Modelling insulated coving′s potential to reducing thermal bridging and moisture risk in solid wall dwellings retrofitted with external wall insulation

David Glew[1*], Matthew Brooke-Peat[1], Christopher Gorse[1]

Leeds Sustainability Institute, Leeds Beckett University, Woodhouse Lane, Leeds, LS2 9EN, UK,

[*] Corresponding author, d.w.glew@leedsbeckett.ac.uk, +44 00 113 8127623

Abstract

Mould growth and surface condensation are problems for many dwellings, and the retrofitting of insulation can increase the risk of these occurring. This is especially the case for historical solid wall properties receiving external wall insulation (EWI), which often have architectural details at the roof eaves that cause discontinuities in the insulation and so can result in excessive thermal bridging. This paper presents the results of an investigation into retrofitted solid wall properties where modelling is used to investigate the problem and effectiveness of insulated coving products which are designed to reducing thermal bridging. Thermal modelling is undertaken to establish the optimum design to reduce risk. The insulated coving was found to be effective in reducing thermal bridging in all the scenarios investigated and to reduce moisture risks occurring in some solid walls situations.

1. Introduction

External wall insulation (EWI) is major component of English Government domestic energy efficiency policy, included within the Energy Company Obligation (ECO). By the end of 2015 ECO, EWI had been installed in over 100,000 dwellings in the UK (DCLG, 2015). Observations of EWI installed as part of government schemes between 2014 and 2015, in the North of England, have identified incomplete thermal barriers at the eaves in many solid wall properties, especially as a result of the architectural features as identified in Figure 1. This scenario had previously been observed by Hopper et. al., (2012) in the retrofitting of EWI to pre-1919 solid wall properties in Wales and other large-scale projects in the North of England (English Heritage, 2014).

Figure 1, Common causes of incomplete EWI thermal barrier at eaves

Figure 2 shows a thermogram taken of the internal wall surfaces in a dwelling, which illustrates the thermal bridging occurring at the eaves, caused by the incomplete thermal envelope provided by a compromised EWI installation. The implication of this is that there could be an increased risk of mould growth and surface condensation following EWI retrofit in some solid wall properties. In addition to the potential physical impacts (for example, reducing the thermal performance of the retrofit and increasing the risk of moisture related problems occurring) there are economic and consumer protection issues, which are in many cases linked to government funded interventions in people's homes. The implications of encouraging thermal upgrades where such problems manifest make this phenomenon a particular concern. Furthermore, it raises the necessity to adopt a more tailored approach to deal with these issues, as has previously been articulated (Ascione et al., 2015). Whilst a more tailored approach has been called for few detailed examples addressing the difficult to treat junctions exist

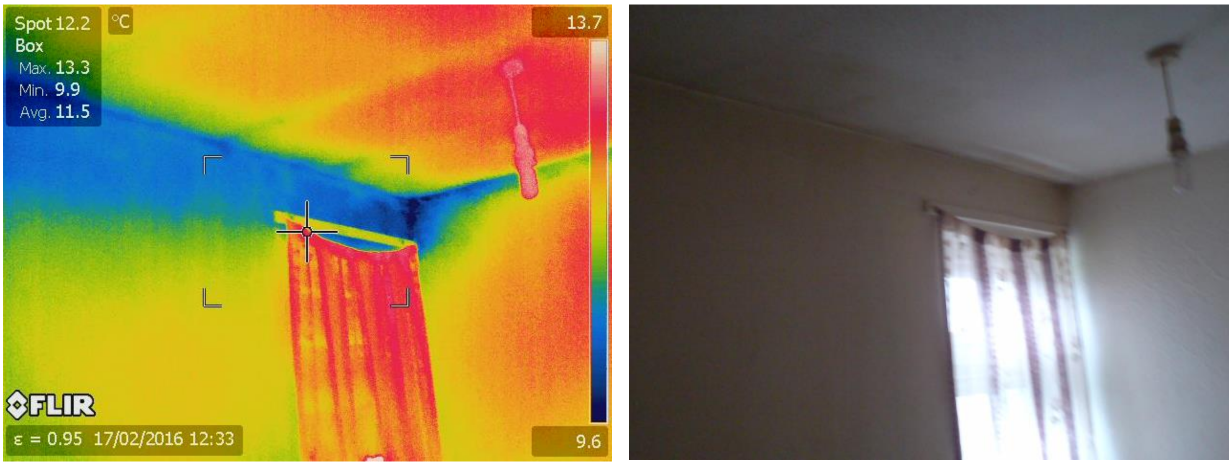

Figure 2, Thermal bridging along the eaves following a compromised EWI installation

Planning restrictions and impractical detailing can make it difficult to extend EWI over architectural features and extending roofs where detailing creates incomplete thermal envelopes are often cost prohibitive. Alternative solutions are therefore needed to address this difficult to treat, yet commonly occurring, junction. One solution to complete the thermal envelope could be through the use of internal wall insulation (IWI), using a combination of EWI and IWI to overcome issues of buildability. At the eaves, in solid wall construction, it often becomes more practical and buildable to use IWI on the internal corner of the wall to ceiling junction to limit the impact of this thermal bridge. Interestingly IWI is often a less practicable solution over the remainder of the external wall, due to the interference of intermediate floors, wall sockets, fitted features and cupboards which interrupt internal surfaces and would disrupt the thermal envelope. To maintain the aesthetic appeal and provide the necessary thermal resistance, an insulated coving component can be fixed on the inside face of external walls improving the continuity in the thermal envelope, as shown in Figure 3.

