°F
Insulation Material	0.035	0.243
Reinforcement steel	50	350
Stainless steel	15	100
Concrete	1.8	14

Table 1: thermal conductivity of a range of materials

The thermal resistance R is the resistance, a material counters a heat flow with at 1 °K for one m² and is based on the conductivity K. R is calculated as the thickness of the material divided by its thermal conductivity:

$$R = \frac{l}{k}$$

k: Thermal conductivity in BTU in/hr/ft²/oF (W/(mK))
l: Material thickness in (m)

This calculation of the R-value can also be performed for multilayer components, named as R_T:

$$R_T = \frac{l_1}{k_1} + \frac{l_2}{k_2} + \dots + \frac{l_n}{k_n}$$

Based on the R-value the U-value thermal transmission coefficients, describe the amount of heat flow of an assembly. It is calculated as the reciprocal value of the sum of the thermal resistance and the surface resistances $1/h_0$ and $1/h_i$:

$$U = \frac{1}{\frac{1}{h_0} + R_T + \frac{1}{h_i}}$$

So the U-value describes the heat flow in a one dimensional way, which is needed to describe the energy loss of areas of the same assembly. This is not applicable to areas of thermal bridges, see Figure 15. More informations about Basic Definitions, see chapter 5.1.

Heat Flow Equations - Parallel Path Method

Before the ready availability of computer models, heat flow through building assemblies was typically calculated using one dimensional, parallel path heat calculations.

The general equation is

$Q = (U_1 \cdot A_1 + U_2 \cdot A_2 + U_3 \cdot A_3 + \ldots) \cdot \Delta T$ (equation 1)

where:

Q	is the heat flow through a defined area of a building enclosure with multiple adjacent assemblies.
U_x	is the Thermal Transmission Coefficient in BTU/ h/ ft^2/°F for assembly x including the effect of the interior and exterior surface films
A_x	is the Area of assembly x, in ft^2
ΔT	is the difference between the indoor air temperature and the outdoor air temperature

Some people are more comfortable working with the concept of thermal resistance (R) than its inverse thermal transmission (U). Using Thermal Resistance, equation 1 then becomes

$Q = (A_1/R_{T1} + A_2/R_{T2} + A_3/R_{T3} + \ldots) \cdot \Delta T$ (equation 2)

where:

R_{Tx} is the thermal resistance for assembly x, generally obtained by summing the resistance of each layer of material in the assembly including inner and outer air films

and

$R_{effective} = (A_1/R_1 + A_2/R_2 + A_3/R_3 + \ldots) / A_{total}$ (equation 3)

and

$U_{effective} = 1/ R_{effective}$

Equations 1 and 2 are useful to illustrate some important aspects of material thermal bridges. Consider that the R-value per inch thickness of common insulations is about 50 times that of concrete and about 1500 times that of steel. Consider a wall with R 20 insulation; if 4% of its area is penetrated by a concrete slab and 0.07 % of its area by steel connectors, about the same amount of heat would go through each of the slab, the steel, and the rest of the wall. The Effective R-Value of the wall assembly would be about one third of the insulation value (i.e. about 4.2). Clearly, if one does not take into account the impact of thermal bridging, this can result in major errors in calculating heat flows through building assemblies and the purchased energy required to make them up.

In reality, the above equations only hold true if heat flow is one dimensional and parallel or, in other words, there is little lateral heat flow so that heat does not move sideways and around thermally resistant elements. This has proven to be a reasonable approximation in wood frame construction, where even the structural materials have significant thermal resistance (wood is about R1 per inch). In buildings constructed of highly conductive materials such as concrete, steel, aluminum, and glass, the assumption of parallel heat flow is much less likely to be valid.

Considering Lateral Heat Flow

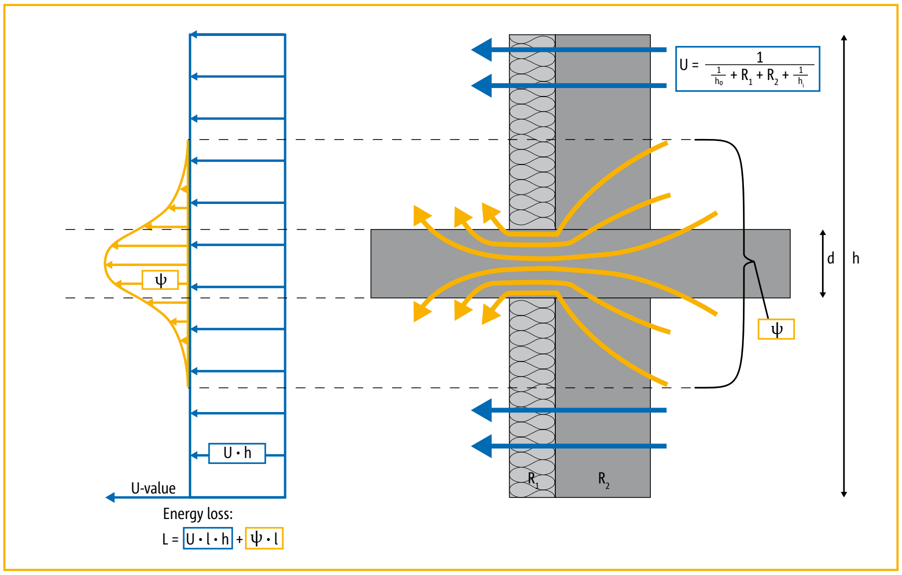


Figure 15: Pattern of heat flow through a building enclosure with materials that allow lateral heat flow to a thermal bridge

Figure 15 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 clear field heat flow (U_0) is the heat flow through an assembly without thermal anomalies. The linear transmittance is the additional heat flow with the thermal anomaly due to lateral heat flow as shown in Figure 15.
- 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).

Recognizing that the heat flow through a thermal bridge can be added to the heat flow through a "clear field" building assembly provides a method of accounting for thermal bridges that cannot really be addressed by the "parallel path" method of equations 1 and 2. This is particularly true when the power of computer modeling 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:

- The impact of small, frequent and distributed bridging elements (e.g. brick ties or Z-girts carrying cladding) (see the girts in Figure 16 below) are generally best handled by adding their thermal influence to **Clear Field Effective U-value** (BTU/ft²/°F) for the assembly. The term $\mathbf{U_0}$ is used to represent this.
- The heat transfer associated with **linear element** (e.g. slab edges, corners, roof/wall intersections, window wall interfaces etc.) can be handled by determining the **Linear Heat Transmittance coefficient** (BTU/h/ft²/°F). 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** BTU/h/°F). The Greek letter Chi (χ) is conventio-nally used to represent a point transmittance.

Figure 16 illustrates an example of using computer modeling 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:

1. The wall without the slab but with the frequent and distributed bridging elements (the Z-girts in this case) that one would want to include in U_0. The program provides the heat flow per unit time for the assembly (Q_0).
2. The assembly including the slab. The program provides the heat flow per unit time for the combined assembly (Q).

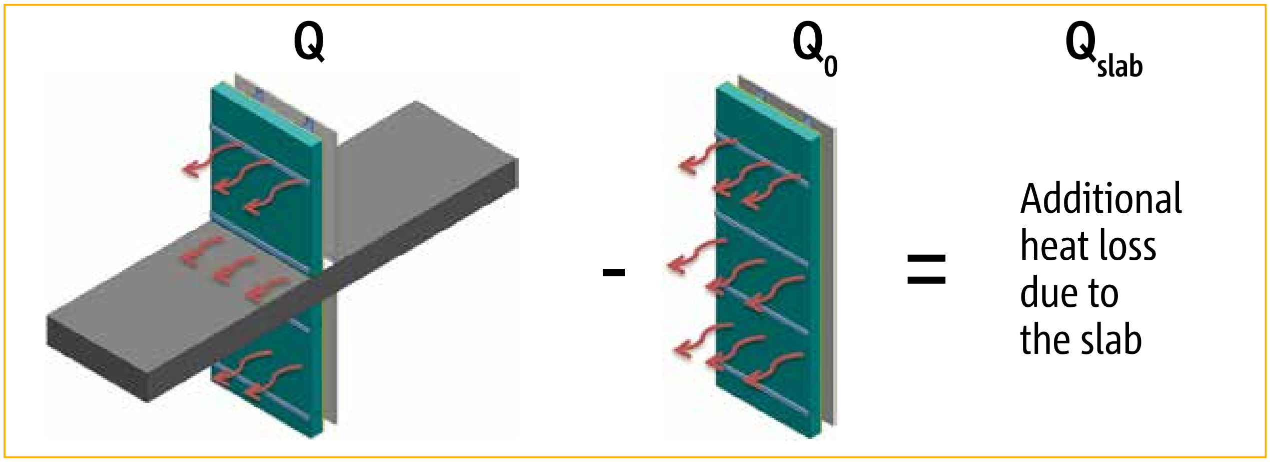


Figure 16: Example of process of determining the linear transmittance of a slab penetrating a wall

The difference in heat flow between the two models divided by the width of the modeled sections is the linear transmittance or Ψ for slab. This value is effectively the area under the yellow curve in Figure 15.

