

Effect of Thermal Bridges on the Heat Balance of Buildings

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ABSTRACT

Thermal bridges in the thermal insulation of envelopes occur in all forms of building construction and should be minimised to reduce local heat losses. This paper presents the effect of thermal bridges on the comfort of the habitat within a building. Indeed, the thermal bridges increase the heat losses of a building and thus the consumption of heating. Thermal bridges cause additional heat losses compared to losses through the walls of the building. These losses can exceed for some 40% of the total heat losses through the envelope. An example of an energetic effect of a thermal bridge has been presented. For this example, the heat losses on a floor height and per meter of façade were calculated. The results showed that from 5 cm thickness of insulation, the difference between the loss curve in the absence of thermal bridge, and the loss curve taking into account the thermal bridge is almost independent of the thickness of the insulating. Another example was also presented to demonstrate the effect on thermal bridging when increasing the levels of insulation to a normal corner. The results showed that for a 50% and 100% increase in the thickness of the insulation, the U-value, linear heat loss coefficient ψ and surface temperature factor f_{Rsi} were considerably decreased.

Keywords : Thermal Bridges, Linear Heat Loss Coefficient, Heat Losses, Insulation, Surface Temperature Factor, Buildings.

I. INTRODUCTION

Thermal bridges are parts of a building where the insulation barrier is broken. Ideally, the insulating complex should be continuous around the heated space. These weaknesses of the insulation can cause the condensation of the water vapor and thus the possible formation of black marks and molds [1-3]. The most common are linear thermal bridges, which correspond to a junction between two walls (low-wall exterior floor, intermediate floor-exterior wall, high-wall exterior floor, balcony-tile, exterior wall-wall, etc.).. There are also thermal bridges on the outline of joinery, thresholds of doors and windows, ducts, etc.

The French energy performance of new building regulation RT 2012 imposes a loss value not to be exceeded for the thermal bridges between floors and

external walls, but also a limit to the sum of all the thermal bridges of a building. This measure should lead to a generalization of insulation from the outside, which remains the best way to eliminate the majority of thermal bridges. In cases where only the thermal insulation from the inside is suitable, it is strongly recommended to set up thermal bridge breakers and to provide insulation on floating screed.

Architects and builders have to be clever to avoid thermal bridging and need to carefully design each detail using a combination of special products and ingenuity. They should be able to show you a blownup detail drawing showing exactly how they propose to avoid a thermal bridge for each building junction. They can also use the Acceptable Details published by the Department of Environment but you need to be certain that these are followed exactly on site with no shortcuts.

Thermal bridges account for 10- 40% of losses. They drag on the inner surface of the wall a local temperature drop and create cold areas located in the house. These areas also cause discomfort for the occupants because the human body will feel cold if the walls are cold, even if the air in the room is hot.

Several studies have been conducted to analyze thermal bridging effects and evaluate energy losses through the envelope of a test room [4-8]. It was concluded that the mere internal retrofit was not a decisive solution to reduce the heat loss from residential buildings if additional proper attention was not paid to non-insulated building elements.

II. STUDY OF THERMAL BRIDGES

2.1 Effects of thermal bridges

Thermal bridges have the disadvantage of cooling the inner surface. This lowering of the inner surface temperature can cause condensation and mold problems, causing stains, drips or efflorescence.

A set of conditions must come together for the molds to grow: Spores and food are needed, which is not a problem because spores are ubiquitous and mold feeds on anything. On the other hand, the local relative humidity must exceed 80% for a long time. This superficial humidity depends on the humidity of the air and the temperature of the surface.

The humidity of the air is controlled by reducing the sources of humidity and ventilating sufficiently. The surface temperature of the outer walls is controlled, for a given climate, by the level of thermal insulation. In winter, the walls facing the outside have a lower surface temperature as the insulation is less strong. If the insulation is weak and the humidity of the indoor air is relatively high, two types of damage may occur:

- As soon as the internal surface temperature is equal to or lower than the dew point of the indoor air, the humidity of the air condenses on the surface, making it humid. At the extreme, drips and stains occur.
- If the relative humidity of the air exceeds approximately 80% near the surface for a long time, then mold can grow on this surface without condensation.

This damage occurs when the insulation is too weak for a given ventilation, or when the ventilation is too weak for a given insulation.

To estimate the risks associated with condensation and mold, SIA 180 [9] uses the surface temperature factor f_{Rsi} given by the following equation:

$$f_{Rsi} = \frac{\left(\theta_{si} - \theta_{e}\right)}{\left(\theta_{i} - \theta_{e}\right)}$$
(1)

Where, $(\theta_{si} - \theta_e)$ is the temperature difference between the inner surface of an envelope element and the outside temperature (°C), $(\theta_i - \theta_e)$ is the temperature difference between inside and outside (°C).