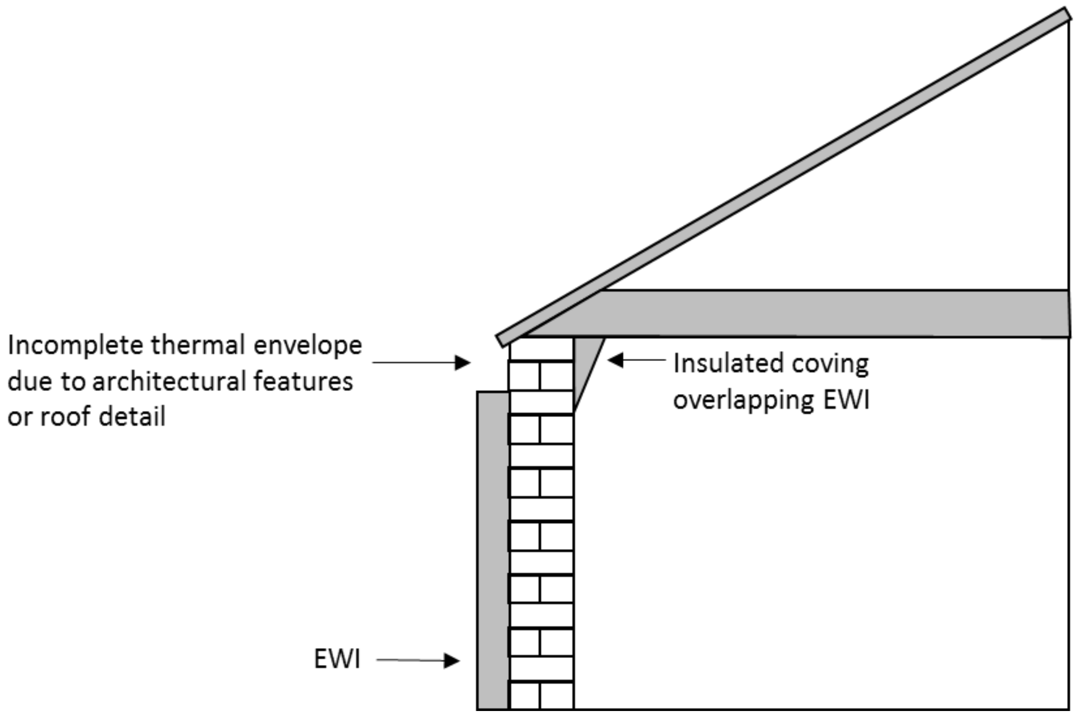

Figure 3, Eaves discontinuity in the thermal envelope of a compromised EWI installation

This paper presents the results of an investigation into the potential effectiveness of using insulated coving, as a complementary component with EWI, to reduce thermal bridging and risk of mould growth and surface condensation in solid wall retrofits. Thermal modelling is undertaken using Physibel TRISCO (Physibel, 2010) software on a range of retrofit scenarios to explore the optimum coving dimensions.

1.1 Mould growth and condensation in dwellings

Risk of mould growth and surface condensation in homes is a problem for a substantial number of dwellings in the UK (Hunter et al., 1988, Sharpe et al., 2015). In England in 2013-14, around 4% of homes had experienced some degree of damp, 618,000 of these were related to mould growth and surface condensation (DCLG, 2015). Problems of this nature are not unique to the UK, this is a global issue. In the US and Canada there are reports that 20% of homes might be affected by damp and in other countries it is suggested that the numbers of buildings affected are higher, such as China, who report figures of 30% (WHO, 2009). Whilst unsightly, of greater concern is the impact on occupant wellbeing and the building fabric. Mould has been widely associated with ill-health (Tischer and Heinrich, 2013, Jaakkola et al., 2013), especially with regards to respiratory ailments (Crook and Burton, 2010, WHO, 2009). On or within the fabric, condensation can cause cosmetic and more serious degradation of building if left untreated or when occurring in inaccessible locations as with interstitial condensation (Langmans et al., 2012, Bellia and Minichiello, 2003).