A similar process can be used to calculate the point transmittance of something such as a beam penetrating a wall.
Linear and point transmittances can be determined by two or three dimensional thermal modeling for specific details. For example, a commonly used software package developed and routinely used to evaluate glazing systems called THERM can also be used to evaluate the thermal performance of any wall detail. Moreover, generic transmittance values becoming more readily available for use by industry (ASHRAE 1365-RP, Building Envelope Thermal Bridging Guide, ISO 14683).
Using this concept, the total heat flow through a building assembly 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.

$Q = [U_o \cdot A + \Sigma(\Psi_i \cdot L_i) + \Sigma(\chi_j \cdot n_j)\ ]\ \Delta T$ (Equation 4)

where

U_o	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 heat 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

To include the effects of thermal bridging transmittances to whole building energy simulation, the overall wall or roof assembly U-value inputs into the energy model should be modified by using the appropriate Ψ and χ factors. An equivalent total U-value can be entered into the models as:

$U_{effective} = U_o + [\Sigma(\Psi_i \cdot L_i) + \Sigma(\chi_j \cdot n_j)]/A$

where $U_{effective}$ is the corrected U-value and all other terms have been previously defined.

If the energy model requires R-values, the surface transfer coefficients (“surface films”) should be

$$R_{effective} = \frac{1}{U_{effective}} - \frac{1}{h_0} - \frac{1}{h_i}$$

where h_o and h_i are the interior and exterior surface transfer coefficients respectively.
The examples in Chapter 3 and 4 use this method of calculation.

2.6 Humidity, Temperature and Condensation Control

One consequence of thermal bridging is that surfaces can reach temperatures that allow condensation of water vapor from the indoor air. The collected moisture can corrode steel, rot wood and allow mold growth. Condensation control is an important factor in the success and durability of buildings.
The term “humidity” refers to water vapor in the air. The amount of water vapor that air can hold depends on its temperature. We use the term **Relative Humidity** (RH) to define the ratio of vapor in the air to what the air could hold at that temperature.

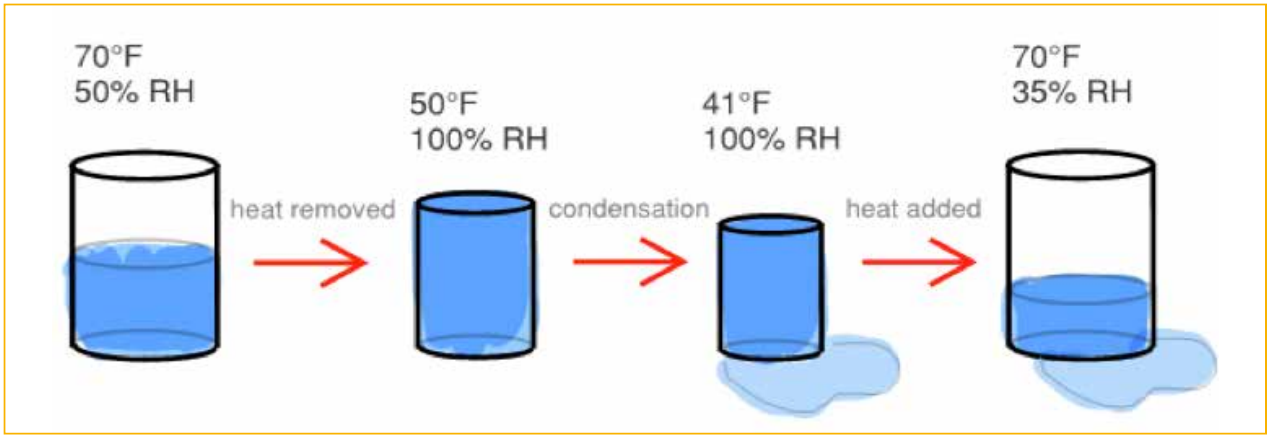


Figure 17: Analogy of condensation process

Figure 17 is an analogy explaining some of the interactions between air, vapor, temperature and liquid water. The analogy 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 70°F 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 50°F, the container is full to the top. This is the point where the air is **saturated** or at 100% RH or is at 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 one now warmed the air (without adding back the condensed moisture) the RH would go down, and when it reached the same starting temperature, the air would be of a lower RH than at the beginning of the exercise.

All these relations 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 vapor 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 vapor 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 condensate forms on a surface of a given temperature below the dewpoint.
- The relative humidity of the air layer in contact with a cold surface will be at a higher relative humidity 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 mold growth. Because mold spores and suitable nutrients (cellulose) are virtually always present in dust, all that is required to cause mold 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 mold species can grow in high humidity conditions without actual liquid water. In Europe, they use a concept called the “Mold Temperature” which is similar to the Dew Point Temperature, but defines the temperature where air is at 75% RH. Figure 18 and 19 compare the Dew Point Temperature and Mold Temperature for a range of indoor conditions.

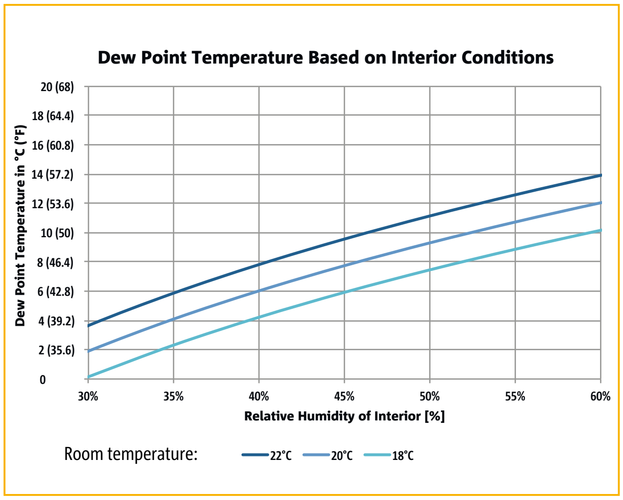


Figure 18: Dependency of the dew point temperature on the humidity and temperature in the room

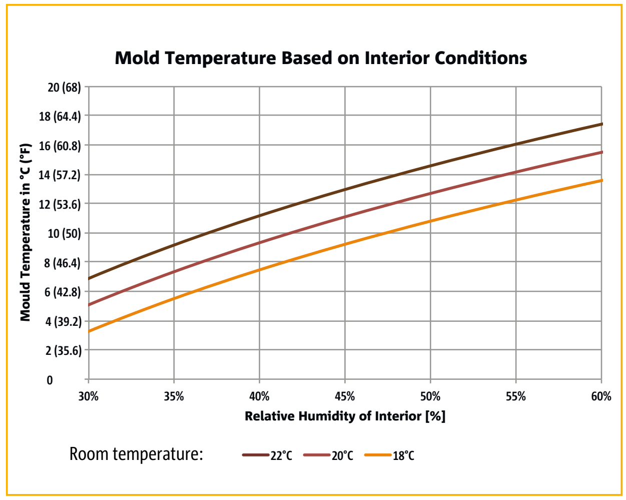


Figure 19: Dependency of the mold temperature on the humidity and temperature in the room

The indoor air in a moderately cold climate could be 68°F and 50% relative humidity. This puts the dew point temperature at 49°F; condensation will form on any surfaces that are below that temperature. Rooms frequently exposed to moisture, such as bathrooms, can easily reach higher relative humidity levels of 60% or more. This also raises the dew point temperature and increases the risk of condensation. At a relative humidity level of 60% in a room, the dew point temperature will be at 54°F.

It should be noted that the indoor humidity is a function of the moisture content (or vapor pressure or dewpoint) of the outdoor air, how much moisture is added to the air inside, and the ventilation rate of the building. In very cold climates, the outdoor air is so cold it cannot contain much water vapor. In cold climates, the indoor relative humidity in winter will be lower than in mild conditions. For example many provisions of the Canadian Building Code are based on the understanding that the indoor humidity is not usually over 35% in winter design conditions.

