Assessing the Impact on Heat Loss and Mould Growth of Thermal Bridges Resulting from Internal Wall Insulation

Hector Altamirano-Medina[1*] and Valentina Marincioni[1]

[1]Institute for Environmental Design and Engineering, Bartlett School of Environment, Energy and Resources, University College London, London, England

[*]*h.altamirano-medina@ucl.ac.uk*

ABSTRACT
Over the coming decades a significant number of existing solid wall dwellings, which represent a large proportion of the current UK housing stock, will have to be retrofitted to reduce fuel poverty and help the Government reach its carbon targets by 2050 (DECC, 2012). One of the most likely retrofit measure is the installation of internal wall insulation, which although it would certainly improve the thermal quality and energy performance of those dwellings, it could create, if wrongly designed and installed, thermal bridges that will increase heat loss and the likelihood of moisture related problems such as mould growth.

This paper examines the severity and impact of thermal bridges on both the risk of mould growth on internal wall surfaces and the heat loss through the junctions of an internally insulated solid wall, as a function of the window position in the wall and the wall insulation thermal conductivity and thickness. The analysis focused on an uninsulated lintel detail. The severity of the thermal bridge was assessed using the surface temperature factor and the temperature difference ratio criteria. The risk of mould growth was analysed considering the mould growth criteria established in the Approved Document F 2010, of the Building regulations for England and Wales (HMSO, 2010).

It was found that the lack of insulation in the lintel has a significant effect on the severity of the thermal bridge and on mould growth risk. The heat loss and risk of mould growth increased with the window position shifting towards the outside surface of the wall; nevertheless the severity of the thermal bridge was found 'unacceptable' in all cases.

KEYWORDS
Thermal bridges, mould growth, heat loss

INTRODUCTION
The UK Government aims to reduce Greenhouse Gas emissions by 80% by 2050 (DECC, 2012). A quarter of these emissions are originating in the residential sector as a result of the high-energy consumption due primarily to space heating. To achieve this target, a significant number of existing solid wall dwellings, which represent a large proportion of the current housing stock, will be upgraded through the introduction of energy efficiency strategies (DECC, 2012) such as the installation of internal wall insulation.

Such intervention has the potential of improving the thermal quality and performance of those dwellings by considerably reducing transmission heat losses through the building fabric. However, it may also increase the likelihood of moisture related problems as a result of inappropriate designs and constructions (e.g. appearance of thermal bridges, mould growth and material decay).

This study seeks to assess and correlate the risk of mould growth and the heat loss occurring at critical junctions where thermal bridges are likely to occur due to poor design and installation of insulation on solid wall dwellings.

METHODS

The study focuses on thermal bridges occurring at a junction that is often left un-insulated. The junction selected for the analysis is the lintel, which has been found to have the highest effect on the total heat loss (Marincioni et al, 2015) of an internally insulated typical end-terrace house (Oikonomou et al. 2012). The study considered a lintel with uninsulated reveals and with two windows positions, at 0 mm and 100 mm from the external surface (see figure 1). The 215 mm-thick wall was simulated with three insulation scenarios: uninsulated wall and internally insulated wall with 60 mm and 100 mm of insulation. Two levels of thermal conductivity of the insulation were considered: 0.026 $Wm^{-2}K^{-1}$ and 0.05 $Wm^{-2}K^{-1}$, to reflect the range of thermal conductivity of conventional insulation materials.