This factor quantifies the level of thermal insulation at any point of a thermal bridge. If it is equal to 1, the insulation is perfect, if it is equal to zero, the insulation is null. For flat and homogeneous surfaces, the surface temperature factor f_{Rsi} is given by the following equation:

$$f_{Rsi} = 1 - U.R_{si}$$
(2)

Where R_{si} is the surface thermal resistance which varies from 0,1 to 0,3 m²°C / W according to the places, U is the surface heat loss coefficient (W/m²°C). Fig. 1(a) shows a material thermal bridge consisting of a slab resting on a wall with internal insulation. The variation of the surface temperature near a thermal bridge is given in Fig. 1(b). According to Fig. 1(c), we note that the degree of insulation is excellent in full wall ($f_{Rsi} = 0.93$), but it is far from sufficient near the thermal bridge ($f_{Rsi} = 0.55$).



(c)

Figure 1: (a) Material thermal bridge consisting of a slab resting on a wall with internal insulation. (b) The variation of the surface temperature near a thermal bridge. (c) Surface temperature factors in the case of the thermal bridge

To avoid the risk of mold, SIA 180 requires that the surface moisture (relative humidity of the air layer near the surface) does not exceed 80% for a prolonged period. If ventilation is sufficient, this requirement is fulfilled when:

- the maximum heat transfer coefficients U are respected for partially solid components and geometric thermal bridges;
- the surface temperature factor f_{Rsi} is greater than or equal to 0.75 at any location in the building envelope, particularly at the thermal bridges, with the exception of windows.

2.2 Types of thermal bridges

There are geometric thermal bridges such as angles and corners, and thermal material bridges, in which a heat conductive material passes through the insulating layer. Thermal bridges are also classified as linear bridges, which have a certain length, and point bridges, in which the interruption of the insulating layer remains local.

Any curvature in the insulating layer or in the wall constitutes a thermal bridge geometric. The isotherms must follow the curvature of the wall and the flux lines, which are perpendicular to them, become narrower towards the inside of the curvature.

Fig. 2 shows a typical geometric thermal bridge, consisting of an angle between two walls, the wall consisting of bricks with mineral wool and an outer lining of cement blocks. Red corresponds to 20 $^{\circ}$ C and blue to 0 $^{\circ}$ C. The hue changes at each degree. Thin lines are flow lines, plotted every W/m. It can be seen that the inside and outside temperatures of the corner are slightly lower than those in the wall. It is also noted that the flow lines are a little tighter towards the inside of the corner than in the wall.

Geometric thermal bridges do not generally have significant effects, especially on heat losses, because the insulating layer is not interrupted, it is only deformed. However, when conditions are critical, lowering the temperature to the inner surface may be sufficient to promote mold growth. Material thermal bridges can be found anywhere where the insulating layer is interrupted or traversed by a more conductive material.



Figure 2: Geometric thermal bridge: angle of a building. On the left, in plan, on the right, isotherms (colored zones) and flux lines.

In the example of the material thermal bridge consisting of a slab resting on a wall with internal insulation (Fig. 1), red corresponds to $20 \degree C$ and blue to $0 \degree C$. The hue changes at each degree. Thin lines are flow lines, plotted every W / m. It is very clear that the flux lines are strongly concentrated across the bridge, like a river in a gorge, and that the isotherms deviate, as the water level drops near a dike break. There is a clear cooling and concentration of the heat flux lines near the thermal bridge. Material thermal bridges often have more serious consequences than geometric bridges.

Fig. 3 (a) shows an example of heat losses which can be modeled by an additional heat leak located along a horizontal line inserted into a wall. It is a linear thermal bridge, which can be assigned a coefficient of linear loss (in W/m°C) and a length.

Fig. 3 (b) shows an example of a metal fixing bar crossing a wall can be modeled by localized additional

point loss; it is a point thermal bridge to which a coefficient of loss (in W /°C) is attributed.



Figure 3: Examples of thermal bridges. (a): Linear thermal bridge; (b): Point thermal bridge

2.3 How to avoid thermal bridges?

Some thermal bridges, such as door and window frames, balcony brackets and fittings between shell elements are unavoidable. They should therefore be designed to reduce their effects. Here are some general principles that can be applied together or separately.

A design that places the insulation on the outside of the load-bearing structure often makes it possible to avoid most thermal bridges. It is as well the double wall (the interior wall being carrier) as the outer insulation plastered or barded. Buildings with homogeneous walls made of light materials (solid wood, autoclaved aerated concrete or porous bricks) can also be considered as such if the slabs are made of similar materials or, if they are more conductive (concrete) they do not completely cross the walls, but stop in the middle.

External insulation has many other advantages:

- Increased inner thermal inertia, thus improving summer comfort and better use of passive solar gains in winter.
- Stabilization of the temperature of the structure, thus slower aging of this one.
- Decrease, and in most cases total elimination of the risks of condensation in the building elements.

