Heat loss from thermal bridging in internal wall insulation of solid buildings - DRAFT

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Section 1: Introduction, executive summary and recommendations

Introduction:

This report was commissioned by the Department of Energy and Climate Change (DECC) on 28th June 2013. The contract states that the funding was "for the provision of the further development of the work summarised in the existing STBA report 'Internal insulation of solid masonry walls – practical limits due to thermal bridging and moisture performance'". This initial report is produced again in Appendix 1. While this research produced some very significant findings, the discussion on page 28 identified a number of factors that required additional or further investigation. Through further investigation following this report, and as identified in the contract documents, the key elements for investigation were seen to be:

- Window openings (ie proportion of external wall area)
- Insulation λ value
- Wall thickness
- Complexity of form
- Building type (terrace, semi, detached etc)

It was also considered necessary to confirm the findings of the earlier report through a more thorough analysis. It was hoped that on the basis of this further research that guidance and possibly rules of thumb could be provided for the specification of Internal Wall Insulation in traditional buildings.

Executive Summary

This paper explores the potential for internal wall insulation to reduce heat loss in traditional buildings. It follows earlier STBA work by Chris Sanders, Valentina Marincioni and Neil May on this subject. The main findings of this latest research are:

1. The finding from earlier research that the reveals of openings (windows and doors) is the main factor for consideration in the assessment of heat loss through thermal bridging in internal wall insulation was confirmed. Other thermal bridges make minimal difference in comparison.

2. Due to largely unavoidable thermal bridging the potential for reduction of heat loss in traditional buildings through the use of Internal Wall Insulation is considerably less than is commonly understood or estimated in prescribed assessments and modelling.

3. Heat loss through thermal bridging in internal wall insulation is greater in the following instances:
    a. In building types with smaller amounts of external walls (ie terraces and flats) than in those with more external wall (ie detached houses)
    b. Where there are larger windows or amounts of windows rather than small windows or few windows
    c. In thicker walls rather than thinner walls

    The first two of these relate to reveals, the third is partly due to reveals (as there is typically greater area between the internal corner of the wall and the window frame and therefore greater heat loss potential in wider walls than in narrower walls) and partly to the greater thermal resistance in wider walls.

    It should be noted, as evidenced in the main part of the report, what a significant difference large windows make to overall heat loss due not only to increased thermal bridging but to the heat loss through glazing. (In all the calculations it has been assumed that double glazing or some secondary glazing or other measure has been installed.)

    The difference between extreme situations is stark. For example in a 500mm brick terrace with large windows (and assuming no complexity and perfect build quality) there is less than 10% reduction in overall heat loss between 20mm and 140mm of insulation on the wall plane when reveals are insulated, and less than 5% when reveals are not insulated. However 140mm of insulation on the wall without insulation of reveals will have almost 10% more heat loss than 20mm of insulation on the wall with insulation of reveals.

    On the other hand in a detached house with 500mm wide brickwork (we did not model a 215mm detached house, but the case would be reinforced further) and relatively small amounts of window openings (and again, no complexity but with perfect build quality) we see a 28% reduction in overall heat loss between 20mm and 140mm of insulation when reveals are insulated (of course still much higher absolutely than the terrace!) and a 23% reduction when reveals are not insulated.

Here 140mm of insulation on walls without insulation of reveals is equivalent to around 60mm of insulation on walls with insulated reveals.

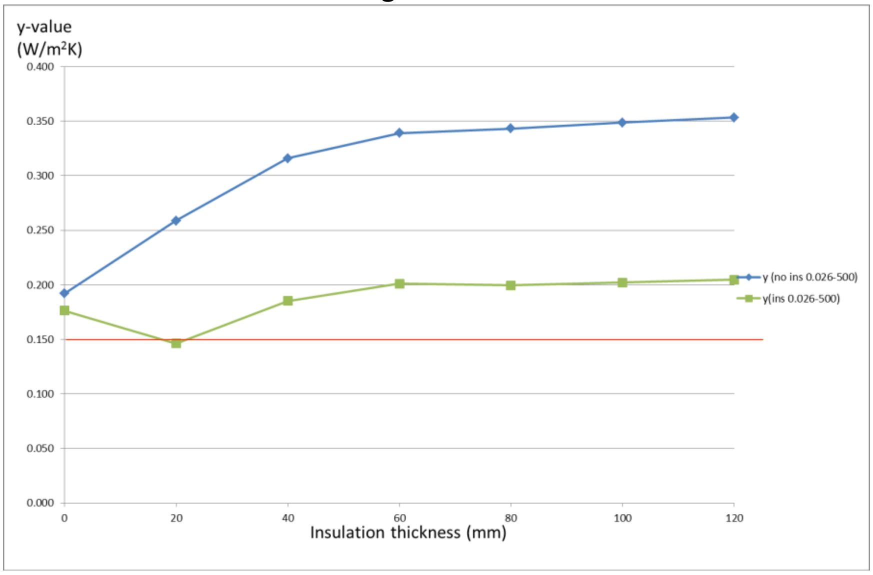
The table below conveys this information. For comparison with these two rather extreme cases a 215mm mid-terrace with average size windows has been added.

