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Assessing condensation risk and heat loss at thermal bridges around openings

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This paper gives guidance on assessing the risk of surface condensation and mould growth at thermal bridges around openings in the external elements of buildings, and describes a method of assessing their effect on overall heat loss. It supports the 1995 revision of the Building Regulations for conservation of fuel and power.

INTRODUCTION

Thermal bridges can occur at any junction between building elements or where the building structure changes. They are usually associated with a reduction in internal surface temperature and an increase in heat loss compared with that of the unbridged structure. Consequently there may be an increased risk of surface condensation and mould growth at the bridge, and a significant additional heat loss through it.

Thermal bridges fall into two categories:

(a) repeating thermal bridges (eg timber joists, mortar joints, mullions in curtain walling, etc) for which the additional heat loss is usually included in the determination of the U-value of the building element containing these bridges, and

(b) non-repeating thermal bridges (eg details at window and door openings) for which the additional heat loss is determined separately.

This paper deals only with type (b). It introduces the idea of a minimum thermal resistance path, the thermal resistance of which is a useful indicator for identifying significant thermal bridges, assessing the risk of condensation and mould growth, and assessing the additional heat loss that contributes to the overall loss through the building fabric.

The data in this paper are based on the areas of plane building elements being measured between finished internal faces of the building. In the case of a window or door opening in a wall, the area of wall extends up to the internal projection of the opening; this extended area is considered to have the same U-value as the wall. For example, in Figure 1 the area of wall extends up to point B, the internal projection of the edge of the window frame.

Note that the heat loss through the door or window frame in the opening is accounted for in the U-value of the window or door.

MINIMUM THERMAL RESISTANCE PATH

The minimum thermal resistance path through a thermal bridge is that path from internal to external surface which has the smallest thermal resistance. Figure 1 illustrates this for a section through a window jamb. The internal surface is from A to B to C, the external surface from D to E to F. The minimum resistance path is from the internal surface at C to the external surface at D. The minimum resistance (R_{min}) for this path is equal to the total length from inside to outside (CD) divided by the thermal conductivity of the material of the jamb. Potentially significant thermal bridges occur where R_{min} is less than 0.45 m^{2}K/W.

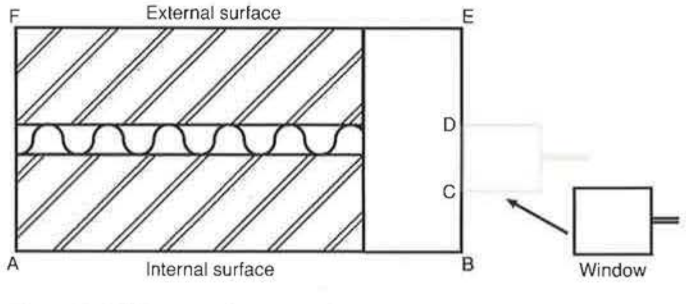

Figure 1 Minimum resistance path

Thermal bridges containing thin layers

For thermal bridges containing layers no more than 4 mm thick (for example metal lintels), a second, modified, calculation of the minimum thermal resistance (R_{mod}) needs to be made. In this calculation the effective thermal conductivity of the thin layer is the greater of 0.1 W/m·K and the thermal conductivities of the materials immediately on either side of the layer.

Where one side of the thin layer is in contact with the frame of the window or door, its effective thermal conductivity is the greater of 0.1 W/m·K and the conductivity of the material immediately on the other side of the layer.

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It is sufficient for R_{min} and R_{mod} to be calculated to two decimal places. The Appendix contains worked examples which illustrate the calculation of R_{min} and R_{mod}.

Condensation and mould

The risk of condensation and mould growth at thermal bridges containing layers no more than 4 mm thick will usually be negligible if:

$R_{min} \geq 0.1$ m²K/W **and** $R_{mod} \geq 0.45$ m²K/W

At other thermal bridges the risk will usually be negligible if:

$R_{min} \geq 0.2$ m²K/W

Heat loss around openings

The quantity that describes the heat loss associated with a thermal bridge is its linear thermal transmittance, Ψ. This is the heat loss per degree per unit length of the thermal bridge, which is not accounted for in the U-value of the plane building element containing the bridge.

