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Parametric study on the impact of thermal bridges on the heat loss of internally insulated buildings

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Abstract

Internal wall insulation as energy efficiency retrofit measure could considerably help to reduce the greenhouse gas emissions of more than 6 million solid wall buildings in the UK. However during retrofit, junctions that are hard to reach are often left uninsulated, increasing heat loss and surface mould growth risk at thermal bridges. This paper presents a parametric study on the impact of thermal bridges on the total heat loss of an internally insulated mid-terrace house. Findings showed that heat flux through junctions occurred mainly at reveals and that the total heat flux at junctions per unit of exposed area was often higher than the default value used in the UK.

Keywords: Thermal bridges; internal wall insulation; retrofit

The aim of the paper is to estimate the impact of junctions on the overall heat loss of typical solid wall dwellings in UK. Previous research focused on the impact of the heat flux through junctions on the total transmission heat flux of a building [1-4]. However, the impact of individual junctions has not been estimated before.

A parametric analysis on a mid-terrace was performed, taking into account two external wall thicknesses, eight internal wall insulation thicknesses, two thermal conductivities of wall insulation and two levels of insulation at junctions (uninsulated junctions or insulated junctions). In this regard, the junctions taken into account are sills, jambs, lintels, intermediate floors and eaves.

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The total heat flux through the building fabric of a dwelling can be divided into heat flux through plane elements (one-dimensional) and heat flux through junctions (two-dimensional). The calculation of heat flux through plane elements is straightforward, and can be done by hand or with simple calculation tools; on the other hand calculating the two-dimensional heat flux requires complex finite element analysis methods. Therefore, for compliance purposes, an alternative in the UK to the full calculation of a dwelling's heat flux through junctions is the use of a conservative default **y-value** (heat flux through junctions per unit area of exposed elements).

A conservative default y-value is provided in part L1A of the building regulations [5], where a y-value of 0.15 $Wm^{-2}K^{-1}$ is specified. Regarding retrofit of existing building, the relevant approved document, part L1B, states that "*it is impractical to expect thermal bridge and temperature factor calculations*" for compliance purposes [6]. However, the EPBD assessment tool for retrofit in the UK, RdSAP [7], defines 0.15 $Wm^{-2}K^{-1}$ as a default value. The analysis shows that in most cases the y-value of the retrofitted buildings assessed in this study exceeds the conservative y-value defined by RdSAP, used as a reference value in this analysis.

Nomenclature

λ	thermal conductivity ($Wm^{-1}K^{-1}$)
U	thermal transmittance ($Wm^{-2}K^{-1}$)
Ψ	linear thermal transmittance ($Wm^{-1}K^{-1}$)
$Q/\Delta T$	total heat flux through the building fabric of a dwelling (WK^{-1})
y	heat flux through junctions per unit area of exposed elements ($Wm^{-2}K^{-1}$)

1. Methodology

The total heat flux through the plane elements of a dwelling and through junctions were calculated for a solid brick dwelling and its y-value compared to a reference y-value of 0.15 $Wm^{-2}K^{-1}$, used as default in RdSAP [7].

1.1. Dwelling assessed

The type of dwelling used in this study was extracted from the English archetypes defined by Oikonomou et al. [8] and correspond to a typical mid terrace two-storey house. The dwelling is 6.25 m wide, 8.9 m long and 5.7 m high, divided in two storeys and has an internal partition wall that runs from front to back in both floors; the back wall presents the same materials and dimensions as the front wall. The size and geometry of individual openings are derived from a Victorian sash window [9], to represent the pre-1919 building stock. The total perimeter of the openings is 50.8 m and the total openings area is 17.4 m^2 compared to an exposed wall area of 54 m^2.

1.2. Junctions selected for the calculation of linear thermal transmittance

The junctions selected for the analysis are the junctions between wall and openings (reveals), between two vertical elements and between vertical and horizontal elements:

- For the reveals, a *lintel*, a *sill* and a *jamb* were analysed according to two levels of insulation: uninsulated reveals and insulated reveals with 20 mm-thick insulation. The lintels are limestone (λ = 1.7 $Wm^{-1}K^{-1}$) and their cross section is 150 mm (height) by 215 or 500 mm (width), depending on the thickness of the existing wall. Their length is the same as the width of the relative window/door. The internal sills are made out of timber, their height is 10 mm and the length is the same as the window width; the internal sill width is 20 mm more than the wall insulation thickness. The window frame is positioned 100 mm from the external surface (see Fig. 1).
- The junctions between two vertical elements refer to the intersection of the external wall with the party wall or the internal partition wall; party and partition walls are uninsulated (see Table 1).