Risk of mould at low levels is ubiquitous in all dwellings due to a wide variety of factors (Dallongeville et al., 2015, Crawford et al., 2015) though mould does not commonly manifest in most dwellings unless there is a fabric or management problem. In dwellings, surface condensation arises when moisture laden air comes into contact with colder surfaces. Thus, the risk of condensation is increased where there is a lack of space heating, inadequate ventilation, insufficient insulation to plane elements, junctions that create excessive thermal bridges or in areas where there are significant thermal bypasses caused by air moving around and through gaps in the insulation. Condensation risk is also directly linked to elevated moisture levels often due to environmental conditions like driving rain (Abuku et al., 2009) but also to specific building fabric problems, typically, leaks, rising damp, failed vapour barriers and where elements are designed without proper attention to moisture control (Othman et al., 2015, Chew, 2005).

High levels of moisture in the air of the internal environment or its relative humidity (RH) is also a major contributing factor of condensation within dwellings (Galvin, 2010). Commonly, high RH levels, which are consistently over 75%, are associated with mould growth in timber materials (Johansson et al., 2005), such conditions are typically observed in buildings when occupants dry clothes indoors with poor ventilation (WHO, 2009). Condensation does not always result in mould growth, however, the risk is exacerbated where fabric characteristics and occupant mismanagement occur together. Additionally, surface effects mean that the air in the immediate vicinity of walls and particularly the air within corners tend to have higher RH than the room air, which further exacerbating the risk of mould growth (BSI, 2011). Reducing heat transfer, to maintain higher fabric surface temperatures and improve the continuity of the thermal envelope, using insulated coving may reduce risks of moisture problems occurring.

Housing associations and councils who own large numbers of properties experience significant disrepair and claims as a direct result of mould growth and surface condensation, and a scrutiny panel review for a collection of large housing associations recently found that moisture related disrepair claims were on the increase (DWF, 2014). The potential impact and damage is often exacerbated as a result of socio-economic circumstance and the solid wall homes occupied, since fuel poor households are often under heated and ventilation practices are not always ideal (Park and

Kim, 2012, BekÖ et al., 2011, Roetzel et al., 2010). Although risk could be controlled, in many instances, through householder management, the education of occupants to change their behaviour is difficult (Levie et al., 2014, Park and Kim, 2012, Sharpe et al., 2015) and, as a result. fabric solutions are often taken to offer more practicable and robust solutions.

1.2 Thermal bridging

The energy efficiency of dwellings in the UK has been the focus of much government policy over the last few decades (NBS, 2010a). In new dwellings the major driver has been incremental increases in the standards required by the Building Regulations (NBS, 2010b). In existing buildings the incentives have tended to offer financial support for installing new boilers to provide improvements to the fabric and heating efficiency of existing buildings (Marchand et al., 2015, Pettifor et al., 2015).

The use of an insulated coving may in some instances offer a reduction in heat loss from dwellings since it improves the continuity of insulation to the building fabric. More significantly, it is the potential reduction in linear thermal transmittance (Ψ) and increase the internal surface temperature (T_{si}) at the external wall to roof junction that is the focus of this paper. Though Ψ-values affect energy efficiency (Theodosiou and Papadopoulos, 2008) typically they only become critical in energy use terms in low energy buildings where it can be proportionally more important factor in the overall heat loss of the building (Ge and Baba, 2015). This paper investigates the improvements in Ψ-values and T_{si} that may be expected from an insulated coving.

1.3 Critical internal surface temperature

Internal surfaces, where risk of mould growth and surface condensation occurs, are those which fall below a critical temperature factor (f_{CRsi}) and are determined for a use class (Taylor et al., 2014). The Temperature Factor (f_{Rsi}) is calculated, as shown in Equation 1, by taking the difference between the internal surface temperature (T_{si}) and the external temperature (T_e), and dividing it by the difference between internal temperature (T_i) and T_e (BSI, 2007). The f_{Rsi} is therefore a unit less parameter. The resulting f_{Rsi} must equal or exceed the f_{CRsi} set for a use type in order to avoid moisture problems (Ward, 2006).

$$f_{Rsi}=\frac{(T_{si}-T_e)}{(T_i-T_e)}$$

Equation 1: Temperature factor (BSI, 2007)

In the UK the f_{CRsi}, for limiting the risk of surface condensation, in dwellings is not explicitly set by the Building Regulations, although indicative values are given for other building types (Ward, 2006). However, the f_{CRsi} for avoiding mould growth in dwellings is set at 0.75 (Ward, 2006) and since this is likely to be exceeded before condensation occurs, in this research 0.75 is deemed an acceptable threshold to avoid risk of moisture related problems to the internal surfaces of the building fabric. The governments of other countries set the f_{CRsi} at different values in relation to the climatic conditions experienced and the accepted level of risk (Kalamees, 2006).