Predicting Surface Temperature

It is common practice to evaluate the "condensation resistance performance" of a building enclosure assembly based on how well it maintains the temperatures of the inside surfaces exposed to indoor air. This is generally done by defining some sort of **Temperature Index (TI)**, which is the ratio of the temperature difference between the inside surface temperature and the outside air temperature, divided by temperature difference between the inside and outside air; or, more formally:

$$TI = \frac{T_s - T_0}{T_i - T_0}$$

Where

T_i is indoor air temperature
T_o is outdoor air temperature
T_s is the temperature of the surface of interest (usually the coldest surface facing indoor air)

The minimum surface temperature arises as a result of a three dimensional analysis. With this number and the air temperature inside and outside the TI can be calculated:

$$TI = \frac{49°F - 5°F}{68°F - 5°F} = 0.70$$

In this example the surface temperature is 49°F and the air temperatures are 68°F and 5°F, this results in an TI of 70.

This ratio remains fairly stable regardless of the size of the temperature difference, so that if one has data on the temperature index, one can predict the interior surface condition at an outdoor temperature.

The concept of the Temperature Index is commonly used with windows. The Condensation Resistance Factor (CRF) used in US window standards is a Temperature Index, as is the **I value** used in Canadian standards (there is a difference in how they define the interior surface temperature for their calculation). A Temperature Index of 45 would be a very poor window and a value over 80 would be a very good one.

It is logical that the temperature index of any point of the opaque part of a building enclosure be higher than that of the windows. The following table, taken the Canadian Special Publication A440.1-00 User Selection guide to CSA A440 Windows, shows guidance provided to window specifiers.

	Dew point Temp.			Heating Design Temperature								
			°F	32	23	14	5	-4	-13	-22	-31	-40
			°C	0	-5	-10	-15	-20	-25	-30	-35	-40
Indoor RH (%)	°F	°C		Temperature Index								
20	25.5	-3.6		-	5	21	32	41	47	53	57	61
25	30.9	-0.6		-	17	31	41	48	54	59	62	66
30	35.4	1.9		9	28	40	48	55	60	64	67	70
35	39.4	4.1		20	36	47	54	60	65	68	71	73
40	42.8	6.0		30	44	53	60	65	69	72	75	77
45	45.9	7.7		38	54	59	65	69	73	75	78	79
50	48.7	9.3		46	57	64	69	73	76	79	80	82
55	51.3	10.7		53	63	69	73	77	79	81	83	84
60	53.6	12.0		60	68	73	77	80	82	84	85	87
65	55.8	13.2		66	73	77	81	83	85	86	88	89
70	57.9	14.4		72	77	81	84	86	87	89	90	91
75	59.7	15.4		77	82	85	87	89	90	91	92	92
80	61.5	16.4		82	86	88	90	91	92	93	94	94

This table is adapted from Table UG-6 of CAN/CSA A440.1-00 User Selection Guide to CSA A440 Windows

	Heating Design Temperature	
City	°F	°C
Edmonton	-22	-30
Chicago	-5	-21
Toronto	-3	-19
Denver	-2	-19
New York	13	-11
Vancouver	20	-7
Dallas	21	-6
Seattle	23	-5

Table 2: Heating Design Temperature related to the Dew point Temperature and the Indoor relative humidity. Some examples of the Heating Design Temperature for different Cities.

Some European countries have standards requiring that all enclosure assemblies have a temperature index above 70 to ensure that condensation is avoided. This might be a reasonable target for opaque assembles in cold climates in North America.

2.7 Code Compliance and Building Regulations

In North America the dominant energy performance standards are

- ASHRAE 90.1 ***Energy Standard for Buildings Except Low-Rise Residential Buildings***
- ASHRAE 189.1 ***Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings***
- ***National Energy Code of Canada for Buildings*** 2011 (NECB) and its predecessor

Some building codes reference these standards directly. Voluntary programs such as Leadership in Energy and Environmental Design (LEED) and Green Globes also reference these standards, generally rewarding performance that is "better than ASHRAE."

The above standards provide minimum requirements for the design and construction of energy-efficient buildings, and address the building enclosure and building systems and equipment for heating, ventilating and air-conditioning, hot water heating, lighting, and electrical systems.

These standards can be met with a "prescriptive" approach by using assemblies and systems meeting a minimum performance defined in the standard. The minimum performance from enclosure assemblies are defined by a maximum assembly effective transmittance ($U_{effective}$) or, inversely, minimum effective R-value. The minimum performance levels for the enclosure were defined with consideration to cost effectiveness, so they vary by type of assembly, the nature of the construction, and the climate zone where the building is located. In general, each assembly used must meet the requirement. There is some capacity to "trade-off" the use of an assembly with a higher $U_{effective}$ value by having others with a lower $U_{effective}$ value.

Alternatively, compliance with energy standards such as ASHRAE 90.1 can be demonstrated by using the "performance path" where a whole building energy model is used to simulate energy use of the proposed building; this is compared to a "base building" that assumes the same building geometry and uses enclosure assemblies and building systems that just conform to the prescriptive requirements and has no more than 40% glazing. The proposed building complies with the requirements of the standard by showing a simulated energy performance that is as good as, or better than, the base building. LEED awards "points" for simulated energy performance defined as percentages better than the baseline building.

It should be noted that the ASHRAE standards are based on **Energy Cost ($)** but for example the current Canadian standard is based on **Purchased Energy (kW)**. The difference can affect what strategy is used to comply with the requirements. This is particularly true when considering thermal bridging in enclosure assemblies, because it affects energy use for heating, which can be supplied by a number of energy sources.

Thermal bridging can have a major impact on $U_{effective}$ of an enclosure assembly, and it must be considered in comparing to prescriptive requirements, or as input data for simulation programs. Each of the above standards provide information and procedures intended to ensure that thermal bridging is considered, but in a simple manner that can be applied consistently, as is required for a compliance test. For the prescriptive path, the standards rely on prescriptive requirement such as requiring layers of **"continuous insulation."** The current procedures used to demonstrate compliance with energy simulation allow some thermal bridges to be ignored for simplicity of evaluation. As research has revealed the significance of thermal bridging, and as methods of evaluating thermal bridging effects have been developed, we can expect changes to these compliance procedures. Further guidance see Chapter 4 Guidance to Whole Building Energy Perfromance.

If designers do not consider the impact of thermal bridging, they will not meet the intent of energy standards such as ASHRAE 90.1 and ASHRAE 189.1, and voluntary sustainability programs such as LEED, Green Globes and Passive House.

3. Best Practice Solutions and Details

3.1 Effective Solutions – Structural Thermal Breaks

Schöck Isokorb® thermal break solutions for concrete structures

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, structural thermal breaks optimize the function and performance of each integral element at the junction.

The high conductive materials such as reinforced concrete (k = 2.2 W/(mK)) or structural steel (k = 50 W/(mK)) at the connection are replaced with an insulating material of expanded polystyrene (EPS, k = 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 (k = 15 W/(mK)), instead of carbon steel (k = 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, as these offer better thermal performance compared to compression bars made of carbon steel or even stainless steel.

As one can imagine, the heat flow paths through the assembly are quite complex and the resistance to heat flow depends upon how much steel and/or concrete is used per foot, which in turn is also dependant on the loads which have to be supported. For the equivalent thermal conductivity of various solutions see Appendix Chapter 5.2.
For a standard balcony, Schöck Isokorb® type CM reduces the thermal conductivity k in the connection area by approximately 90%.

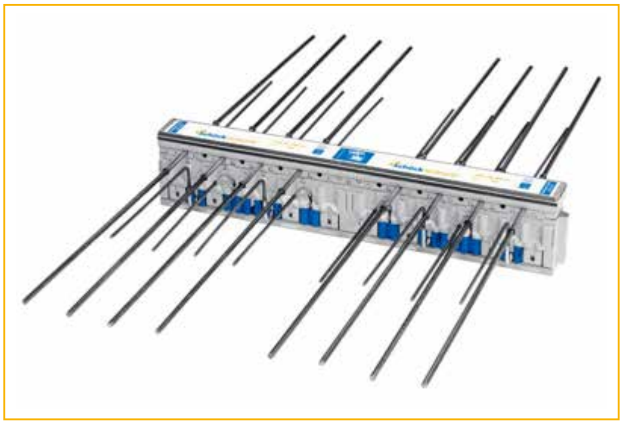


Figure 20A: Schöck Isokorb® type CM for concrete balconies.