- The junctions between vertical and horizontal elements are the following:
  - Solid ground floor (uninsulated, see Table 1) and external wall
  - Intermediate floor (uninsulated or insulated, see Table 1) and external wall
  - Roof (insulated loft, see Table 1; uninsulated or insulated wall plate [10]) and external wall
  - Roof and party wall (insulated loft, uninsulated party wall, see Table 1)
  - Solid ground floor and party wall (both uninsulated)

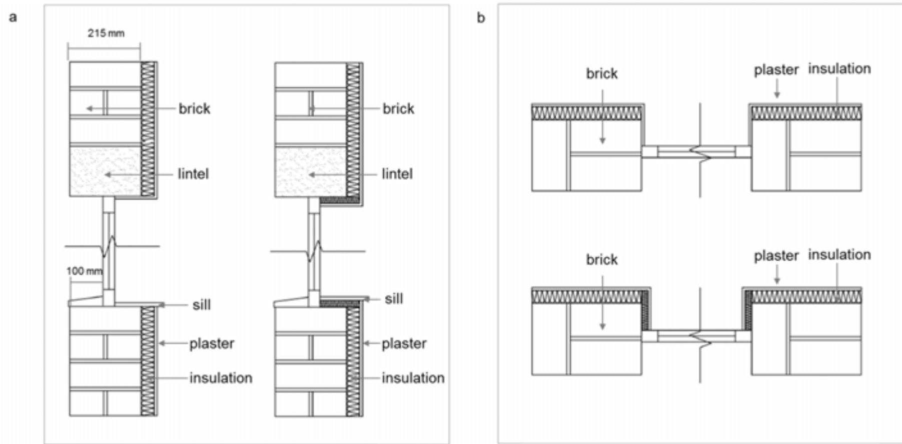

Fig. 1. (a) cross section detail of thin external wall, uninsulated (left) and insulated (right) reveals; (b) plan detail of thin external wall, uninsulated (top) and insulated (bottom) jambs.

The thermal properties of plane elements of the building fabric are shown in Table 1 (outside to inside, top to bottom). The U-values are calculated from BS EN ISO 6946 [11] and BS EN ISO 13370 [12].

Table 1. Plane elements of the building fabric: composition and thermal properties

Element	Layer	Thickness (*mm*)	λ ($Wm^{-1}K^{-1}$)
External wall	Brick	215; 500	0.770
	Internal wall insulation	0; 20; 40; 60; 80; 100; 120; 140	0.026 (low); 0.043 (high)
	Plaster	8	1.2
Roof (insulated loft)	Insulation batt	88	0.038
	Insulation batt between joists (joist fraction 7.2%)	80	0.038 (insulation batt); 0.13 (joists)
	Plasterboard	12.5	0.25
Solid ground floor	Timber flooring	20	0.28
	Concrete	150	2.3
Intermediate floor	Floorboards	12	0.13
	Oriented stranded board	9	0.13
	Unventilated air layer; insulation batt	100	0.056 (air layer); 0.038 (insulation batt)
	Plasterboard	12.5	0.25
Party / partition wall	Plaster	8	1.2
	Brick	215 (party wall) 105 (partition wall)	0.770
	Plaster	8	1.2

Windows and doors are treated as adiabatic boundaries according to BR 497 [13]. For the calculation of the heat loss of plane elements, the windows are double glazed, with U_W=2.3 $Wm^{-2}K^{-1}$ and the thermal transmittance of the doors is U_D=1.8 $Wm^{-2}K^{-1}$.

The following assumptions are made in this analysis:

- The roof is insulated at ceiling level and its structure is not included (according to BR 497)
- The 2D software is not able to calculate three-dimensional corners and treats adjacent junctions (e.g. roof eaves over lintels) as separate
- The neighbouring dwellings are uninsulated

1.3. Calculation method

The calculation of two-dimensional heat flux is carried out using the software Flixo® Pro v.5. The linear thermal transmittance Ψ (*$Wm^{-1}K^{-1}$*) is calculated according to BS EN 10211[14]. The total heat flux related to a dwelling, Q/ΔT (*WK^{-1}*), sum of heat flux through junctions and plane elements, is calculated according to BR 497 [13] and the heat flux through junctions per unit area of exposed elements, y (*$Wm^{-2}K^{-1}$*), is calculated as defined in SAP [7]. The boundary conditions are set according to BR 497.