Uninsulated walls, areas experiencing thermal bypasses and locations where there is thermal bridging all cause heat to be transferred readily and so they create regions of relatively lower internal surface temperature during typical heating seasons. The concern is junctions, such as that which exists between the wall and roof, fall below the f_{CRsi}, present a risk. Installing additional insulation in dwellings increases the internal surface temperatures which may be assumed to reduce mould growth and surface condensation risk, however, various studies have shown hygrothermal complications may arise (Vereecken et al., 2015). This paper investigates the impact of adding insulated coving on internal surface temperatures and determines if it can reduce mould growth and surface condensation risk with respect to the critical temperature factor.

2. Method

Thermal models of the eaves details in a solid wall dwelling were created on which the coving effectiveness could be investigated. The six profiles shown in Figure 4 were assumed in order to assess how coving dimensions affected the thermal performance and effectiveness of the coving as a means to reduce the thermal bridging and risk of condensation. These were based around existing decorative coving designs. The material chosen for the coving was a composite of expanded polystyrene (λ = 0.038 W/m·K) insulating material with a plaster based front (λ = 0.400 W/m·K).

The six designs were deemed to provide sufficient variation to investigate the impact of the coving profile on its success rates, in terms of the resulting heat transfer and internal surface temperature.

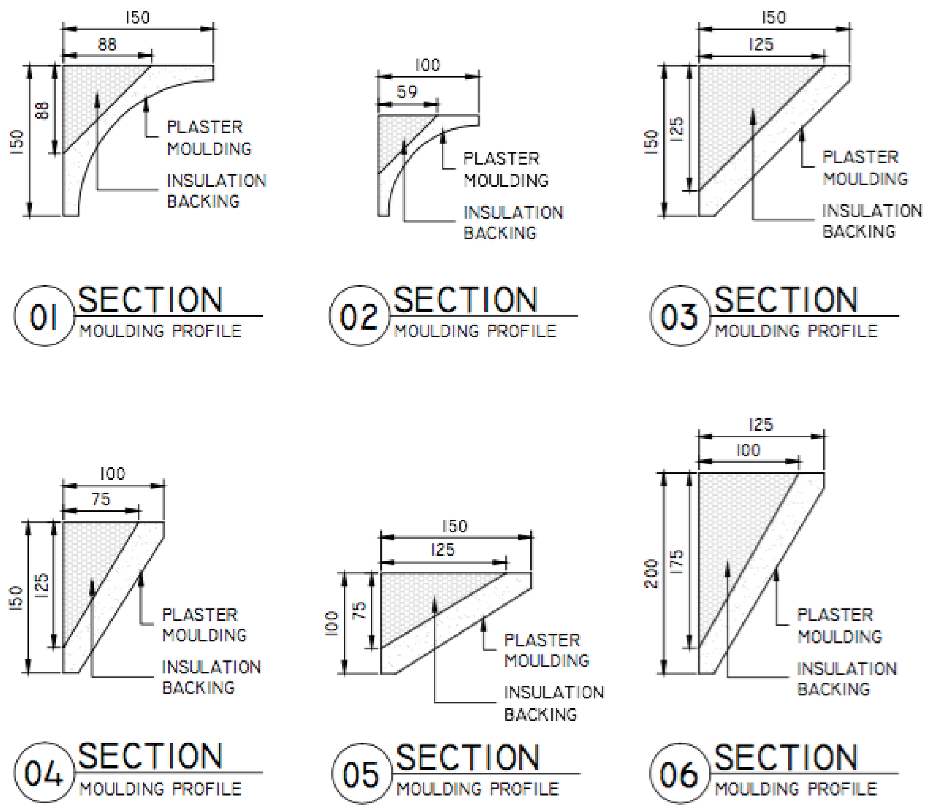

Figure 4, Coving profiles

To compare the effectiveness of the coving profiles the ten scenarios listed in Table 1 were thermally modelled. The first three scenarios were created to model the junction without coving which forms the counterfactuals. The six scenarios model the coving profiles applied to solid walls that have been treated with EWI and which also have the benefit of loft insulation (since it is unlikely that a dwelling will receive EWI without loft insulation first being installed). The final scenario explores how the coving design that was deemed to be the most effective performs as a standalone retrofit component (i.e. without EWI).

