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Risk Assessment of Thermal Bridging and related Mould Growth in Housing Refurbishment

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Abstract
Aim of this paper is to provide a methodology on how to assess the risk of thermal bridging and related mould growth in housing refurbishments. Five apartments with identified problems of thermal bridging and mould were used in this study. They are part of a proposed refurbishment programme in south-east London .Simulations were conducted using THERM 5.2 (LBLN, 2002) on locations where thermal bridging is likely to occur after the refurbishment. Different scenarios of internal temperature and moisture production were tested. The study indicated that in most cases the refurbishment would reduce the risk of thermal bridging and related mould growth. However, in few cases the risk would be considerable even after the refurbishment, and therefore alterations to the initial proposal may be required. The study showed that the methodology proposed in this paper is an effective way of assessing such risks and can help in achieving successful housing refurbishments.

Keywords: risk assessment; thermal bridging; mould growth; housing refurbishment

1 Introduction
"Britain has the oldest housing stock in the developed world with 8.5 million properties over 60 years old" (BRE, 2012) and "the older the stock, the less energy efficient it is likely to be" (Power A., 2008). In fact, the UK housing sector is responsible for 27% of CO_2 emissions (Killip, 2008).

Following the Kyoto Protocol of 1997, the UK government set out its own target of an 80% reduction of CO_2 from the 1990 levels by 2050 (The National Archives, 2008). This target, combined with the belief that around 85% of the houses in 2050 will consist of dwellings which already exist today (Killip, 2008), explain why housing refurbishment is an undisputable need.

This paper focuses on the assessment of the severity of thermal (or cold) bridges, a problem often encountered in housing refurbishments (Energy Saving Trust, n.d.; Hopper et al, n.d.). The issue is examined from the mould growth aspect, as in many cases thermal bridges are responsible for mould occurrence (Ward, 1994). This happens because the internal surface temperature is usually colder on cold bridges than in the rest of the room. Thus, the surface relative humidity (RH) is higher compared to the room RH (Ward, 1994). According to researches, high surface RH (above 70%) over a period of time can be responsible for mould growth (Oreszczyn et al, 2000). Mould can result in health problems for the occupants, ranging from eye irritation to severe respiratory problems (Rose, 2005). Furthermore, it can damage the building fabric and cause aesthetical deterioration.

Thermal bridges can be avoided if the refurbishment is done properly. However, there are cases where inadequate preliminary survey and poor detailing were proven to be the reasons for increase in the severity of thermal bridging (Hopper et al, n.d.). Hence, a risk assessment of thermal bridging and mould growth is important in the early design stage. Therefore, aim of this paper is to provide a methodology on how to assess the risk of the above issues in housing refurbishments.

2 Methods

Five apartments with identified problems of thermal bridging and mould growth are used as case studies. They are located in south-east London and are part of a refurbishment programme which suggests the addition of 110 mm external wall and roof insulation. Due to accessibility regulations, in some locations the wall insulation will be reduced to 60 mm. Therefore, the risk assessment is conducted for three cases: pre-refurbishment, application of 60 mm wall insulation and application of 110 mm wall insulation. The locations of possible thermal bridges are determined for each flat and then modelled as details in THERM 5.2 (LBLN, 2002).

2.1 External Conditions

The risk assessment was conducted using external conditions of 5 °C and 80% relative humidity (CIBSE Guide A, 2006; Oreszczyn et al, 2005; 2006; Ridley et al, 2007), typical conditions found in the UK during the heating period.

2.2 Internal Conditions

2.2.1 Internal Air Temperature

Three internal air temperatures were used for this study: 14 °C, 20 °C and 24 °C. These values correspond to cold, normal and hot conditions respectively (Moore et al, 1996).

2.2.2 Moisture Production

Three main scenarios of moisture production (vapour pressure excess) were used here: 150 Pa, 300 Pa and 500 Pa. They represent the dry, average and wet moisture class respectively, which, according to a recent research by Ridley, are typical moisture classes for the UK (Ridley et al, 2007). This research analysed 1600 dwellings from the Warm Front data (Ridley et al, 2007).15% of the dwellings belong to the dry moisture class, 70% to the average and the rest 15% to the wet moisture class. The vapour pressure excess values for 5 °C external air temperature range between 100 and 200 Pa for the dry class, 200 and 400 Pa for the average and 400 and 500 Pa for the wet class (Ridley et al, 2007).

2.3 Thermal Bridging

Eight main locations of possible thermal bridges were determined and then modelled as details in THERM 5.2 (LBLN, 2002). Some of them are: cantilevered balconies, archways adjacent to external walls, wall corners, window and door reveals, flat roofs and ground floor slabs. The details were simulated for the selected external and internal temperatures. The minimum surface temperature was given by THERM.