There is a negative correlation between Ψ and R_{min} (or, where appropriate, R_{mod}). Small values of Ψ correspond with large values of R_{min} (or R_{mod}) and vice versa. This correlation is not sufficient, however, to enable values of Ψ to be predicted accurately.

Nevertheless, if R_{min} (or R_{mod}) is at least 0.45 m²K/W, the value of Ψ is likely to be small. The additional heat loss associated with these thermal bridges will usually have little effect on the total heat loss from a building and can therefore be ignored.

If R_{min} (or R_{mod}) is less than 0.45 m²K/W, the additional heat loss should not be ignored and can be calculated from:

$$\text{Rate of heat loss per degree} = \Sigma(l \times \Psi)$$

where:

Ψ = the linear thermal transmittance of the thermal bridge

l = the length over which it applies.

BUILDING REGULATIONS

The Building Regulations[1] specify that provision should be made to limit thermal bridging around openings to avoid the possibility of local condensation problems and excessive additional heat loss.

To limit the risk of condensation and mould growth the minimum thermal resistances around openings should be at least those specified above.

To limit heat loss, either the details at openings should conform to those shown in Diagram 3 (or 7) of Part L of the Building Regulations[1], or R_{min} (or R_{mod}) should be at least 0.45 m²K/W (in which case the additional heat loss can be ignored). If the heat loss is not limited in this way it should be accounted for as follows.

1 For dwellings, when using the target U-value method[1], the average U-value should be increased by the following amount:

$$\frac{\Sigma(l \times \Psi')}{\text{(Total exposed surface area)}}$$

2 For other buildings, when using the calculation procedure[1], the rate of heat loss for the proposed building should be increased by the following amount:

$$\Sigma(l \times \Psi')$$

In 1 and 2:

l = length of the relevant thermal bridges

Ψ' = difference between Ψ, the actual linear thermal transmittance, and Ψ_o, the linear thermal transmittance of a thermal bridge which just meets the minimum resistance value of 0.45 m²K/W.

Representative values for Ψ_o are:

0.15 W/m·K for lintels, and

0.05 W/m·K for all other thermal bridges.

If Ψ is not known then Ψ' may be taken as 0.3 W/m·K (the same value as that given in Appendix D of Part L of the Building Regulations[1]), which will generally not underestimate the additional heat loss.

As an alternative, Ψ can be derived from measurement (eg in a hot box) or by using a numerical calculation method (eg finite element).

An explanation of the technical basis of the critical minimum thermal resistance values and the values of Ψ_o is to be published[2].

REFERENCES

1 **Department of the Environment and the Welsh Office.** *The Building Regulations Approved Document L. Conservation of fuel and power* (1995 edition). London, HMSO, 1994. (Equivalent revisions to the Building Regulations in Scotland and Northern Ireland are in preparation.)

2 **Ward T I.** A paper on assessing thermal bridge heat loss and condensation risks using minimal thermal resistance is in preparation.

APPENDIX: TWO WORKED EXAMPLES

The minimum resistance path through a thermal bridge is often the shortest path, but this is not necessarily so. The resistance of a path segment is given by:

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

where l is the length in metres and λ the thermal conductivity in W/m·K of the path segment, so both length and thermal conductivity affect the resistance, and paths other than the shortest may need to be considered especially where there are materials of high thermal conductivity.

For the thermal bridge detail in Figure 2, this means that two paths must be considered:

path 1 (shortest distance):
A → E → F
with two segments AE and EF, and

path 2 (via material of high thermal conductivity):
A → B → C → D → E → F
with five segments AB, BC, CD, DE and EF.

For the thermal bridge detail in Figure 3 only one path needs to be considered (since it is both the shortest distance and is via material of high thermal conductivity), namely:

A → B → C
with two segments AB and BC.

For each path segment the minimum resistance is through the material with the higher thermal conductivity.

Example 1: an insulated metal lintel

Calculation of R_{min}
The data in Tables 1 and 2 have been used to calculate the resistance (R) for each segment of paths 1 and 2 in Figure 2, by dividing the length (l) of the segment in metres by its thermal conductivity (λ) in W/m·K (see Table 3 overleaf). The total resistance for path 1 is 1.694 m^2K/W and for path 2 it is 0.122 m^2K/W. Path 2 is therefore the minimum thermal resistance path for the calculation of R_{min}.