Table 1 Scenarios investigated

Retrofit Scenario	Description
1	Solid wall without loft insulation
2	Solid wall with loft insulation
3	Solid wall with loft insulation and EWI
4	Solid wall with loft insulation, EWI and cove profile 1

5	Solid wall with loft insulation, EWI and cove profile 2
6	Solid wall with loft insulation, EWI and cove profile 3
7	Solid wall with loft insulation, EWI and cove profile 4
8	Solid wall with loft insulation, EWI and cove profile 5
9	Solid wall with loft insulation, EWI and cove profile 6
10	Solid wall with loft insulation and optimal coving profile

The numerical modelling technique known as thermal modelling was employed to inform thermal bridging calculations. All thermal modelling was undertaken using the Physibel TRISCO version 12.0w software (Physibel, 2010). TRISCO is a program for the analysis of steady-state heat transfer in three-dimensional problems (*ibid*). The software solves a system of linear equations based on the energy balance technique using an iterative method (*ibid*). TRISCO is validated against the standard BS EN ISO 10211 (BSI, 2007). The conventions given in BR 497 (Ward and Sanders, 2007) were followed throughout to prepare thermal bridging calculations in accordance with BS EN ISO 10211(BSI, 2007). The thermal conductivity (λ) of each material was sourced from manufacturers' literature, BS EN 12524(BSI, 2000) and BR 443 (Anderson, 2006) as appropriate. Each scenario was assessed on two metrics; its ability to reduce thermal bridging i.e. the change in Ψ-value, and any reduction in mould growth risk i.e. the change in f_{Rsi}.

2.1 Modelling input data

Table 2 and Table 3 show the input parameters for the thermal models.

Table 2 Thermal Conductivity

Material:	λ (W/m·K):
Brickwork	0.770
Mortar Protected	0.880
Plaster	0.400
300 mm Roof Insulation	0.044
Render	1.000
Softwood	0.130
90 mm EWI	0.032

Table 3 Boundary Conditions

Boundary:	Temperature (°C):	Surface Heat Transfer Coefficient (W/m2K):
External	0.0	25.000
Internal Horizontal	20.0	7.692
Internal Upwards	20.0	10.000
Roof Void	1.0	10.000
Soffit	0.0	10.000

2.2. Modelling geometry

Figure 5 shows the base geometry of the eaves junctions thermally modelled.