All insulation is λ = 0.026	No insulation on walls	20mm IWI	60mm IWI	80mm IWI	140mm IWI
500mm terrace with large windows: insulated reveals	185	149	143	139	135
500mm terrace with large windows: uninsulated reveals	188	169	168	166	162
215mm terrace with average windows: insulated reveals	233	158	136	133	126
215mm terrace with average windows: uninsulated reveals	235	173	153	150	144
500mm detached with small windows: insulated reveals	376	254	213	198	182
500mm detached with small windows: uninsulated reveals	385	282	246	234	217

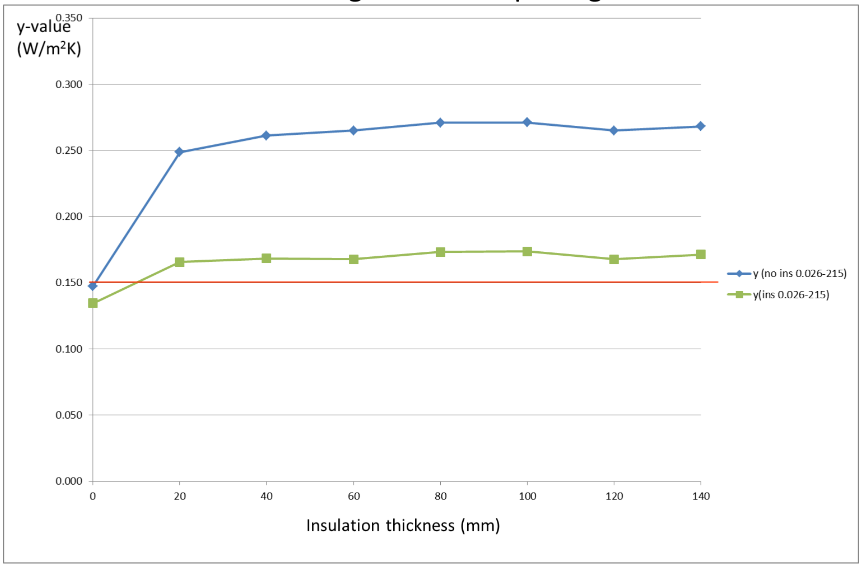
Figures in table are W/K from standard uncomplex house types (described in the main report). The reason for slight variation in starting points in the two types is due to assumptions about other non-reveal thermal bridges.

The heat loss through thermal bridging in all cases is considerable. And in most cases far more than the default y values given in SAP and RDSAP. The following 3 charts give the y values for these particular cases described in the table above. The red line is the default y value for thermal bridging in IWI given in SAP.