Calculation of R_{mod}
Since the lintel is made from thin sheet metal less than 4 mm thick, a second minimum resistance (R_{mod}) must be calculated.

For path 2, using the rules for adjusting the thermal conductivity of thin layers:

1 Consider the path segment AB — the effective thermal conductivity (λ') for this length of the lintel is the largest of 0.1 W/m·K, and from Table 1, 0.94 W/m·K (λ of region 1) and 0.04 W/m·K (λ of region 3). Thus λ' = 0.94 W/m·K.

2 Next consider segments BC and CD — λ' for this length of the lintel is the largest of 0.1 W/m·K, and from Table 1, 0.035 W/m·K (λ of region 2) and 0.04 W/m^2K (λ of region 3). Thus λ' = 0.1 W/m·K.

3 Then segment DE — λ' for this length is the largest of 0.1 W/m·K, and from Table 1, 0.04 W/m·K (λ of region 3) and 0.60 W/m·K (λ of region 4). Thus λ' = 0.60 W/m·K.

Adjusting the thermal conductivity of these lengths of the lintel in this way gives the values of λ' shown in Table 3. The effective resistance (R') for each path segment is then obtained by dividing the length (l) of the path segment in metres by the effective thermal conductivity (λ') of the path segment in W/m·K.

Path 1 has no thin layers and so for each path segment λ' equals λ. The total modified resistance for path 1 is therefore 1.694 m^2K/W (the same as before). For path 2 it is 1.480 $m^2 K/W$, and so Path 2 is the minimum thermal resistance path for the calculation of R_{mod}.

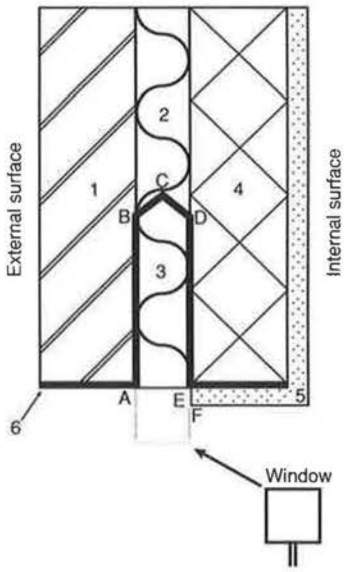
Assessing the risk of surface condensation and mould growth
For this thermal bridge (which has thin layers) two conditions are applied:

condition 1: R_{min} (= 0.12 m^2K/W) should be at least 0.1 m^2K/W — so this condition is met, and

condition 2: R_{mod} (= 1.48 m^2K/W) should be at least 0.45 m^2K/W — so this condition is also met.

Therefore the risk of surface condensation and mould growth is acceptably low.

Assessing the additional heat loss
For this thermal bridge (which has thin layers) R_{mod} (= 1.48 m^2K/W) is greater than 0.45 m^2K/W and so the additional heat loss at this thermal bridge may be ignored.



Key to Figures 2 and 3
1 Brick outer leaf
2 Insulation
3 Insulation
4 Block inner leaf
5 Lightweight plaster
6 Metal lintel

Figure 2 Example 1: an insulated metal lintel (3 mm thick) in a twin leaf wall with a 70 mm cavity

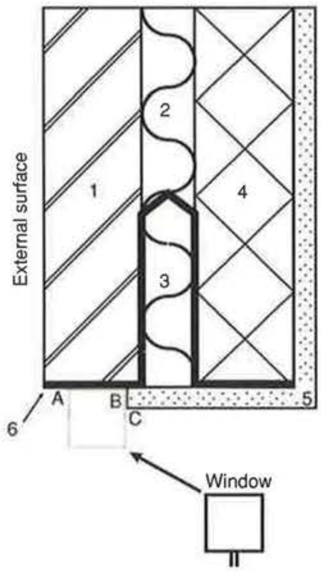


Figure 3 Example 2: as Example 1 but with the window moved to the outer leaf of the wall

Table 1 Thermal conductivity of materials in Figures 2 and 3

Region	Material	λ (W/m·K)
1	Brick outer leaf	0.94
2	Insulation	0.035
3	Insulation	0.04
4	Block inner leaf	0.60
5	Lightweight plaster	0.16
6	Metal lintel	17.0