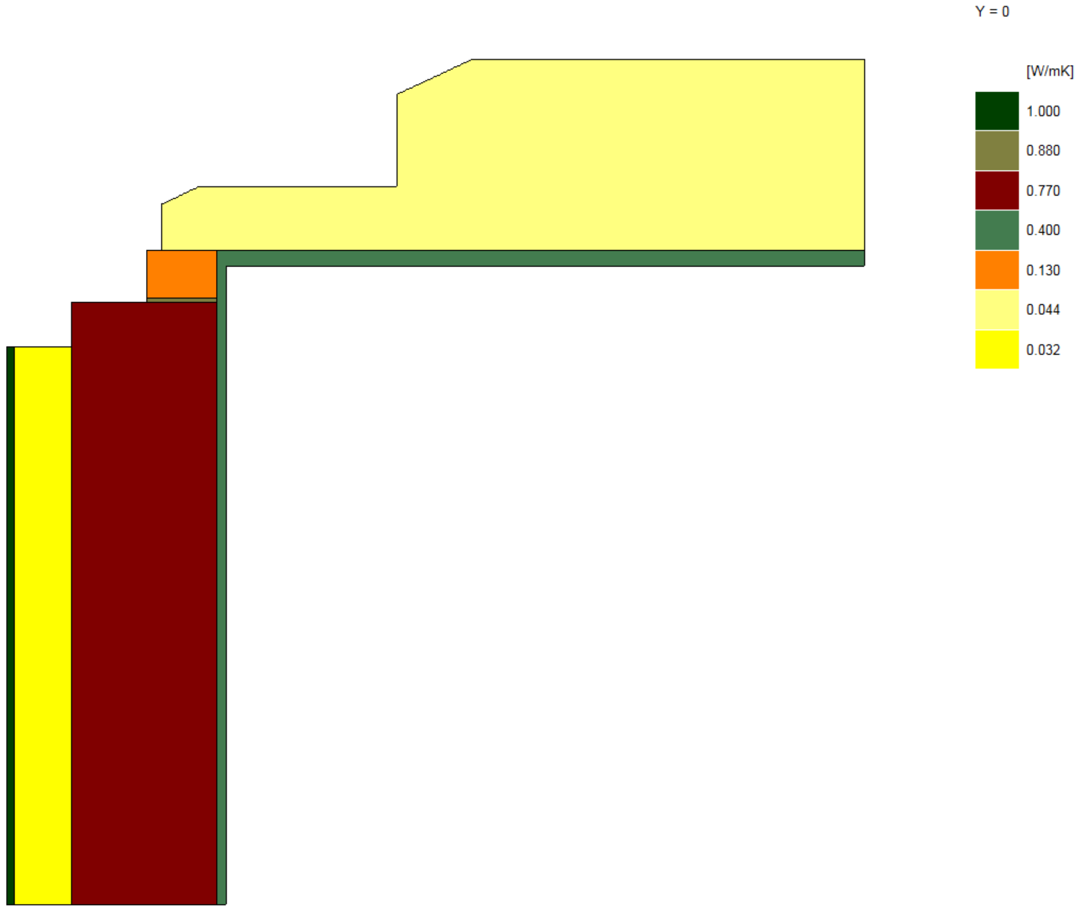

Figure 5 Geometry of Eaves Junction

3. Results and Discussion

3.1 Coving profile

Table 4 presents the Ψ-value and f_{Rsi} for each scenario. Profile 6 is the longest coving option and achieves the lowest Ψ-value and highest f_{Rsi} and so is deemed to be the most successful. Whereas profile 2, the shortest profile is the worst performing. There is relatively little difference between profiles 1 and 5 which are relatively short in design and which are both only marginally better than profile 2. Profiles 3 and 4 are slightly taller than 1 and 5, and as a result are even more effective. As stated profile 6 was the best performing profile; it was also the tallest extending 175mm down from the junction (200mm including the plaster finish), however it was not the widest indicating that the most important aspect, in the scenarios modelled, is the coverage on the external wall, not the ceiling. Commonly coving profiles are shorter than the proposed profile 6, except for elaborate coving in historic houses, which is considered to represent a small proportion of the UK housing stock.

Table 4 Thermal bridging and critical surface temperatures for each scenario

Retrofit Scenario	Description	Ψ (W/m·K)	f_{Rsi}
1	Solid wall without loft insulation	-0.411	0.583
2	Solid wall with loft insulation	0.140	0.720
3	Solid wall with loft insulation and EWI	0.607	0.782
4	Solid wall with loft insulation, EWI and cove profile 1	0.543	0.784
5	Solid wall with loft insulation, EWI and cove profile 2	0.577	0.775
6	Solid wall with loft insulation, EWI and cove profile 3	0.508	0.770
7	Solid wall with loft insulation, EWI and cove profile 4	0.528	0.778
8	Solid wall with loft insulation, EWI and cove profile 5	0.551	0.762
9	Solid wall with loft insulation, EWI and cove profile 6	0.477	0.791
10	Solid wall with loft insulation and optimal coving profile	-0.048	0.692

3.2 Thermal bridging

Figure 6 shows the negative effect of installing loft insulation and EWI on increasing thermal bridging at the eaves junctions in solid wall dwellings. A negative Ψ-value represents that there is relatively less heat loss through the junction than that lost through the flanking plane elements of the wall and roof.