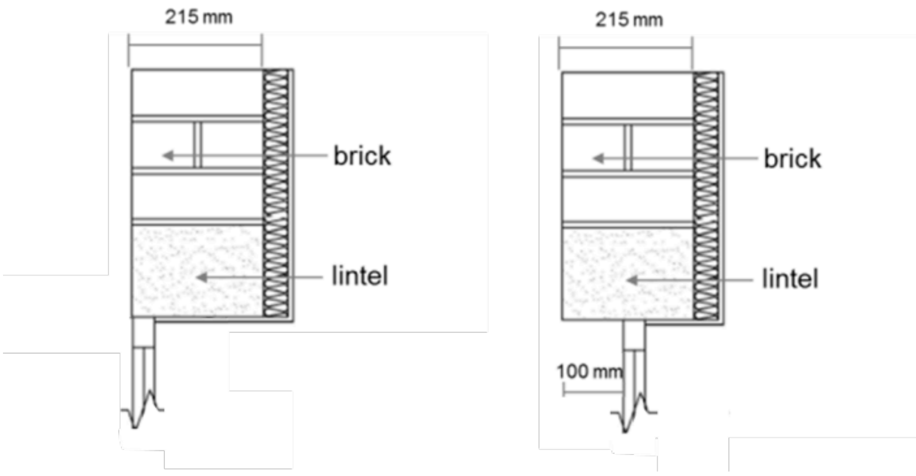

Figure 1 Lintel cross section detail, with window located at 0 mm (left) and 100 mm (right) from the external surface.

The linear thermal transmittance was calculated to describe the heat flux through the junction and the surface temperature of the junction was determined. The severity of thermal bridge was evaluated for each junction considering the calculation of the surface temperature factor and the temperature difference ratio criteria. In addition, the risk of mould growth was assessed applying the criteria for the control of mould introduced in the Approved Document F 2010 (ADF, 2010) as part of the ventilation regulations for England and Wales (HMSO, 2010).

Linear thermal transmittance

The linear thermal transmittance Ψ ($Wm^{-1}K^{-1}$) of individual junctions was calculated according to BS EN 10211 (BSI, 2007a). The simulation of two-dimensional steady-state heat flux was carried out using the software Delphin© v.5.8.3, a heat and moisture transfer simulation tool based on the control volume method. The boundary conditions were set according to BR 497 (Ward and Sanders, 2007), using $h_e = 25$ $Wm^{-2}K^{-1}$ as external surface heat coefficient and $h_i = 7.69$ $Wm^{-2}K^{-1}$ as internal surface heat coefficient, according to BS EN ISO 10211 (BSI, 2007a).

The thermal properties of plane elements of the building fabric are shown in Table 1 (outside to inside). The U-values are calculated according to BS EN ISO 6946 (BSI, 2007b).

Table 1. Wall: composition and thermal properties

Element	Layer	Thickness (*mm*)	λ ($Wm^{-1}K^{-1}$)
External wall	Brick	215	0.770
	Internal wall insulation	60; 100	0.026 (low); 0.05 (high)
	Plaster	8	1.2

Heat fluxes were calculated considering a lintel of limestone (λ = 1.7 $Wm^{-1}K^{-1}$) and with a cross section of 150 mm (height) by 215 mm (width). Windows were treated as adiabatic boundaries according to BR 497 (Ward and Sanders, 2007).

Surface temperature

The surface temperature was determined from a steady-state simulation as defined in BS EN ISO 10211:2007 (BSI, 2007a), through the use of Delphin© v.5.8.3.

Each simulation was carried out using the external surface heat coefficient h_e = 25 $Wm^{-2}K^{-1}$ and the internal surface heat coefficients h_i = 7.69 $Wm^{-2}K^{-1}$ for glazing and frames and h_i = 4.0 $Wm^{-2}K^{-1}$ for all other internal surfaces, according to BS EN ISO 13788:2002 (BSI, 2002). The simulation considers double glazed windows, with U_W=1.6 $Wm^{-2}K^{-1}$.

Severity of thermal bridging

The severity of thermal bridging was characterised using the surface temperature factor f_{Rsi}, and the categories that define the severity of a thermal bridge proposed by Oreszczyn (1992).

Surface temperature factor

The surface temperature factor f_{Rsi}, (a dimensionless coefficient between 0 and 1) was calculated based on the determined surface temperature (θ_{si}), the internal air temperature (θ_i) and the external temperature (θ_e) as indicated below:

$$f_{Rsi} = (\theta_{si} - \theta_e) / (\theta_i - \theta_e) \quad (1)$$

The value of f_{Rsi} is close to 1.0 for a well-insulated structure, but will fall below 0.5 for severe thermal bridges.