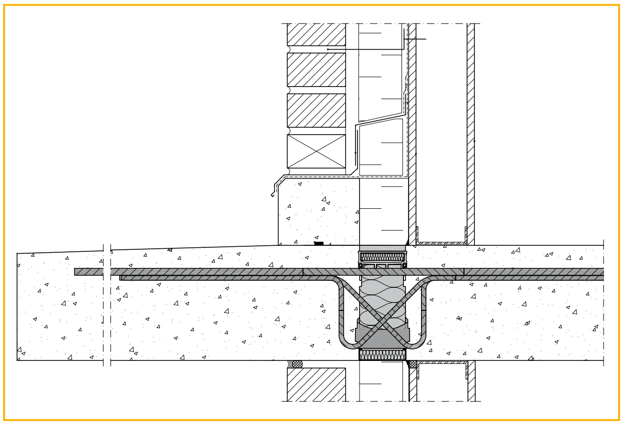


Figure 20B: Placement of Schöck Isokorb® in the assembly. The thermal conductivity of thermal break solutions compared to non-insulated connections is reduced by up to 92%.

Schöck Isokorb® thermal break solutions for steel structures

Figure 21A: Schöck Isokorb® type S22 for steel beams

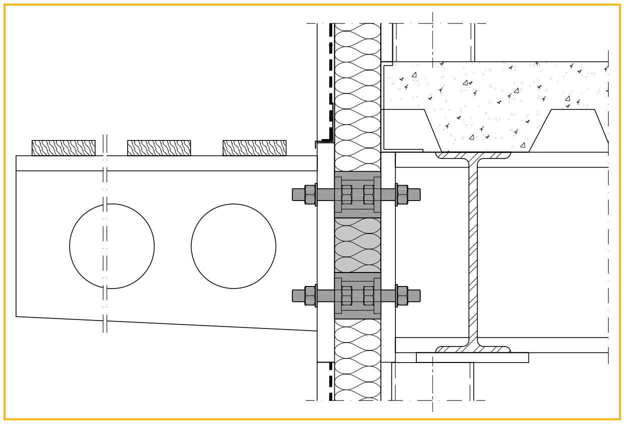


Figure 21B: Sample detail at a typical steel canopy for reference purposes

The high conductive material of structural steel (k = 50 W/(mK)) at the connection is replaced with an insulating material of expanded polystyrene (EPS, k = 0.031 W/(mK)) with a thickness of 80mm -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 k=15W/mK, compared to carbon steel 50W/mK.).

Typically two Isokorb® type S22 are used per beam connection. Appendix Chapter 5.2 show the k_{eq} and R_{eq} respectively. Note that heat transfer through the connection is about 85% reduced compared to the heat transfer through a continuous steel beam.

3D thermal modelings in the following sections show examples of Schöck Isokorb® for concrete structures and steel structures and without thermal breaks.

3.2 Concrete Balconies

The following example considers a concrete balcony slab intersection with exterior and interior insulated 3 5/8" x 1 5/8" steel stud (16" o.c.) wall assembly with horizontal Z-girts (24" o.c.) and supporting metal cladding, see Figure 22. It is taken from the comprehensive report "Thermal Break Performance for Various Construction Types" (Report 5131042.00).
3D thermal modeling was performed to compare the energy flows and temperature profiles of building enclosure with and without thermal breaks. The thermal model is shown in Figure 22, and the thermal conductivity of each member is shown in table 3. The type of Schöck Isokorb® thermal break shown in the model can be found in Figure 20. The structural capability of the thermal break can be found in the Schöck Isokorb® Technical Manual.

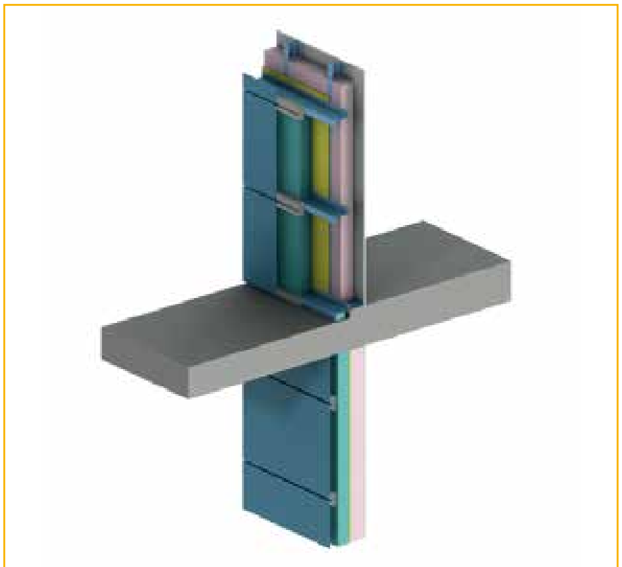


Figure 22A: Thermal model for the balcony intersection with exterior and interior insulated steel stud assembly

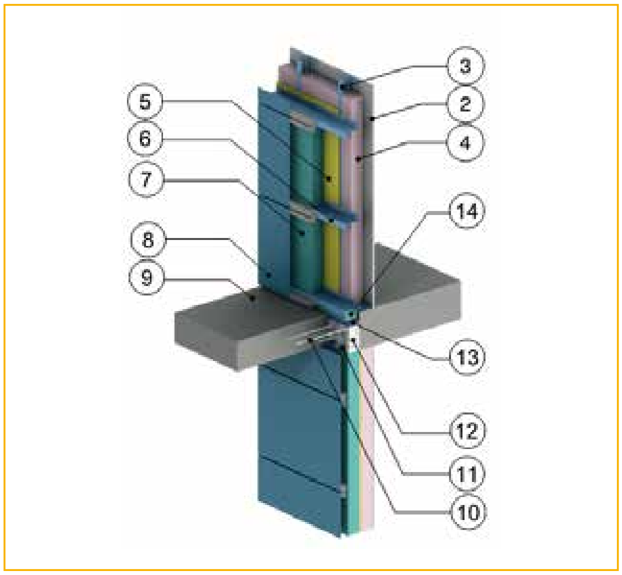


Figure 22B: Thermal model for the balcony intersection including Schöck Isokorb® thermal break

ID	Component	Thickness Inches (mm)
1	Interior Films (right side)[1]	-
2	Gypsum Board	1/2" (13)
3	3 5/8" x 1 5/8" Steel Studs with Top and Bottom Tracks	18 Gauge
4	Fibrglass Batt Insulation	3 5/8" (92)
5	Exterior Sheathing	½" (13)
6	Horizontal Clips w/ 1 ½" horizontal rail	18 Gauge
7	Exterior Insulation	Varies
8	Metal Cladding with ½" vented airspace incorporated into exterior heat transfer coefficient	
9	Concrete Slab	8" (203)
10	Stainless Steel Rebar	-
11	HDPE Plastic Sleeve	-
12	Polystyrene Hard Foam Insulation	3" (76)
13	Cement Board	1" (25)
14	curb insulation	3" (76)
15	Exterior Film (left side)[1]	-

Table 3: Components

Three scenarios have been modelled, starting from a balcony section without curb insulation above the balcony and without a thermal break (Figure 23A), moving to an improved scenario with a Schöck Isokorb® thermal break (Figure 23B) to a further improved scenario with thermal break and curb insulation (Figure 23C). The results of the thermal modelling with and without thermal break are presented in table 4. The temperature distribution is shown in Figure 23.

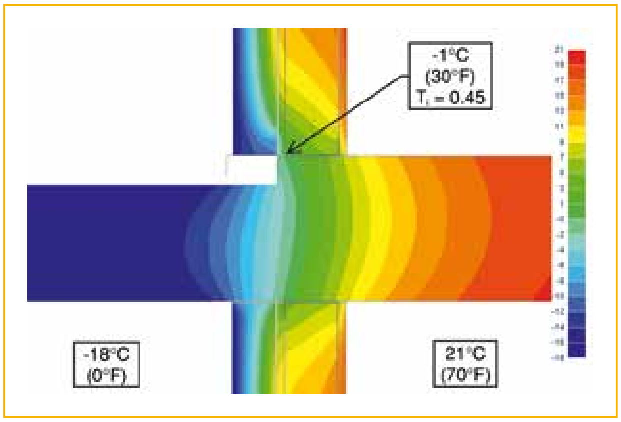


Figure 23A: Temperature distributions: Balcony section without curb insulation and without thermal break

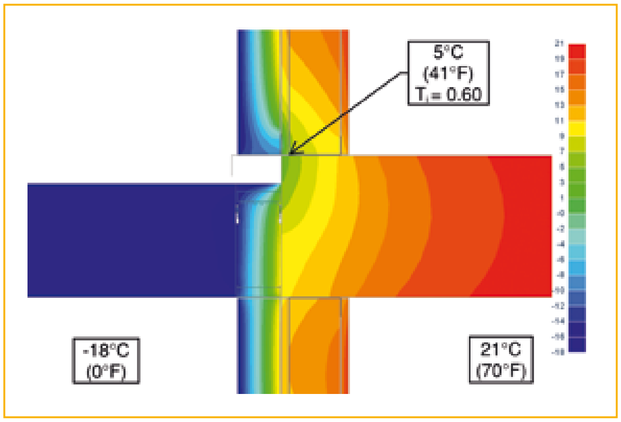


Figure 23B: Temperature distributions: Balcony section without curb insulation and with Schöck Isokorb® thermal break