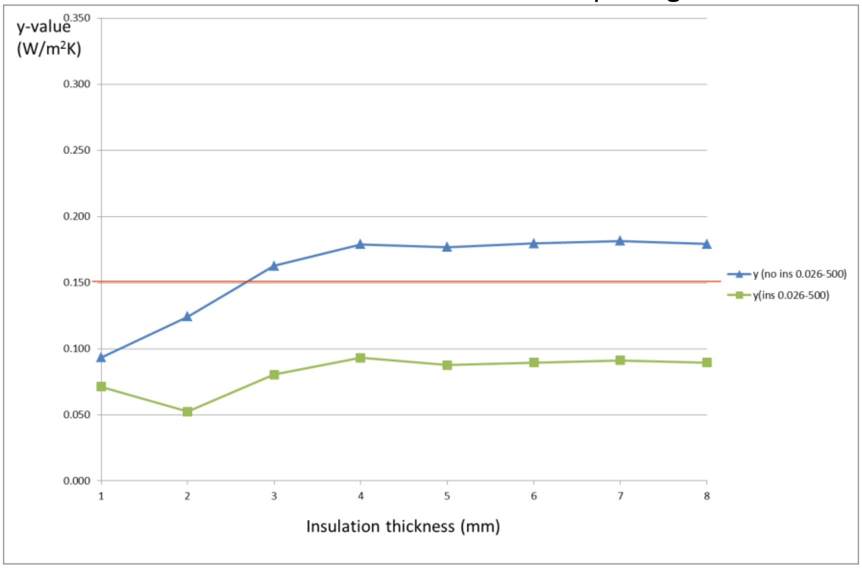
500mm brick terrace with large windows



215mm terrace with average window openings



500mm detached house with small window openings



This shows how even in the best case modelled (ie detached house with small window openings) the default y value of 0.15W/m2K in SAP is too low. In the worst case (500mm terrace with large openings) it is far too low even where thermal bridges are supposedly addressed. In this case, where reveals are uninsulated, even without complexity and assuming perfect build quality, the y value is 0.35W/m2K at 100mm of insulation rather than 0.15. It should also be noticed of course that the y values increase considerably from 0 to 60mm of insulation in all charts and should not be taken as a constant for lower levels of insulation.

An important point also relates to the total heat loss reduction possibility and the effect of smaller amounts of insulation on wall plane elements.

All insulation is λ = 0.026	Heat loss reduction from 0 to 140mm insulation	Heat loss reduction from 0 to 60mm insulation	Heat loss reduction from 0 to 20mm insulation
500mm terrace with large windows: insulated reveals	28%	23%	20%
500mm terrace with large windows: uninsulated reveals	14%	11%	10%
215mm terrace with average windows: insulated reveals	46%	42%	32%
215mm terrace with average windows: uninsulated reveals	39%	35%	27%
500mm detached with small windows: insulated reveals	52%	43%	33%
500mm detached with small windows: uninsulated reveals	44%	36%	27%

This table shows that it is very difficult to achieve above a 50% cut in heat loss through walls, and in the majority of cases it will be considerably less. Furthermore it should be noted that the vast proportion of heat loss reduction is achieved in the first 60mm of insulation, particularly where the total heat loss potential is lower. In all cases the biggest gain in heat loss reduction is in the first 20mm of insulation, in one case this being over 70% of the heat loss reduction of an application with 140mm on the wall.

4. The thermal resistance of the insulation has a minor effect, but not as much as the reveals. The trends are identical. More thermal resistance in the insulation (whether due to lambda value or thickness) has greater effect where there is greater potential for this due to the factors identified in point 3 above, ie thinner (less thermally resistant) walls, smaller openings and greater external wall area.

5. Complexity and buildability have not been factored in. It is considered that these will increase the case (below) for caution in regard to claims about the thermal effectiveness of IWI, and strengthen the case for less rather than more insulation thickness.

6. Moisture issues have also not been dealt with in this paper. These are a concern in traditional buildings both in terms of interstitial condensation and trapped moisture from driven rain and “in service” conditions (see STBA Moisture Risk Assessment and Guidance document). Furthermore the concerns on reveals are significantly more and different from those on inside plane wall elements. Further research is required to give guidance on the most appropriate way to insulate reveals in different situations.

7. The issue of thermal comfort also has not been addressed in this paper. Heat loss calculations are only one indication of effectiveness, and it may well be that small amounts of internal wall insulation have a considerable effect on comfort and therefore on the use of heating in buildings.

Recommendations:

1. In consideration of the reduced effectiveness of IWI in reducing heat loss due to thermal bridging as highlighted in this report, there should be alterations to SAP and RDSAP assumptions.
2. Attention should in all cases be focused on insulation of reveals, as this is the most cost effective way of dealing with heat loss in IWI. Additional insulation on walls can rarely if ever compensate for insulation of reveals once insulation above 40mm is applied to walls.
3. It might be possible to draw up a matrix for recommending maximum insulation levels on different buildings according to wall thickness, proportion of openings (or, better, length of reveals) to wall area, type of building, and level of complexity.
4. However, unless buildings are very simple and quality of construction is high, the possibility of dealing effectively with all thermal bridging remains low. In consideration also of cost, loss of internal space, and the embodied impact (carbon and energy) of additional insulation, as well as the increased moisture risk in many applications, a maximum insulation level might be considered in the following types:

   Mid-Terrrace/ Flat: 60mm of any insulation
   Semi/ End Terrace/ Detached: 100mm of any insulation

   However much less than this may be considered reasonable and safe in those building types identified above as having less potential for heat loss reduction, and/or where there is a moisture risk from internal wall insulation (this will vary according to type of insulation). In some situations no insulation may be the safest and best option.
5. Internal Wall Insulation assessment, specification and application should only be undertaken with a proper moisture risk assessment as laid out in the STBA Moisture Risk Assessment and Guidance document 2014. The criteria for safety and effectiveness, particularly in regard to mould formation, are more demanding in regards to moisture than heat loss. Moisture assessment should therefore be prioritised in any assessment.
6. Further desk research and in-situ monitoring is required to further understand the issues around thermal bridging in Internal Wall Insulation. However it is the opinion of the authors of this document that enough has been discovered in this work to require immediate action on the part of policy makers and industry. It is not considered likely that there will be further changes to the main elements of this report.
7. Industry including assessors, certification bodies, bodies giving guidance and training providers should be made aware of this work and adjust or change their advice, processes and activities accordingly.

Section 2: Research process and findings

The research process built upon the earlier research paper, in the following way:

1. The thermal bridging of the mid- terrace previously modelled was used as the basis for work. Existing details were harmonised as much as possible.
2. The outstanding thermal bridging details were agreed and also the variables that required investigation. At this point we were still considering 6 variables.
3. These were modelled in 3D and in 2D and the results compared
4. On the basis of this, it was agreed that the factors of wall thickness, building type and amount of openings were the main variables. The issues of building type (detached versus mid-terrace), and window openings (small or large) were then explored in two wall thicknesses by using spreadsheets of the 2D psi values.

The following sections explain

1. The model of the mid-terrace house
2. The 3D modelling outputs
3. The 2D modelling outputs as compared to the 3D process (and show similar results, with one minor exception)
4. The issue of the significance of window openings through 2D modelling
5. A comparison of detached with mid-terrace house through 2D modelling

1. Terraced House Model 2/6/94

Internal Dimensions: 6658mm wide by 6005mm high by 4372mm deep (half house)

3 windows each 1500 mm by 1500mm, 1 door 916mm wide by 2500mm high.

Walls.

Uninsulated: 215mm or 500mm brick λ= 0.77 W/mK
8mm plaster lining λ = 1.2 W/mK

IWI: 20 to 140 mm of Pavadentro λ = 0.042 W/mK or PU λ = 0.026 W/mK
12.5mm Plasterboard lining λ = 0.21 W/mK

Windows and Door

Frame and glass replaced by adiabatic boundary condition, 50mm wide, 15mm from the outer surface for the 215mm brick and 100mm from the outside for the 500mm brick.

Reveals

Uninsulated: lined with 8mm plaster
Insulated: 20mm of Pavadentro or PU lined with 12.5mm plasterboard.

Party walls between houses

215mm brick with 8mm plaster on either side. Adjacent houses uninsulated walls.

Partition wall within house

100mm brick with 8mm plaster on either side.

Ground Floor

Uninsulated: 150mm of concrete λ= 2.3 W/mK, 20mm of flooring λ=0.28 W/mK

Intermediated floor

12mm floorboards, 9mm OSB, 100mm unventilated air layer, 9mm OSB, 25mm unventilated air layer, 12.5mm plasterboard, no joists