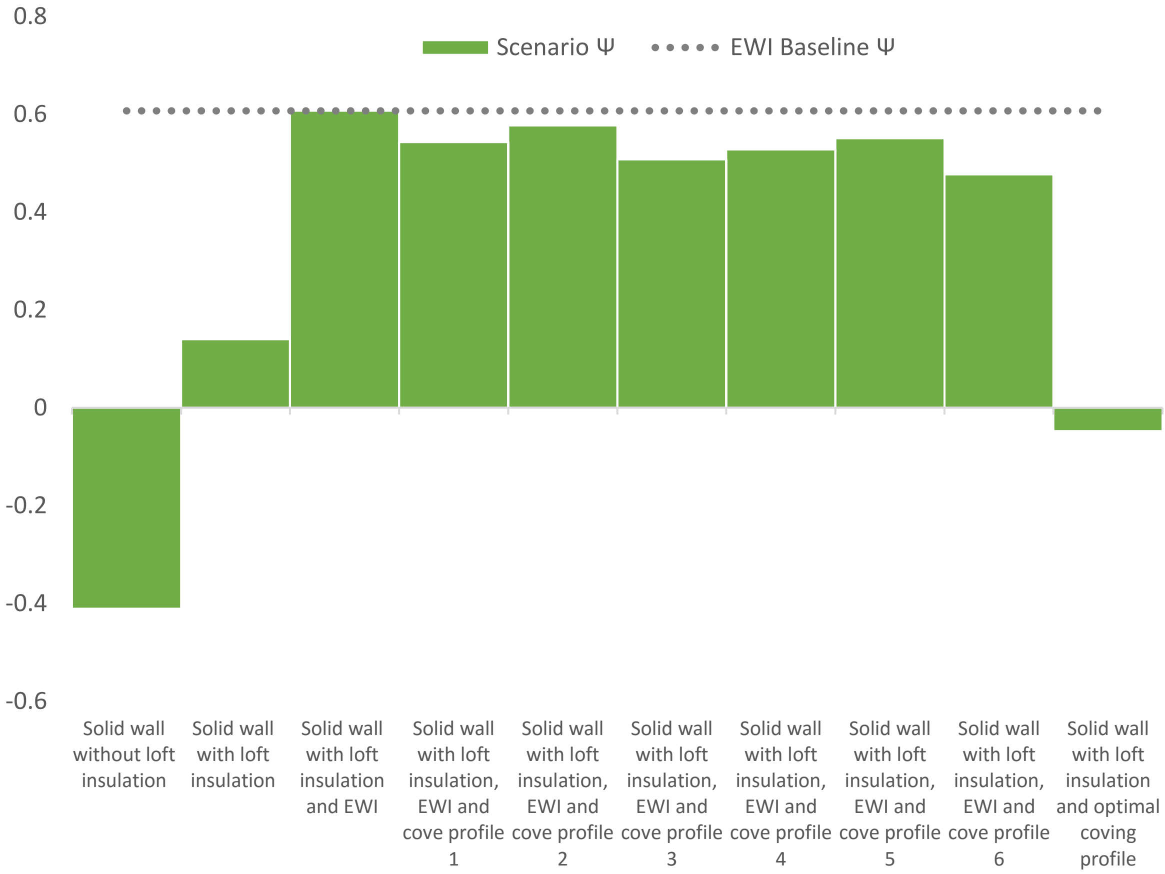

Figure 6 Influence of coving on thermal bridging

In the situation where there is a compromised EWI installation, the presence of EWI increases Ψ-values in every case, however, the coving has reduced the extent of the heat loss at the eaves junction. Figure 7 illustrates the before and after temperature distributions for coving profile 6, the most effective scenario. The internal surface temperature can be seen, in Figure 7, to increase at the head of the wall where coving profile 6 has been installed.

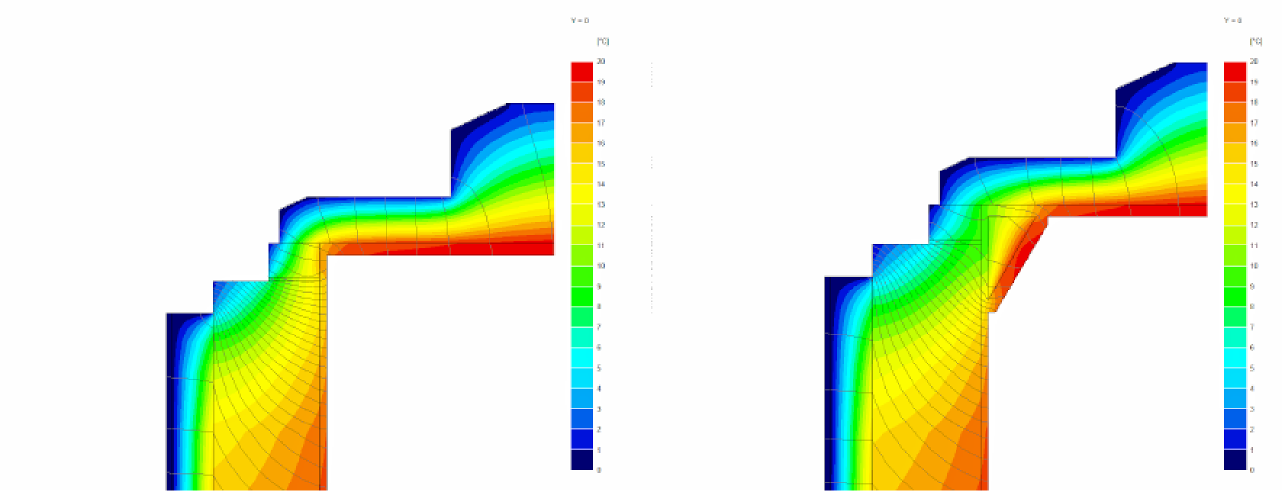

Figure 7 EWI with and without insulated coving (profile 6)

3.3 Critical temperature factor

The effects of installing EWI and insulated coving on the resulting temperature factors are shown in Figure 8. Installing EWI has a positive effect on surface temperatures, raising them above critical temperature factor of 0.75 and reducing the risk of mould growth and surface condensation.