The assessment of the thermal bridge severity was based on the **Surface Temperature Factor fRsi** (Ward, 2001) and the **Temperature Difference Ratio (TDR)** (Oreszczyn, 1992), which are given by equations [2-1] and [2-2] respectively:

$$f_{Rsi} = \frac{\text{Minimum internal surface temperature} - \text{External temperature}}{\text{Internal temperature} - \text{External temperature}} \qquad [2\text{-}1]$$

$$TDR = \frac{\text{Internal air temperature} - \text{Cold bridge temperature}}{\text{Internal air temperature} - \text{External air temperature}} \qquad [2\text{-}2]$$

Regarding the surface temperature factor, the lower it is "the higher the risk of condensation and possible mould growth" (Roaf et al, 2003). According to Ward the **critical temperature factor** for the avoidance of mould growth in dwellings and residential buildings is $\mathbf{f_{CRsi} = 0.75}$ (Ward, 2001). On the other hand, the greater the TDR the more severe the thermal bridge is. Table 2-1 shows the four categories that cold bridges are divided into, depending on the TDR (Oreszczyn T., 1992).

Table 2-1. Cold bridge categorization (Source: Oreszsczyn, 1992, pg 181)

Cold bridge category	TDR	Examples
Negligible	<0.15	Plain walls U-values less than 1.2 W/m^{2}K. External corners u-value less than 0.6 W/m^{2}K. Insulated lintels.
Moderate	0.15-0.2	Plain walls U-values greater than 1.2 W/m^{2}K. 3D corner u-value greater than 0.6 W/m^{2}K.
Severe	0.2-0.3	External corners U-value 0.9 to 1.5 W/m^{2}K. Un-insulated lintels. Concrete party wall or floor.
Unacceptable	>0.3	2D corners U-value>1.5 W/m^{2}K. 3D corners U-value > 1.0 W/m^{2}K. Party wall of drylined wall. Window reveal of drylined wall.

2.4 Mould Growth

The risk of mould growth was assessed for the critical **surface water activity (a_w)** given in Table 2-2 (HM Government, 2010). These are the maximum values above which mould is likely to grow, during the heating season and for each stated period of time. The surface a_w can also be defined as the surface RH divided by 100. The corresponding values of surface RH are also presented in Table 2-2.

Table 2-2. Moisture criterion for mould growth (Source: HM Government, 2010)

Period	Surface a_w	Surface RH (%)
1 month	0.75	75%
1 week	0.85	85%
1 day	0.95	95%

The method used to find the surface RH is analysed below:

Firstly, the external air temperature (θ) of 5 °C is used in Equation [2-3], which calculates the **saturated vapour pressure p_s** (CIBSE Guide A, 2006).

$$p_s = 610.5\exp\left(\frac{17.269 x \theta}{237.3+\theta}\right) \qquad [\ 2\text{-}3\ ]$$

Thereafter, the external saturated vapour pressure found above is applied in Equation [2-4] in order to calculate the **external vapour pressure p** (IEA, Annex 14, 1991).

$$\mathbf{p = (\varphi/100)*p_s} \qquad [\ 2\text{-}4\ ]$$

where φ is the external relative humidity of 80%.

The **vapour pressure excess (VPX)** can be defined as the internal vapour pressure minus the external vapour pressure (Ridley et al, 2007). Therefore, the VPX values determined in Section 2.2.2 are used to calculate the **internal vapour pressure** $\mathbf{p_i}$ for each moisture class, which is given by Equation [2-5].

$$\mathbf{p_i = VPX + p} \qquad [\ 2\text{-}5\ ]$$

The **internal saturated vapour pressure** $\mathbf{p_{s\ i}}$ is then defined for each of the chosen internal temperatures of 14 °C, 20 °C and 24 °C by applying them in Equation [2-3]. The **surface RH** can be found by applying in Equation [2-3] the surface temperatures given by THERM and then using Equation [2-4].

3 Results and Discussion

All modelled locations suffer from severe or even unacceptable thermal bridging prior to refurbishment. Thermal bridging is also found after the refurbishment in some details. However it is either moderate or severe. Risk of mould growth was found in all three cases, mainly for wet moisture class and low temperatures. Two of the locations, where the intervention would not eliminate the risk of thermal bridging and mould growth, are analysed below.

Flat roof: There is unacceptable thermal bridge before the intervention and moderate in the two post-refurbishment cases. The risk of mould growth is observed in all cases; However, only under low temperature (14 °C) and high moisture production.