Temperature Difference Ratio

Temperature Difference Ratio (TDR) is a coefficient that defined how cold a surface is relative to the inside and outside temperature and can be calculated as indicated below.

$$\text{TDR} = 1 - f_{Rsi} \quad (2)$$

Depending on the resulted coefficient the severity of a thermal bridge can be classified as indicated in table 2:

Table 2. Thermal bridge categorization (Oreszsczyn, 1992)

Cold bridge category	TDR	Examples

Negligible	<0.15	Plain walls U-values less than 1.2 $Wm^{-2}K^{-1}$. External corners u-value less than 0.6 $Wm^{-2}K^{-1}$. Insulated lintels.
Moderate	0.15-0.2	Plain walls U-values greater than 1.2 $Wm^{-2}K^{-1}$. 3D corner u-value greater than 0.6 $Wm^{-2}K^{-1}$.
Severe	0.2-0.3	External corners U-value 0.9 to 1.5 $Wm^{-2}K^{-1}$. Uninsulated lintels. Concrete party wall or floor.
Unacceptable	>0.3	2D corners U-value>1.5 $Wm^{-2}K^{-1}$. 3D corners U-value > 1.0 $Wm^{-2}K^{-1}$. Party wall of insulated wall. Window reveal of insulated wall.

Risk of mould growth

The risk of mould growth was assessed according to the performance criteria for the control of mould introduced as part of the ventilation regulations for England and Wales (HMSO, 2010). The criteria, stated in the Approved Document F 2010 (ADF 2010), established limiting values of air relative humidity (RH) and water activity (a_w) to prevent mould growth on external walls. The criteria for new and existing dwellings will be met if the average surface water activity on internal surface of external walls is lower than the values established in Table 3 for each period of time during the heating season.

Table 3. Moisture criteria for mould growth prevention (HMSO, 2010)

Period	Surface a_w	Room air RH
1 month	0.75	65%
1 week	0.85	75%
1 day	0.95	85%

Relative humidity on surfaces (RH_s) was calculated using the saturated vapour pressure (E_s) for the determined surface temperature (θ_s) and saturated vapour pressure (E_{dp}) for the dew point temperature (θ_{dp}) given when applying the equations below and boundary condition of outdoors temperature = 0^oC (θ_e), indoor temperature = 20^oC (θ_I) and an internal relative humidity of 50% (RH_i).

$$E_s = 6.11*10\text{^}(7.5*\theta_s/(237.7+\theta_s)) \quad (3)$$

$$E_{dp} = 6.11*10\text{^}(7.5*\theta_{dp}/(237.7+\theta_{dp})) \quad (4)$$

$$RH_s = E_s/E_{dp} * 100 \quad (5)$$

RESULTS AND DISCUSSION

Each simulated lintel has a range of surface temperatures that is wider for window frame close to the external surface, with a difference of 3.7 °C between the min and max surface temperature calculated while 1.8 °C for window frame 100 mm from external surface. Tables 4 and 5 show the minimum and maximum temperature (T_{min} and T_{max}) and linear thermal transmittance Ψ of the junction, when the window is located at the external surface (0 mm) and 100 mm far from the external surface. As seen in Tables 4 and 5, the linear thermal transmittance at the junction increases significantly for a lintel with more exposed surface to the indoor environment, i.e. when the window frame is closer to the external surface. On the other hand, under the assumptions of this study the insulation thickness and thermal conductivity have a negligible impact on the linear thermal transmittance.