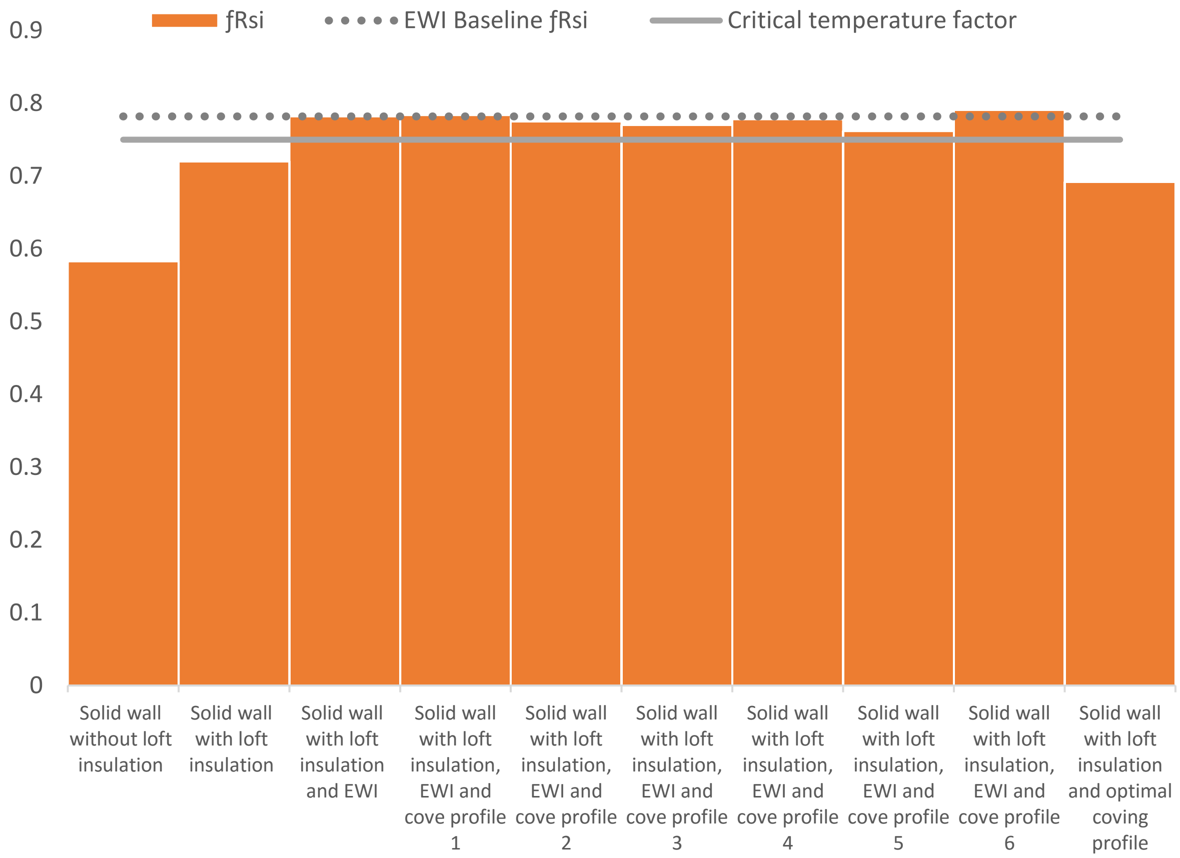

Figure 8 Influence of coving on temperature factors

The coving profiles all have a marginal negative impact on surface temperatures, except in profile 6, however, in no scenario were temperature factors seen to drop below the critical level (0.75 f_{CRsi}). This indicates that unless the profile of any insulated coving has similar characteristics to profile 6 it may actually increase risk. This is an example of how thermal and moisture issues relating to retrofits are relatively complex and unintended consequences are not easy to predict without undertaking numerical modelling or physical testing.

Installing insulated coving is unlikely to have any substantial impact on reducing risk of mould growth and surface condensation risk in EWI retrofits. Figure 8 also suggests that in solid wall properties without EWI, where there is already a risk of mould growth and surface condensation, the use of an insulated coving may even increase the risk.

4. Conclusion

EWI retrofits are an important part of the UKs strategic domestic energy efficiency landscape. In some installations there are constraints that mean the EWI installation is compromised and it has been specifically observed that architectural features at the eaves can restrict EWI being installed to the height that would provide a sufficient continuity with the roof insulation. This paper has used thermal modelling to investigate a series of insulated coving scenarios for solid wall properties with and without EWI to understand its impact on linear thermal transmittance and temperature factors.

As may be expected the coving was shown to improve thermal bridging (reduction of Ψ value) and so reduce heat loss through the junction regardless of its profile or the starting condition of the junction. However, for uninsulated solid walls, the coving alone was not sufficient to bring temperature factors above the critical level, and in fact, applying insulated coving may marginally reduce temperature factors, worsening the situation. This indicates that insulated coving alone is not a sufficient solution to reducing moisture risk to the internal surface of solid walls at eaves junctions. Conversely, it was discovered that insulated coving increases internal surface temperature factors in solid wall properties that have been installed with EWI suggesting it could be a useful complementary product for EWI, especially where architectural features and roof details means that the EWI cannot be extended all the way up to the eaves.

Future assessments could investigate the number of dwellings that have EWI designs where there are incomplete thermal envelopes, as described in this paper. It would then be possible to estimate the potential need to develop an insulated coving solution to compliment EWI retrofits. It may also be possible to investigate how the reduced thermal bridging achieved translates to fuel bill reductions for an average household using dynamic thermal simulations. Furthermore, it would also be useful to understand how insulated coving influences the thermal behaviour of a more extensive set of eaves junctions, which could impact on a wider range of building archetypes, construction features and retrofit scenarios. For example cavity wall insulation has been observed to settle over time (Rasmussen and Nicolajsen, 2007), this is also expected to have a similar effect of creating cold spots at roof and wall junctions. Finally, an investigation of how changes to the thermal conductivity of the coving materials alters performance would inform any future development of components of this type.

5. Acknowledgements

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