To prevent a thermal bridge from being inevitable causes damage, it is advisable to take measures that will increase its internal surface temperature. This amounts to dividing it, heating it, or lengthening it. These operations will often increase energy consumption but reduce the risk of condensation or mold

2.4 Detection of thermal bridges

In the plane and section of construction details, a material thermal bridge appears as an interruption of the insulation layer. It is therefore easy to detect, and should be corrected or treated appropriately before building. plans and detail cuts represent only a section of the envelope element, and it is possible that a thermal bridge, including a point bridge, exists outside this section. The more complicated the construction, the higher the probability of finding thermal bridges.

On an existing building, the thermal bridge is detected primarily by its effects: appearance of mold, condensation, cold or hot areas. It can also be detected using thermography [10-12]: it is an image of the external surface temperature. As this temperature is even higher than the external surface is better heated, especially by thermal bridges, it is also, to a certain extent, an image of thermal bridges.

Fig. 4 shows the result of the diagnosis of the face of a building using an infrared thermal camera. We notice the presence of thermal bridges. They are located at the junction of partitions. Most likely, the reason is the lack of insulation of the thermal connection panels on the building.

Thermal bridges should therefore be avoided, but this is not always possible and in this case, it must be taken into account in the thermal balance of the building.



Figure 4: Thermography of the face of a construction using an infrared thermal camera.

III. THEORETICAL AND EXPERIMENTAL STUDY OF THERMAL BRIDGES

3.1 Calculation of heat losses due to thermal bridges

The thermal losses (in Watt) of a flat wall without thermal bridge are calculated by multiplying the area of this wall by its coefficient U and by the temperature difference between inside and outside. The thermal losses is given by:

$$\phi = A.U(\theta_i - \theta_e) \tag{3}$$

Where, A is the surface of the wall (m²), U is the surface heat loss coefficient (W/m^{2°}C), $\theta_i - \theta_e$ is the temperature difference between inside and outside (°C).

In order to take into account thermal bridges in the calculation of heat losses, a linear heat loss coefficient

 ψ (W/m°C) has been attributed to thermal bridges of this type which, multiplied by the length of the thermal bridge (for example the perimeter of the slab), is added to the losses of the walls as indicated by the following equation:

$$\phi = \left[\mathbf{A}.\mathbf{U} + \mathbf{l}.\boldsymbol{\psi} \right] \left(\theta_{i} - \theta_{e} \right)$$
(4)

Table 1 gives the maximum value for the linear coefficient of heat transfer ψ of thermal bridges according to the SIA 380/1 standard [13].

Table 1 Limit values for thermal bridges

Lincon host loss so ff signt sh	Limit values				
Linear neat loss coefficient ψ	(W/m°C)				
Type 1: projecting part such as	0.30				
balconies, eaves					
Type 2: interruption of thermal	0.20				
insulation by walls, slabs or ceilings					
Type 3: interruption of the insulating	0.20				
envelope towards the horizontal or					
vertical edges					
Type 5: window sill against wall	0.10				
	Limit				
Thermal transmittance coefficient χ	values				
	(W/°C)				
Point elements crossing the thermal	0.30				
insulation					

Similarly, a thermal transmittance coefficient χ is attributed to the local thermal bridges constituted by fasteners or bar-shaped elements passing through the insulating layer (Table 1). If all the elements of the envelope are taken into account, the coefficient of transmission losses of this envelope is calculated by the following equation:

$$H_{T} = \sum_{i=1}^{n} A_{i} U_{i} + \sum_{k=1}^{n} l_{k} \psi_{k} + \sum_{j=1}^{n} \chi_{j}$$
(5)

This H_T coefficient is the power required to compensate for transmission losses through the

enclosure for a difference of 1 degree between the inside and the outside.

3.2 Example of energetic effect of a thermal bridge

We are interested in the example shown in Fig. 1. A classic case of thermal bridge results from the interior insulation technique. The slabs, or even the walls of the slit, pass through the insulating layer to cling to the outer bearing wall.

The heat losses on a floor height and per meter of façade were calculated. The results of these calculations are illustrated in Fig. 5. The dotted line indicates these losses in the absence of thermal bridge, and the continuous line gives the losses taking into account the thermal bridge. It is noted that, from a thickness of 5 cm of insulation, the difference between these two curves is almost independent of the insulation thickness, namely about 10 W/m.







The relative importance of additional heat losses resulting from thermal bridging increases significantly with insulation thickness, as shown in Fig. 5 on the right. They go from a few percent if there is no insulation to 60% for 10 cm and almost 100% with 20 cm of insulation. Thus, at the thicknesses of insulation currently installed, losses through the thermal bridge consisting of a slab passing through the interior insulation are comparable to those of the solid wall or, in other words, and taking into account thermal bridges, 20 cm of interior insulation is no more effective than 10 cm of external insulation, which does not have a thermal bridge of this type.