2. Results and discussions

The total heat flux through the building fabric of a dwelling was simulated and its reduction after retrofit calculated (Fig. 1a, 2a), together with the heat flux through individual junctions and the corresponding y-value (Fig. 1b, 2b).

2.1. Thin external walls

The total heat flux reduction of a dwelling with a thin external wall (215 mm) was assessed as a function of wall insulation thickness, thermal conductivity and insulation level at junctions. The initial total heat flux of a mid-terrace with uninsulated thin external walls was 230 WK^{-1}.

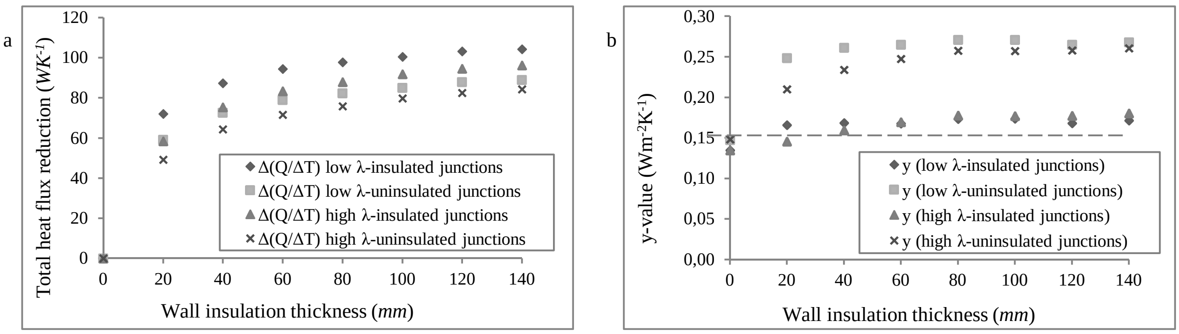

Fig. 2. (a) heat flux reduction in a mid-terrace with thin external walls; (b) y-value

Although the maximum total heat flux reduction for the dwelling with the best combination of parameters (thickest wall insulation, lower λ and insulated junctions) tested was 107 WK^{-1}, the total heat flux was found to be similar to the result of other combinations (as shown in Fig. 2a).

It was also found that the thermal conductivity of the wall insulation has a small impact on the total heat flux reduction of the dwelling, if compared with the impact of insulation in junctions: a maximum reduction of 7.7 % was found if a low λ is preferred to a high λ (insulating the junctions leads to a maximum reduction of 16.5 %).

If the impact on the total heat flux reduction of each individual junction is analysed, insulating the jambs leads to the highest heat flux reduction among junctions (accounting for the 7.8 % of the total heat flux reduction, in the case of thickest wall insulation), followed by insulating the lintel (4.4 %), the sill (2.2 %), the intermediate floor (1.9 %) and eaves (0.2 %). In general, uninsulated reveals have the biggest impact on the heat flux through junctions in the mid-terrace house with thin external walls (maximum cumulative reduction of heat flux through reveals of around 14.4 % of the total heat flux reduction of a dwelling).

The thicker the wall insulation, the lower the heat flux through plane elements and the higher the heat flux through junctions. As a consequence, the gradient of total heat flux reduction becomes smaller as the insulation gets thicker (Fig. 2a); for example, no difference in total heat flux reduction is found between 120 mm and 140 mm of wall insulation, if the junctions are uninsulated.

Also, highly insulated dwellings with no insulation at junctions could present the same heat flux as dwellings with lower wall insulation thickness but insulated at junctions. For example, 40 mm of wall insulation, with insulated junctions, presents a similar heat flux reduction to 140 mm of wall insulation but uninsulated junctions (lower λ).

The y-value was compared to the default value for RdSAP, y=0.15 $Wm^{-2}K^{-1}$ (Fig. 2b), as the default value should represent the worst case scenario regarding heat loss at junctions. This means that all calculated y-values should fall below the default value. However, it was found that the y-value falls below the default value only in the uninsulated case; as soon as the wall is insulated, the heat flux through junctions increases and y-values of 0.27 $Wm^{-2}K^{-1}$ are reached in the case with uninsulated junctions and 0.17 $Wm^{-2}K^{-1}$ with insulated junctions.