Table 2 Lengths of path segments in Figures 2 and 3

Figure	Path segments	l (m)
2	AB	0.200
2	BC	0.042
2	CD	0.042
2	DE	0.200
2	EF	0.015
2	EA	0.064
3	AB	0.064
3	BC	0.015

Table 3 Minimum resistance paths in Figure 2

Segments	l (m)	λ (W/m·K)	R (m²K/W)	λ' (W/m·K)	R' (m²K/W)
Path 1					
AE	0.064	0.04	1.600	0.04	1.600
EF	0.015	0.16	0.094	0.16	0.094
			R_{min} 1.694		R_{mod} 1.694
Path 2					
AB	0.200	17.0	0.012	0.94	0.213
BC	0.042	17.0	0.002	0.1	0.420
CD	0.042	17.0	0.002	0.1	0.420
DE	0.200	17.0	0.012	0.60	0.333
EF	0.015	0.16	0.094	0.16	0.094
			R_{min} 0.122		R_{mod} 1.480

Table 4 Minimum resistance path in Figure 3

Path 1 Segments	l (m)	λ (W/m·K)	R (m²K/W)	λ' (W/m·K)	R' (m²K/W)
AB	0.064	17.0	0.004	0.94	0.068
BC	0.015	0.16	0.094	0.16	0.094
			R_{min} 0.098		R_{mod} 0.162

Example 2: an insulated metal lintel with the window moved to the outer leaf of the wall

Calculation of R_{min}

The data in Tables 1 and 2 have been used to calculate R (Table 4) for each path segment of the minimum thermal resistance path in Figure 3, by dividing the length (l) of the path segment in metres by its thermal conductivity (λ) in W/m·K. R_{min} for the path is 0.098 m²K/W.

Calculation of R_{mod}

As the lintel is made from thin sheet metal less than 4 mm thick, R_{mod} must be calculated.

Consider the path segment AB using the rules for adjusting the thermal conductivity of thin layers. One side of this length of the lintel is in contact with the frame and so the effective thermal conductivity (λ') is the larger of 0.1 W/m·K and 0.94 W/m·K (λ of region 1) which is the thermal conductivity of the material on the other side of the lintel. Thus λ' = 0.94 W/m·K.

Adjusting the thermal conductivity of this length of the lintel in this way gives the value of λ' shown in Table 4. The effective resistance (R') for each path segment is then obtained by dividing the length (l) of the path segment in metres by the λ' of the path segment in W/m²K. R_{mod} for the minimum thermal resistance path is 0.162 m²K/W.

Assessing the risk of surface condensation and mould growth

For this thermal bridge (which has thin layers) two conditions are applied:

condition 1: R_{min} (= 0.10 m²K/W) must not be less than 0.10 m²K/W — so this condition is met,

condition 2: R_{mod} (= 0.16 m²K/W) must not be less than 0.45 m²K/W — so this condition is not met.

There is therefore a risk of surface condensation and mould growth at this thermal bridge where the frame is moved fully forward to the outer leaf of the wall.

Assessing the additional heat loss

For this thermal bridge R_{mod} (= 0.16 m²K/W) is less than 0.45 m²K/W and so the additional heat loss at this thermal bridge should not be ignored.

If this lintel detail with the frame located on the outer leaf was being considered for the window openings of, say, a dwelling where:

- the heat loss through the plane elements, ie $\Sigma(A \times U)$, is 111.9 W/K
- the total length (l) for these lintels is 15 m
- the actual Ψ for this thermal bridge is unknown so that Ψ' can be taken as 0.3 W/m·K
- the total exposed surface area for the building is 170.5 m²,

then the average U-value ignoring the additional heat loss at these thermal bridges would be:

$$\frac{\Sigma(A \times U)}{\text{(Total exposed surface area)}} = \frac{111.9}{170.5} = 0.66 \text{ W/m}^2\text{K}$$

where:

A = area of element

U = thermal transmittance of element

To take account of the additional heat loss at these thermal bridges,

$$\frac{\Sigma(l \times \bar{\Psi})}{\text{(Total exposed surface area)}} = \frac{15 \times 0.3}{170.5} = 0.03 \text{ W/m}^2\text{K}$$

should be added to the average U-value. The average U-value, taking account of the additional heat loss at these lintels, is now (0.66 + 0.03) = 0.69 W/m²K.

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