3.3 Example of Calculation of equivalent U-value

Fig. 6 presents a wall at one of the intermediate floors . It has a wall corner, partition wall, and balcony. The wall is insulated and its U-value without thermal bridges is 0,65W/m^{2°}C. The U-value of the window is 3.00W/m^{2°}C. Linear heat loss coefficient are given in Table2.

Table 2 Linear heat loss coefficient [14].

Description	ψ	
Description	(W/m°C)	
Window perimeter	0.15	
Window perimeter if the frame is in the	0.00	
plane of the thermal insulation		
Outer corner of homogeneous wall	0.10	
Outer corner of wall with external	0.15	
insulation		
External wall with internal insulation	0.00	
Joint of homogeneous external wall and	0.06	
internal wall		
Joint of external wall with external	0.03	
insulation and internal wall		
Joint of homogeneous external wall and	0.15	
floor slab with insulated strip		
Joint of external wall with external	0.03	
insulation and floor slab		
Parapet wall, cornice	0.20	
Balconies	0.25	



Figure 6: Description and dimensions of the insulated wall

The total surface of the wall $A = 5.00 \times 2.65 = 13.25 \text{m}^2$ The total surface of the window: $A_{\text{win}} = 2 \times [0.75 \times 1.50] + [1.50 \times 2.40] = 5.85 \text{m}^2$ The surface of the brick wall: $A_{\text{wall}} = A - A_{\text{win}} = 13.25 - 5.85 = 7.40 \text{m}^2$

Table 3 gives the linear heat loss coefficient of the different elements multiplied by the length of the thermal bridge.

	linear best loss	length of		
Floment	coefficient	the	<u>Σ</u> Ψ.1	
Element		thermal	(W/°C)	
	φ(₩/шС)	bridge l(m)		
Window	0.15	9.30	1.395	
Corner	0.15	2.65	0.398	
Balcony	0.25	6.00	1.500	
Ring beam	0.03	4.00	0.120	
Partition	0.03	2.65	0.080	
Total			3.493	

The coefficient of transmission losses is calculated by equation 5 :

$$H_{T} = \sum_{i=1}^{n} A_{i} U_{i} + \sum_{k=1}^{n} l_{k} \psi_{k} + \sum_{j=1}^{n} \chi_{j}$$

$$H_{T} = \left[U_{wall} \times A_{wall} + U_{win} \times A_{win} \right] + \sum \psi . l + \left[\sum_{j=1}^{n} \chi_{j} = 0 \right]$$

$$H_{T} = \left[0.65 \times 7.40 + 3.00 \times 5.85 \right] + 3.493$$

$$H_{T} = 25.850 \text{ W} / ^{\circ}\text{C}$$

3.4 Effect on thermal bridging when increasing the levels of insulation

In order to demonstrate the effect on thermal bridging when increasing the levels of insulation to a normal corner, we chose a wall based on blocks (thermal conductivity equal to 0.11W/m°C) and an insulation (thermal conductivity equal to 0.020W/m°C) with variable thickness (50 mm, 75mm and 100 mm) [15].

Table 4 Calculation of U-value and ψ value for different insulation thickness

Insulation thickness (mm)	Increase	U-value (W/m²°C)	ψ value (W/m°C)	frsi
50	-	0.27	0.052	0.957
75	50%	0.21	0.043	0.967
100	100%	0.17	0.038	0.973

According to the results presented in Table 4, it is noted that for a 50% and 100% increase in the thickness of the insulation, the value of U decreases by 22% and 37% respectively. Regarding the values of linear heat loss coefficient, there is also a decrease of 16% for an insulation thickness of 75mm, and a decrease of 27% for an insulation thickness of 100mm. we also note a condensation risk reduction since the values of the surface temperature factor f_{Rsi} have been decreased by 1% and 2% respectively.

IV.CONCLUSION

Through this work, it has been shown that the method of construction chosen should make it possible to avoid as much as possible the thermal bridges which must always be taken into account in the calculation of the thermal transmittance.

Under normal conditions, the maximum values of the thermal transmittance of the building elements of the heated rooms make it possible to satisfy the requirements of thermal comfort and absence of superficial condensation. In addition, the absence of condensation on the thermal bridges must be ensured. The following conclusions can be drawn:

- The presence of thermal bridges allows heat loss and cooling of interior surfaces.
- Thermal bridges increase the risk of mold especially when the relative humidity of the air layer near the surface exceed 80% for a prolonged period.
- To avoid thermal bridging, place the insulation on the outside, the supporting structure being inside the insulating layer.

If necessary, the thermal bridges must be treated so as to increase their inner surface temperature, even if they lose energy.

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