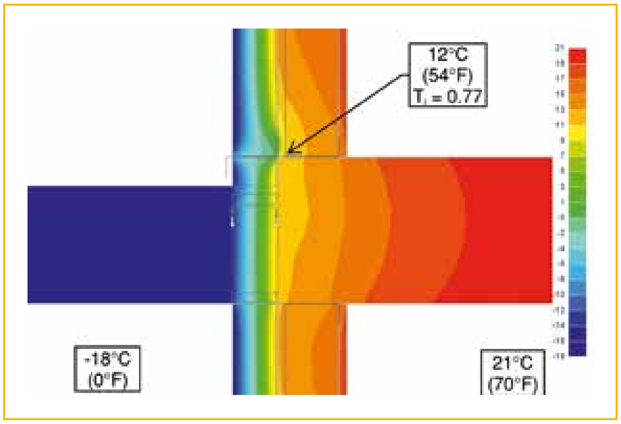


Figure 23C: Temperature distributions: Balcony section with thermal break and with curb insulation resulting in a continuous and effective insulation layer

Exterior Insulation 1D R-values	R_o ft²·hr·°F / Btu (m² K / W)	$R_{effective}$ ft²·hr·°F / Btu (m² K / W)	ψ Btu/ft hr °F (W/m² K)	Minimum Temperature Index on Slab
R-15 insulation to slab, without curb insulation and without thermal break (Figure 23A)	R-18.5 (3.26)	R-8.6 (1.51)	0.615 (1.064)	0.45
R-15 insulation to slab, without curb insulation and with thermal break (Figure 23B)	R-18.5 (3.26)	R-12 (2.07)	0.307 (0.531)	0.60
R-15 insulation to slab, with curb insulation and with thermal break Schöck Isokorb® (Figure 23C)	R-18.5 (3.26)	R-13.8 (2.43)	0.181 (0.314)	0.77

Table 4: Thermal modeling results

From the results it can be seen that
- Structural thermal breaks provide a continuous insulation layer for the balcony intersection
- The thermal transmittance (ψ-values) through balcony slabs by implementing thermal breaks is reduced by up to 70%
- The temperature factor f is improved by over 50% which results in significantly higher interior slab temperatures

The following recommendations are made as a result of the analyses:
- Providing a continuous insulation layer requires a holistic approach to the building envelope, closing the gap at the balcony intersection as well as insulating the curb above the balcony
- the thermal transmittance (ψ-values) can be used to calculate whole building energy performance, further guidance see chapter 4 guidance to whole building energy performance
- One can see that even with a high quality thermal insulation of the slab with Schöck Isokorb® thermal break element, the structural design of the adjacent area is also important. This means that only considering the impact of the whole constuction on the heat losses results in an optimized approach to prevent thermal bridging.

3.3 Steel Beams

The following example considers a Steel Floor Beam Penetrating Exterior and Interior Insulated 3 5/8” x 1 5/8” Steel Stud (16” o.c.) Wall Assembly with Horizontal Z-girts (24” o.c.) Supporting Metal Cladding, see Figure 24. It is taken from the comprehensive report “Thermal Break Performance for Various Construction Types” (Report 5131042.00).
3D thermal modeling had been performed to compare the energy flows and temperature profiles of building enclosure with and without thermal breaks. The thermal model is shown in Figure 24, the thickness of each member is shown in table 5.

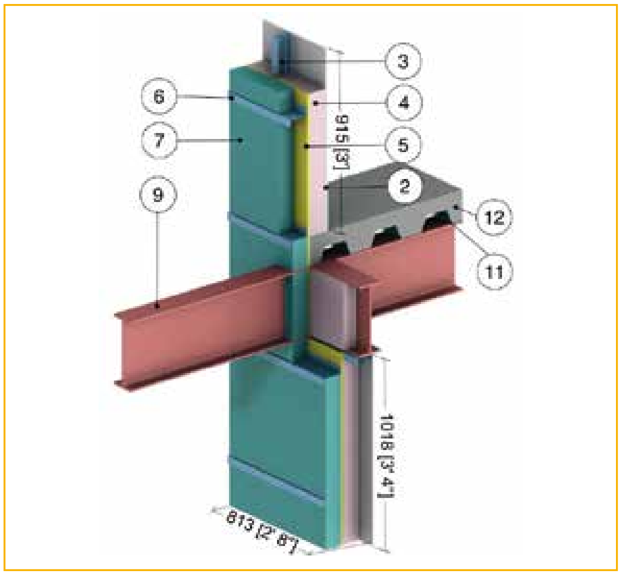


Figure 24A: Thermal model of the steel beam intersection without thermal break

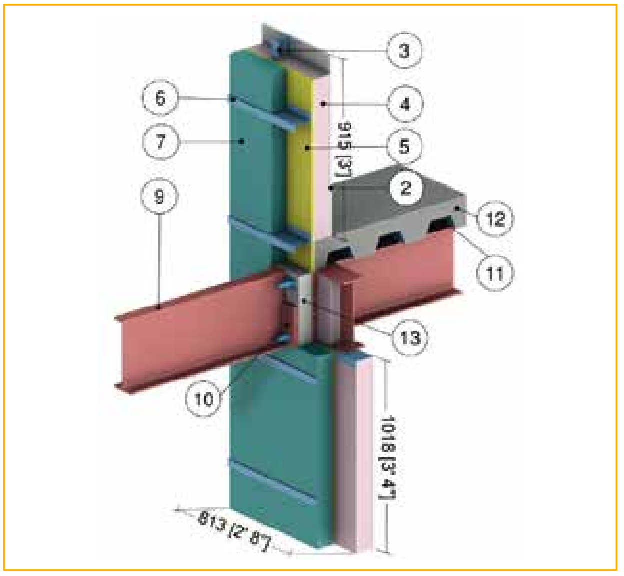


Figure 24B: Thermal model of the steel beam intersection with thermal break

ID	Component	Thickness Inches (mm)
1	Interior Film (right side)[1]	-
2	Gypsum Board	1/2" (13)
3	3 5/8” x 1 5/8” Steel Studs with Top and Bottom Tracks	18 Gauge
4	Fiberglass Batt Insulation	3 5/8” (92)
5	Exterior Sheathing	½” (13)
6	Horizontal Z-girts with 1 ½” Flange	18 Gauge
7	Exterior Insulation	3 1/8” (80)
8	Metal Cladding with ½” vented airspace incorporated into exterior heat transfer coefficient	
9	Steel Beam W14x26 (W360x39)	-
10	Steel Bearing Plates	1 3/16” (30)
11	Steel Deck	1/16” (1.6)
12	Concrete Topping	6” (152)
13	Isokorb® type S modules	3 1/8” (80)
14	Exterior Film (left side)[1]	-

Table 5: Components of Figure 24

The results of the thermal modelling with and without thermal break are presented in table 6.
The temperature distribution is shown in Figure 25.

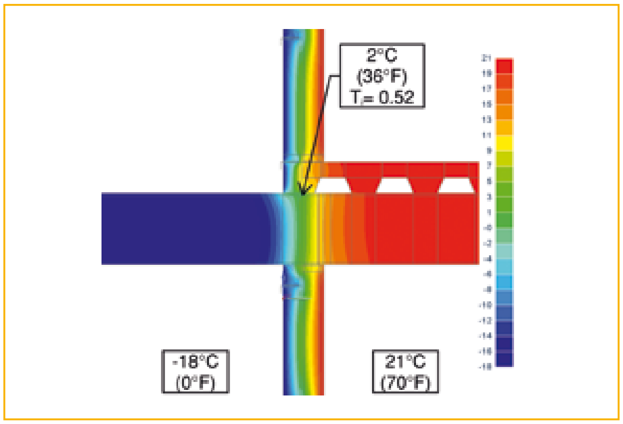


Figure 25A: Steel beam without thermal break Figure 24 Temperature distributions

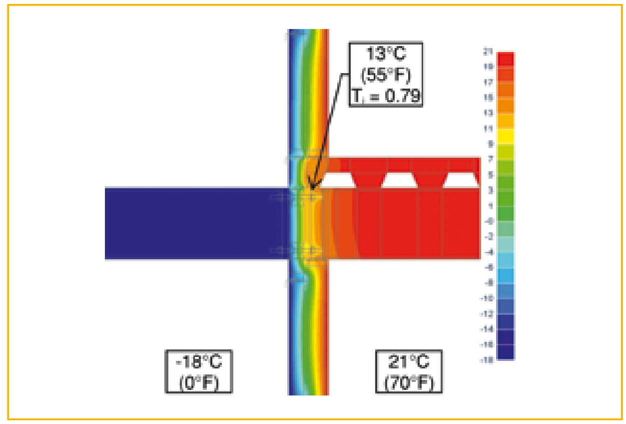


Figure 25B: Steel beam without thermal break Figure 24 Temperature distributions

	Clear Wall R-value ft² ·hr ·°F / Btu (m² K/W)	Overall R-value[1] ft² ·hr ·°F / Btu (m² K/W)	$R_{effective}$ ft²·hr·°F / Btu (m² K / W)	χ Btu/hr °F (W/K)	Minimum Temperature Index on slab
Continuous Beam	**R-18.5 (3.25)**	R-6.9 (1.21)	R-7 (1.19)	1.73 (0.92)	0.52
With Isokorb® type S	**R-18.5 (3.25)**	R-9.4 (1.65)	R-9 (1.61)	0.91 (0.48)	0.79