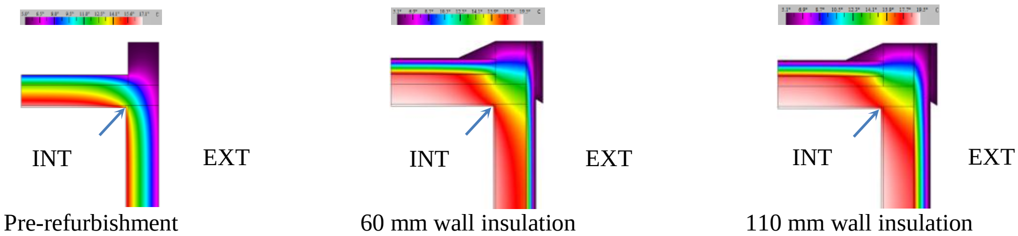

Figure 3-1 Infrared images of the ‘Flat Roof’ detail for 20 °C internal temperature

Although there will be a reduction in the severity of thermal bridging and mould growth risk after the addition of insulation, the problem will not be avoided. According to the proposed intervention the parapet will be left un-insulated and this will create a cold bridge in the area.

Archway – Horizontal Section: Similar situation is described here**.** The thermal bridge is unacceptable before the refurbishment, severe in the 60mm wall insulation case and moderate in the 110 mm wall insulation case. The problem is not eliminated because insulation will only be added to the wall and will not continue to cover the archway.

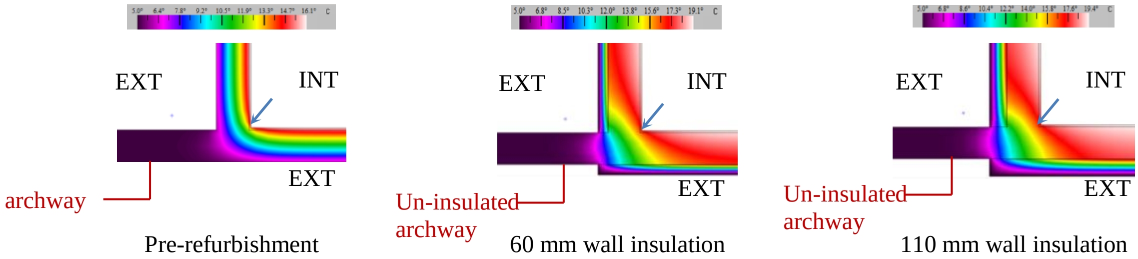

Figure 3-2 Infrared images of the ‘Archway – Horizontal Section’ detail for 20 °C internal temperature

In terms of mould growth, the risk is apparent in all three cases for high moisture production. More specifically, prior to refurbishment the temperature threshold below which mould may occur (for wet moisture class) is 21 °C. This threshold is 17 °C for both post-refurbishment cases (Figure 3-3). According to a research by Oreszczyn (Oreszczyn et al, 2005) that analysed data from the Warm Front Scheme, temperatures around 17 °C can be found in insulated houses. More specifically, the mean temperature in bedrooms was found to be 17.1 °C and in living rooms 18.7 °C (Oreszczyn et al, 2005). Therefore, although the proposed refurbishment seems to decrease the temperature threshold below which mould may occur, it will not eliminate the risk.

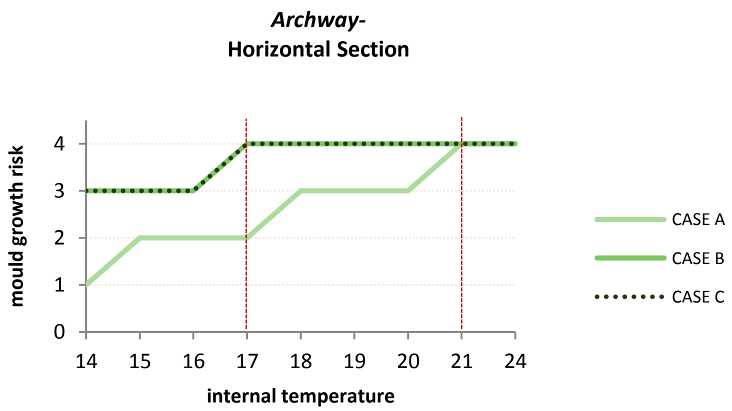

Figure 3-3 Risk of mould growth for the three cases according to internal temperature [where 1=high risk (1 day), 2=medium risk (1 week), 3=low risk (1 month), 4=negligible]

After assessing the risk of thermal bridging and mould growth, the proposed methodology was used in order to find solutions for the problematic areas. According to this, modifications to the proposed refurbishment were suggested.

The results showed that a risk assessment is needed if issues like thermal bridging and mould growth are to be avoided. However, it was also found that mould growth would always be a risk under high levels of moisture. Hence, other measures should be undertaken in order to avoid this problem, like reduction of moisture production, adequate ventilation and heating.

4 Conclusion

This study showed that the risk assessment of thermal bridging and mould growth is important in the early design stage, in order to achieve successful housing refurbishments. Therefore, the provision of a proper methodology for such an assessment is essential.

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