2.2. Thick external walls

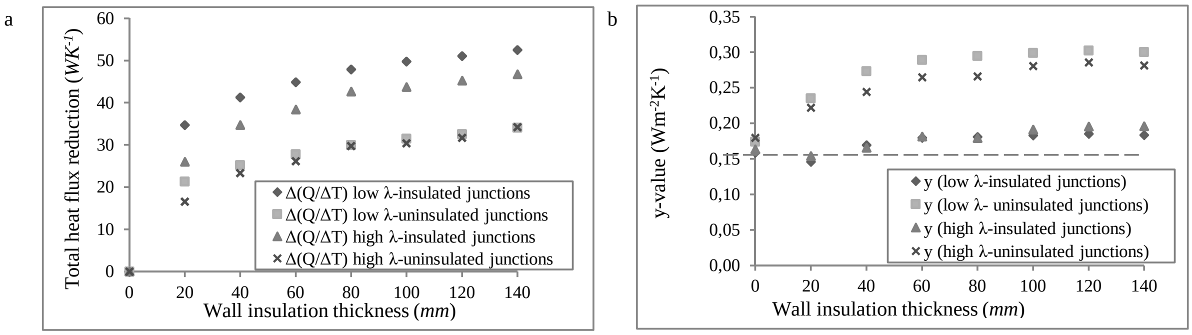

Fig. 3. (a) heat flux reduction in a mid-terrace with thick external walls; (b) y-value

Here, the existing wall presents a higher resistance to heat loss; the initial total heat flux of a mid-terrace with uninsulated thick external walls was 181 WK^{-1}. Therefore, the benefit of insulating the plane elements reduces and the total heat flux reduction in the case of thick walls was lower than in the case of thin walls.

Using the best combination of parameters tested (thickest wall insulation, lower λ and insulated junctions), resulted in a total heat flux reduction of 52 WK^{-1}, which is similar to the result of other combinations (Fig. 3a). The thermal conductivity of the wall insulation has a small impact on the total heat flux reduction of the dwelling, if compared with the impact of insulation in junctions: a maximum reduction of 13.2 % was found if a low λ is preferred to a high λ; insulating the junctions leads to a maximum reduction of 38.2 % (thickest wall insulation).

As in thin external walls, uninsulated reveals have the biggest impact on the heat flux through junctions in the mid-terrace house (maximum cumulative reduction of heat flux through reveals of around 35.5 % of the total heat flux reduction of a dwelling).

The heat flux through junctions increases with the insulation thickness; hence, the gradient of total heat flux reduction becomes smaller as the insulation thickens. There is hardly any difference in terms of total heat flux reduction between 120 or 140 mm of wall insulation and, for example, 20 mm of wall insulation with insulated junctions presents a similar heat flux reduction as a 140 mm-thick wall insulation without insulating the junctions (lower λ).

The y-value related to the mid-terrace with 500 mm-thick brick walls is presented in Fig. 3b. The graph shows that the calculated y-value is above the default value in all cases; hence, it was found that the default value is not able to represent worst case scenario.

3. Conclusions

The parameters that affect the overall heat flux reduction of a mid-terrace dwelling are assessed. The parametric analysis considers variations of wall thickness, internal insulation thickness, insulation thermal conductivity and two levels of insulation at junctions.

It was found that, in all cases, the impact of thermal conductivity on the overall heat flux reduction is smaller than the impact of insulating the junctions.

In general, the total heat flux reduction in the dwelling with thicker walls was found to be lower than in the case of thin walls, because the heat flux through plane elements is already low (uninsulated walls and junctions).

Looking at the heat flux through individual junctions, reveals (jambs in particular) account for the majority of heat flux through junctions. The thicker the existing wall, the higher the heat flux through reveals.

It was found that the heat flux through junctions increases with thicker wall insulation; as a consequence, the total heat flux profile flattens at higher wall insulation thicknesses. Therefore, there is little benefit of applying internal wall insulation with high thickness. Insulating the junctions can be a more appropriate solution than increasing the insulation thickness or reducing its thermal conductivity.

The y-value of a mid-terrace falls usually above the conservative default value defined by the compliance tool for retrofit, RdSAP [7], 0.15 $Wm^{-2}K^{-1}$; the analysis shows y-values of up to 0.3 $Wm^{-2}K^{-1}$. Further research will include multiple criteria decision analysis for the assessment of building fabric insulation strategies, taking into account the risk of mould growth and cost.

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