Table 6: Thermal modeling results

From the results it can be seen that

- Structural thermal breaks provide a continuous insulation layer for the steel beam intersection at the wall
- The thermal transmittance (ψ-values) through balcony slabs by implementing thermal breaks is reduced by around 50%
- The temperature factor f is improved by over 55% which results in significantly higher interior slab temperatures
- The temperature index TI is above the recommended value of 70 (see Chapter 2.6) to avoid any condensation risks

4. Guidance to Whole Building Energy Performance

4.1. Data on Linear Transmission and Categories of Details

The concept of using linear and point transmission as a way of calculating effective thermal resistance has been common in Europe, in part because it is incorporated in energy use standards of some countries and programs such as Passivhaus. Because heat flow and linear transition is so geometry- and material-dependent, the most accurate estimated Ψ values come from specific 2D or 3D modeling, see also explanations in chapter 2.5 heat flow calculations. 2D modeling services with programs such as THERM are widely available and should be considered. There are, however, sources of generic data that allow anyone with a calculator or spreadsheet program to assess the impact of thermal bridges using “catalog data.”

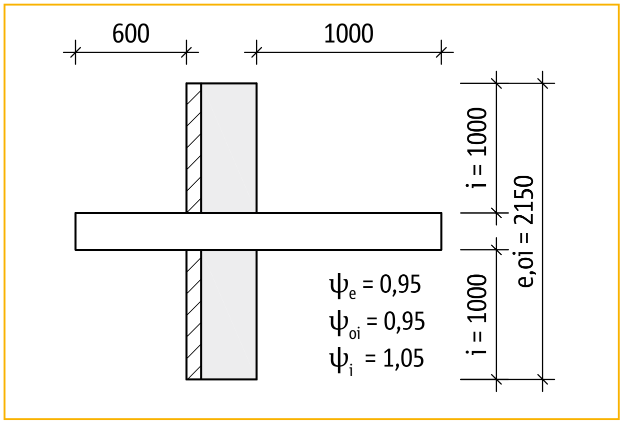
A good source of data, in the absence of more specific information is **ISO 14683:2007, Thermal bridges in building construction -- Linear thermal transmittance -- Simplified methods and default values,** which is available for download on the internet. This standard outlines the methods of calculating linear transmission used in the European standards and provides an Annex with default **Ψ values** for many generic intersections of building enclosure assemblies. The default values, some shown on the below, are based on 2D analysis using:

- assumed depths of building assemblies, and
- assumed values of insulation in the building assemblies

The assumptions used were select to provide conservative **Ψ values** (i.e. maximum expected values).
The standard generally provides three different Ψ values, based on:

- external dimensions, measured between the external faces of the enclosure assemblies;
- internal dimensions, measured between the finished internal faces of each room (thus excluding the thickness of internal partitions); and
- overall internal dimensions, measured between the finished internal faces the enclosure assemblies (thus excluding thickness of internal partitions)

Any of these dimensional system can be used in the $Q = [U_o \cdot A + \Sigma(\Psi_i \cdot L_i) + \Sigma(\chi_j \cdot n_j)]\ \Delta T$ calculation procedure, provided it is used consistently throughout the procedure. Most energy modelers calculate their area inputs from plans and elevation that show external dimensions so they would use $\boldsymbol{\Psi_e}$.



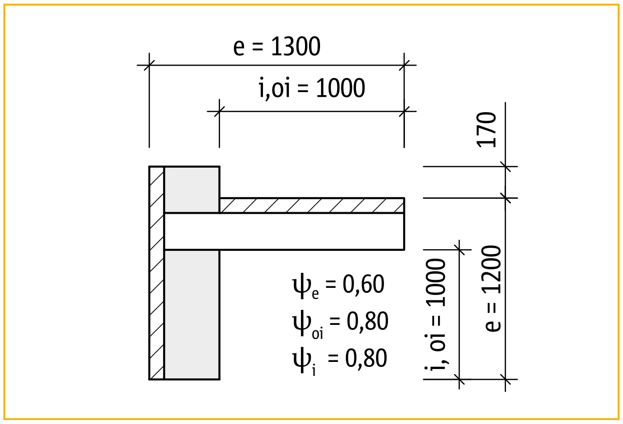


Figure 26: examples (like balconies, intermediate floors, parapets) used in the International Standard ISO 14683, they give a certain number for the typical energy loss for a constuction

In the ASHRAE-sponsored research program, **ASHRAE 1365 RP Thermal Performance of Building Envelope Details for Mid- and High-Rise Buildings**, 3D thermal modeling was used to assess the heat transfer and surface temperatures of 40 construction details common in noncombustible construction. Data is provided on the specific of construction effective U-values, linear and point transmission at junctions and temperature indexes at critical surfaces.
The authors of ASHRAE 1365, Morrison Hershfield Limited, have subsequently undertaken work for a variety of clients extending this catalog of information. They have summarized their observations in the table below categorizing the range of Ψ values they have come to expect. Morrison Hershfield recently completed the Building Envelope Thermal Bridging Guide – Analysis, Applications, and Insights in 2014 and is available for download. This Guide expands on the 1365-RP methodology, adds the results of many more details, and provides insights to various strategies to mitigate thermal bridging in the context of energy savings and cost effectiveness.

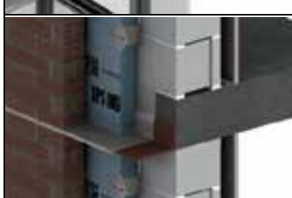
Performance Category		Description and Examples	Linear Transmittance	
			Btu / hr ft F	W / m K
	Efficient	**Fully insulated with only small conductive bypasses** Examples: exterior insulated wall and floor slab	0.12	0.2
	Improved	**Thermally broken and intermittent structural connections** Examples: structural thermal breaks, stand-off shelf angles	0.20	0.35
	Regular	**Under-insulated and continuous structural connections** Examples: partial insulated floor (i.e. firestop), shelf angles attached directly to the floor slab	0.29	0.50
	Poor	**Un-insulated and large conductive bypasses** Examples: un-insulated balconies and exposed floor slabs	0.58	1.0

Table 7: Summary of results Morrison Hershfield Limited has observed, categorizing the range of Ψ values they have come to expect.

4.2 Example: Calculating $U_{effective}$

A primary input into any energy modeling program is the effective U-value ($U_{effective}$) or effective R-value ($R_{effective}$) of enclosure assemblies. Thermal bridging at interface details, such as at intermediate floor slabs or parapets, can reduce the “effective” R-value of the building envelope much lower than the nominal R-value of the insulation. Reduced effectiveness of the insulation results in higher energy consumption. A detailed U-value calculation is necessary to account for the impact of thermal bridging at interface details and to accurately estimate the energy use.
Recalling the previous reference to calculating heat flow and, specifically, Equation 4,

$$Q = [U_o \cdot A + \Sigma(\Psi_i \cdot L_i) + \Sigma(\chi_j \cdot n_j)]\,\Delta T \qquad \text{(Equation 4)}$$

where

U_o 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 heat 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,” and
n is the number of point thermal bridges of type “j” in the analysis area,

The total heat flow through any defined section of a building enclosure can be summed with the heat flow through linear or point thermal bridges to the heat flow through the clear field of the enclosure. For example, we are going to determine the heat flow, $U_{effective}$ and $R_{effective}$ for the opaque walls of the building illustrated below.