Table 4. Surface temperature and heat loss at lintel for insulation of 0.026 $Wm^{-1}K^{-1}$

Insulation	Window frame at 0mm			Window frame at 100mm		
Thickness	Tmin	Tmax	Ψ	Tmin	Tmax	Ψ
(mm)	*°C*	*°C*	$Wm^{-2}K^{-1}$	*°C*	*°C*	$Wm^{-2}K^{-1}$
60	6.8	10.5	0.59	6.8	8.8	0.29
100	6.7	10.3	0.60	6.7	8.6	0.29

Table 5. Surface temperature and heat loss at lintel for insulation of 0.05 $Wm^{-1}K^{-1}$

Insulation	Window frame at 0mm			Window frame at 100mm		
Thickness	Tmin	Tmax	Ψ	Tmin	Tmax	Ψ
(mm)	*°C*	*°C*	$Wm^{-2}K^{-1}$	*°C*	*°C*	$Wm^{-2}K^{-1}$
60	7.1	10.8	0.59	7.2	9.0	0.32
100	6.9	10.5	0.60	7.0	8.8	0.31

The range of surface temperatures calculated at the junction and the corresponding severity of the thermal bridge applying the surface temperature factor (f_{Rsi}) and the temperature difference ratio criteria (TDR) are presented in Table 6. The table also reports on the surface RH (used to estimate the risk of mould growth) resulting from the calculated surface temperature and three levels of internal air RH.

Table 6. Severity and hygrothermal conditions calculated according to the range of surface temperatures calculated at the thermal bridge (lintel)

Surface temp	Thermal Bridge Severity		Surface RH (%)		
range (°C)	f_{Rsi}	TDR	40% air RH	50% air RH	60% air RH
6.5	0.33	Unacceptable	96.7	>100	>100
7.0	0.35	Unacceptable	93.4	>100	>100
7.5	0.38	Unacceptable	90.3	>100	>100
8.0	0.40	Unacceptable	87.2	>100	>100
8.5	0.43	Unacceptable	84.3	>100	>100
9.0	0.45	Unacceptable	81.5	>100	>100
9.5	0.48	Unacceptable	78.8	98.3	>100
10.0	0.50	Unacceptable	76.2	95.1	>100
10.5	0.53	Unacceptable	73.7	92.0	>100

It has been found that the severity of the thermal bridge at the junction is always unacceptable regardless of the position of the window frame or the type of insulation and thickness applied. Generally, a surface temperature factor of 0.75 is considered to be acceptable to avoid mould growth in UK dwellings (BSI 5250:2002). Here, the value of f_{Rsi} was below 0.5, which represents a severe thermal bridge (close to 1.0 for a well-insulated structure). The lower the f_{Rsi} the colder and hence worse the thermal bridge. Double glazing, for example, can have a f_{Rsi} of 0.7 so any detail that has a f_{Rsi} lower than 0.7 (which is the case of the studied lintel) will mean that the surface is colder than the glazing, this is particularly dangerous as occupants are not very good at detecting high RH levels and so rely on window condensation as a warning.

As for the assessed lintel the surface temperature factor was never above 0.50, mould is expected to develop. This is also confirmed when using the surface RH calculated (see Table 4) and the criteria proposed in the Approved Document F 2010 (ADF 2010); even if low levels of internal air RH (40% or below) are kept constant for a day there are high chances of mould growth.

Although the risk of mould growth is high in all details analysed, it could be argued that the risk could be higher in the lintel where the window is closer to the external surface since there are higher surface temperatures, hence high relative humidity and not condensation (as mould does not grow on liquid water).

CONCLUSIONS

For the boundary conditions and construction details modelled, the lack of insulation in the lintel has a significant impact on the severity of the thermal bridge, which was found to be ‘unacceptable’ in all cases. Surface temperatures at the lintel varied slightly, however they were most of the time below the temperature dew point. The risk of mould growth at the lintel was always high, regardless of the insulation thickness, the insulation system used and even under low levels of internal air RH. It is also important to note that the position of the window has an important effect on the heat loss and the risk of mould growth.

This study has demonstrated the importance of insulating the junctions when applying internal wall insulation.

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