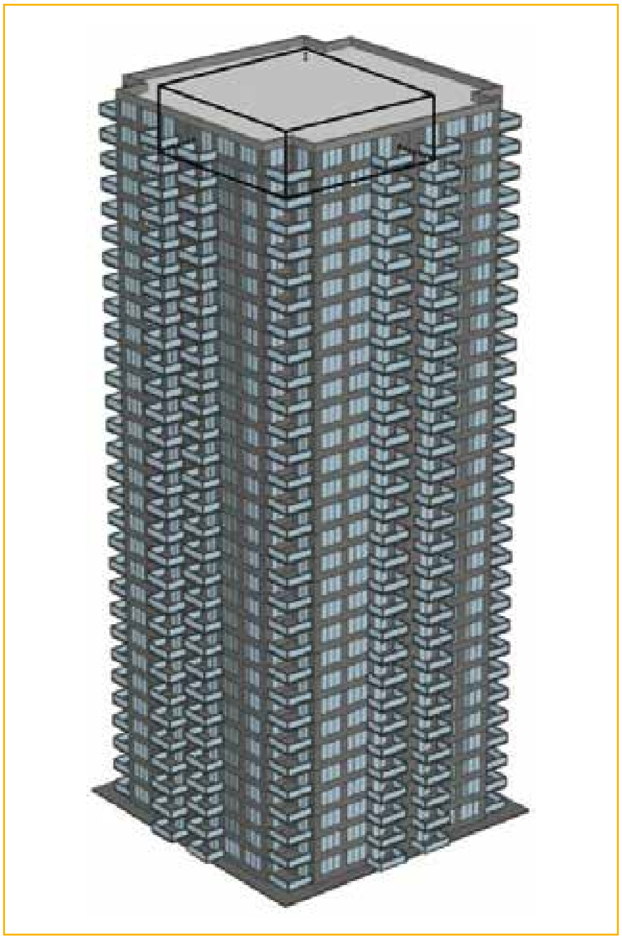


Figure 27A

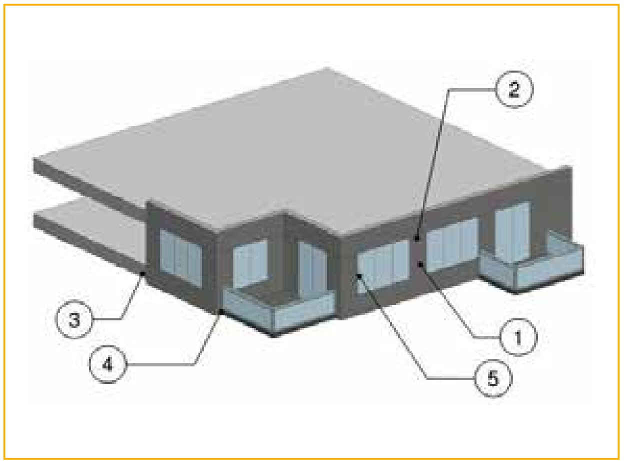


Figure 27B

This example uses an exterior insulated, steel stud wall assembly similar to that shown in 3.2. Table 8 Imperial and 9 Metric are spreadsheets showing the heat flow through each type of thermal bridge and wall area as calculated from input quantities and transmittance values. These heat flows are summed and the $U_{effective}$ is determined by dividing by the opaque wall area.
These tables also compare the result of thermally breaking the balcony slabs and the concrete parapets.

Detail Type			Quantity (A or L)	Without Thermal Breaks			With Schöck Isokorb® Thermal Breaks		
				Transmittance (U or ψ)	Heat Flow in Btu/hr·°F (U·A or ψ·L)	% Total	Transmittance (U or ψ)	Heat Flow in Btu/hr·°F (U·A or ψ·L)	% Total
Area (ft^2)	1	2x4 Steel Stud Assembly with R-10 Exterior Insulation	63539 (ft^2)	0.062 (ft^2)	3939	61%	0.062 (Btu/hr·ft^2·°F)	3812	72%
Lenght (ft)	2	Parapet	420 (ft)	0.45 (Btu/hr·ft·°F)	189	3%	0.14 (Btu/hr·ft·°F)	59	1%
	3	Floor Slab	8379 (ft)	0.11 (Btu/hr·ft·°F)	922	14%	0.11 (Btu/hr·ft·°F)	922	18%
	4	Balcony Slab	2041 (ft)	0.62 (Btu/hr·ft·°F)	1265	20%	0.18 (Btu/hr·ft·°F)	367	7%
	5	Window/Door Frame	846 (ft)	0.12 (Btu/hr·ft·°F)	102	2%	0.12 (Btu/hr·ft·°F)	102	2%
Total					6417	100%		5262	100%
$U_{effective}$ (Btu/hr·ft^2·°F)			= (Total Heat Flow/Total Area)		0.10			0.08	
Effective R-Value (hr·ft^2·°F/Btu)			= (Total Area/Total Heat Flow)		9.90			12.00	

Table 8: Imperial values of components with heat flow and transmittance of Figure 27A&B, summed and dividing by the opaque wall area. Compares result of thermally breaking the balcony slabs and the concrete parapets.

Detail Type			Quantity (A or L)	Without Thermal Breaks			With Schöck Isokorb® Thermal Breaks		
				Transmittance (U or ψ)	Heat Flow in W/K (U·A or ψ·L)	% Total	Transmittance (U or ψ)	Heat Flow in W/K (U·A or ψ·L)	% Total
Area (m^2)	1	2x4 Steel Stud Assembly with R-10 Exterior Insulation	5903 (m^2)	U 0.35 (W/m^2K)	2066	61%	U 0.35 (W/m^2K)	2066	70%
Lenght (m)	2	Parapet	128 (m)	ψ 0.78 (W/mK)	100	3%	ψ 0.24 (W/mK)	31	1%
	3	Floor Slab	2554 (m)	ψ 0.19 (W/mK)	485	14%	ψ 0.19 (W/mK)	485	16%
	4	Balcony Slab	622 (m)	ψ 1.07 (W/mK)	666	20%	ψ 0.31 (W/mK)	193	7%
	5	Window/Door Frame	258 (m)	ψ 0.20 (W/mK)	52	2%	ψ 0.20 (W/mK)	52	2%
Total					3368	100%		2826	100%
$U_{effective}$SI (W/m^2K)			= (Total Heat Flow/Total Area)		0.57			0.48	
Effective R-Value (m^2K/W)			= (Total Area/Total Heat Flow)		1.75			2.09	

Table 9: Metric value of components with heat flow and transmittance of Figure 27A &B, summed and dividing by the opaque wall area. Compares result of thermally breaking the balcony slabs and the concrete parapets.

4.3 Modifying Input for Whole Building Energy Analyses

Some computer programs used for whole building energy analysis allow for the direct input of Effective U-values or Effective R-values determined outside the program.
The energy simulator should be aware of how the energy model deals with heat transfer coefficients and make any necessary adjustments. Often the heat transfer coefficients are explicitly calculated by the energy model, which requires estimates of “effective” R-values to be corrected as follows:

$$R_{effective} = \frac{1}{U_{effective}} - \frac{1}{h_0} - \frac{1}{h_i}$$

where

h_o and h_i are the interior and exterior surface transfer coefficients, respectively.

The ASHRAE and Canadian Energy Codes allow use of a variety of energy simulation programs but require that the programs be capable of simulating dynamic effect, considering the influence of thermal mass. This requires that the characteristics of opaque building enclosure assemblies are inputted by layers, with information on thickness, conductance, thermal mass and the extent of framing and other thermal bridges. The programs generally have a data entry subroutine or “wizard” that calculates the effective U-value for a “clear field” enclosure assembly from such input. These subroutines cannot foresee every circumstance. So what can be done when there is data that better assesses the $U_{effective}$ than that provided by the program?

The recommended approach is to adjust the R-value of the layer with high resistance and low thermal mass. This is typically the insulation layer. The U-value of the layer can be adjusted by modifying the input thickness, conductance or framing factor until the U-value of the assembly matches.

Example

In the example shown in Section 4.2, we determined that the $U_{effective}$ of the opaque wall assembly with the thermal bridges we identified was 0.10 BTU/hr/ft^2/°F.

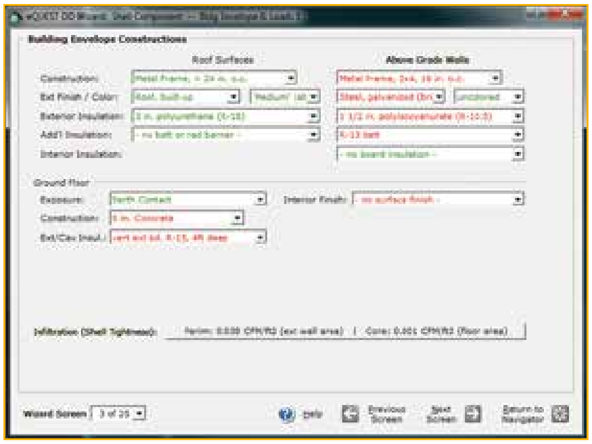
The effective R-value of the assembly is calculated as $R_{effective} = 1/ U_{effective} =$ R9.9.
If eQuest was being used for energy simulation, the input for the layers would be as in the first screenshot on the next page. The $U_{effective}$ provided by the program as shown in the second screenshot is 0.056 BTU/hr/ft^2/°F. This translates to $R_{effective}$ of R17.9. The R-value of the insulating layer is provided directly by eQuest, but in some other programs it may have to be calculated as:

Thickness/conductivity

The difference in insulating value needs to be removed from the insulation layer. In eQuest, the calculated R-value of the insulation layer can be overwritten. With other programs, it may be required to:

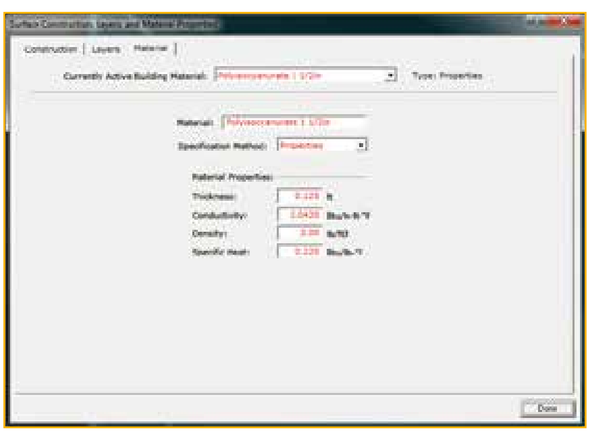
- Reduce the thickness of the insulation
- Increase the conductivity
- Adjust the framing factor.

The last screenshot shows the wall assembly adjusted to have the same $U_{effective}$ value as calculated by the thermal analysis.



1. The first screen shot shows one input screen in the building creation wizard in eQuest. Here, one can select from a number of options for framing, exterior finish, and insulation. This same screen shows selections for roof and floor constructions; these have no bearing on the current example. The selections made here will be used by eQuest to create a layer-by-layer construction for a single type of wall.

2. The second screen shot shows the construction created automatically by eQuest based on these inputs. This is a layer-by-layer construction, with a total calculated U-value shown. The "EL1..." material combines batt insulation and a framing factor based on the framing selected in the wizard (shown in the first screen shot.)



3. The third screen shot shows how the conductivity of an insulation layer can be changed to obtain the desired overall U-value.

4. eQuest will automatically update its calculation of overall U-value when the properties of a layer are changed; the fourth screen shot shows the overall U-value including the effects of changing the conductivity of the insulation.

5. Appendix

5.1 Basic Definitions of Thermal Values

Term	symbol	Units Imperial	Units SI	Description
Conductivity	k	$\frac{(BTU \cdot in)}{(h \cdot ft^2 \cdot {}^oF)}$	$\frac{W}{(m \cdot K)}$	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	k_{eq}	$\frac{(BTU \cdot in)}{(h \cdot ft^2 \cdot {}^oF)}$	$\frac{W}{(m \cdot K)}$	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	$\frac{(h \cdot ft^2 \cdot {}^oF)}{(BTU)}$	$\frac{(m^2 \cdot K)}{W}$	The thermal resistance R is the resistance a material counters a heat flow with at 1 °K for one m². R= l/k
Thermal resistance of a layered assembly	R_T	$\frac{(h \cdot ft^2 \cdot {}^oF)}{(BTU)}$	$\frac{(m^2 \cdot K)}{W}$	Thermal resistance of an assembly with uniform layers of materials, including air films, which can be added to get the total. $R_T = R_1 + R_2 + R_3 ...$
Effective Thermal Resistance	$R_{effective}$	$\frac{(h \cdot ft^2 \cdot {}^oF)}{(BTU)}$	$\frac{(m^2 \cdot K)}{W}$	The inverse of Ueffective but the convention is to exclude the interior and exterior air films. $R_{effective} = 1/U_{effective} - 1/h_o - 1/h_i$ where h_o and h_i are the exterior and interior surface transfer coefficients respectively
Thermal Transmission Coefficient	U	$\frac{(BTU)}{(h \cdot ft^2 \cdot {}^oF)}$	$\frac{W}{(m^2 \cdot K)}$	Heat flow per unit time through a unit area of an assembly under a temperature drive of ΔT. $U=1/R_T$
	U_0	$\frac{(BTU)}{(h \cdot ft^2 \cdot {}^oF)}$	$\frac{W}{(m^2 \cdot K)}$	Heat flow coefficient for a „clear field“, for an assembly without considering the impact of thermal bridges.
	$U_{effective}$	$\frac{(BTU)}{(h \cdot ft^2 \cdot {}^oF)}$	$\frac{W}{(m^2 \cdot K)}$	Heat flow coefficient including the effect of all considered thermal bridges and anomalies. The convention is to include the impact of air films.
Heat Flow	Q	BTU/h	W	Heat flow per unit time through an assembly under a temperature drive of ΔT, see (equation 1).
Linear Heat Transmittance coefficient	Ψ	$\frac{(BTU)}{(h \cdot ft \cdot {}^oF)}$	$\frac{W}{(m \cdot K)}$	A calculated value representing the added heat flow associated with a linear thermal bridge.
Point Heat Transmittance coefficient	χ	$\frac{(BTU)}{(h \cdot {}^oF)}$	$\frac{W}{(K)}$	A calculated value representing the added heat flow associated with a linear thermal bridge.

5.2 Thermal Conductivity of Schöck Isokorb® Thermal Breaks

Schöck has determined equivalent thermal conductivity values (k_{eq}) for their products as published in the tables below. This is the thermal conductivity of an imaginary homogenous material of the same depth and thickness (80mm or 3 5/32”) and height that allows the same heat flow.

Schöck Isokorb® type CM for cantilevered concrete slabs

The heat flow paths through the assembly are quite complex and the resistance to heat flow depends upon how much steel and concrete is used per foot, which in turn depend on the loads that have to be supported.

k_{eq}-value										
Schöck Isokorb® type	units	Isokorb® height H								
		180 mm [7'']		200 mm [7 7/8'']		220 mm [8 5/8'']		250 mm [9 7/8'']		
		R0[2)]	R120[2)]	R0[2)]	R120[2)]	R0[2)]	R120[2)]	R0[2)]	R120[2)]
CM10	W/mK	0.161	0.19	0.148	0.173	0.136	0.158	0.123	0.143
	[Btu/(h*°F*ft)]	[0.093]	[0.11]	[0.086]	[0.1]	[0.079]	[0.092]	[0.071]	[0.083]
CM20	W/mK	0.193	0.222	0.176	0.201	0.161	0.184	0.145	0.165
	[Btu/(h*°F*ft)]	[0.112]	[0.129]	[0.102]	[0.116]	[0.093]	[0.107]	[0.084]	[0.096]
CM30	W/mK	0.225	0.253	0.204	0.229	0.186	0.209	0.167	0.186
	[Btu/(h*°F*ft)]	[0.13]	[0.147]	[0.118]	[0.133]	[0.108]	[0.121]	[0.097]	[0.108]
CM40	W/mK	0.257	0.286	0.232	0.258	0.212	0.235	0.188	0.209
	[Btu/(h*°F*ft)]	[0.149]	[0.166]	[0.134]	[0.15]	[0.123]	[0.136]	[0.109]	[0.121]

As indicated, the higher the structural capacity, the higher the heat transmission; yet, the conductivity remains much less than concrete (typically 0.5 BTU/h/^{0}F/ft or 0.9 W/m/^{0}K).
The real value is this information used together in a 2D heat flow simulation such as THERM. Where the model of a projecting balcony can be created, inserting an 80 mm x H rectangular element (representing the Isokorb®) and assigning the material thermal conductively. The program can provide reasonable estimates of heat flow and surface temperatures.

Schöck Isokorb® type S22 for cantilevered steel beams

This same practice can be performed with steel beam calculations.

Schöck Isokorb® type	k_{eq}-value 3.dim[1)]	
	units	Isokorb® height H
		80 mm [3 1/8"]
2 x S22	W/mK [Btu/(h*°F*ft)]	1.405 [0.814]
continuous steel beam	W/mK [Btu/(h*°F*ft)]	4.12 [2.387]

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