Gap either air cavity, or filled with insulation, λ=0.038 W/mK

Ceiling

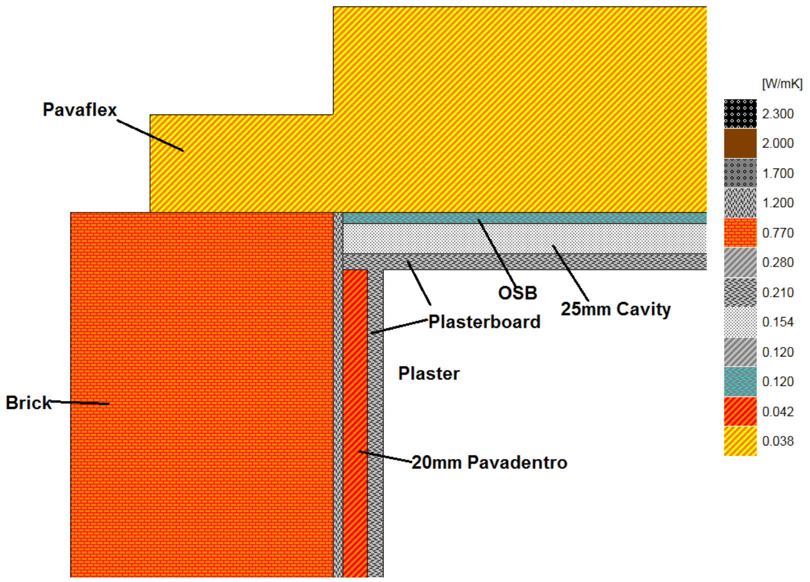
12.5mm plasterboard, 25mm unventilated air layer, 9mm OSB, 168mm insulation, λ=0.038 W/mK

a) 80mm of insulation taken over half the wall head

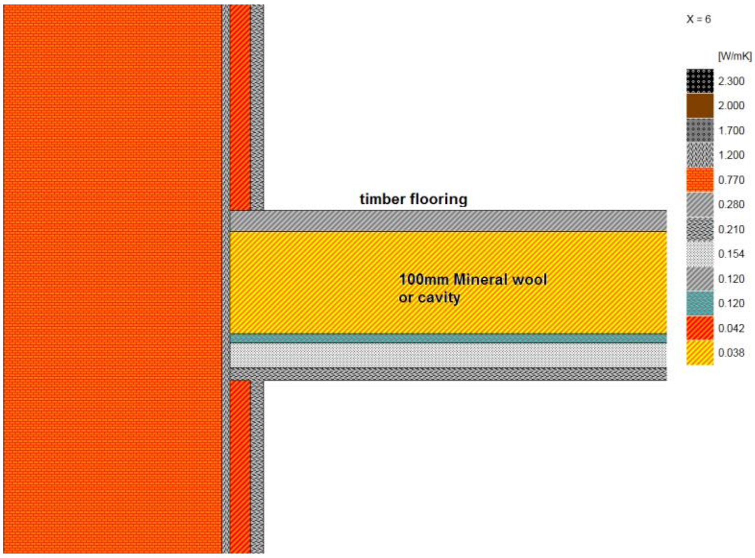
b) insulation stops at internal surface of brick

Loft Temperature: 1°C   (as specified in BR 497)

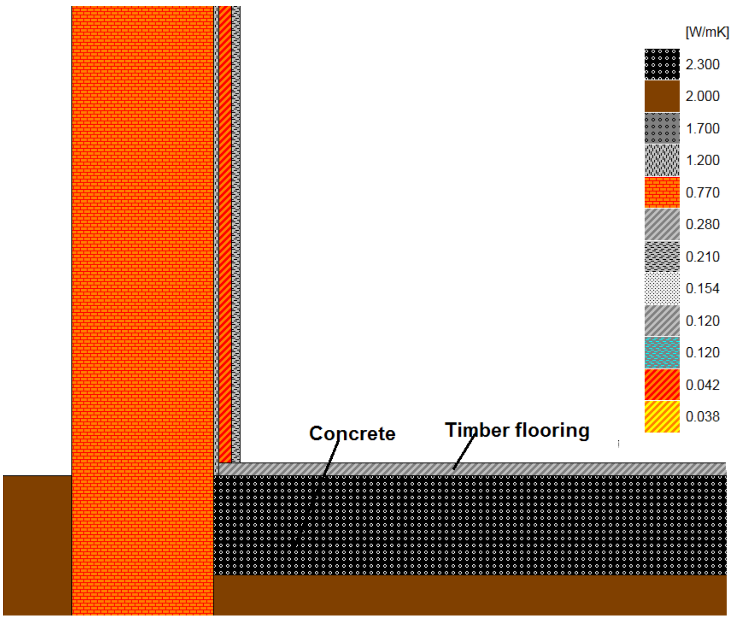
The details shown below illustrate the way the different materials go together especially the relation of the IWI to the pre-existing structure (only new materials are labelled in each diagram)



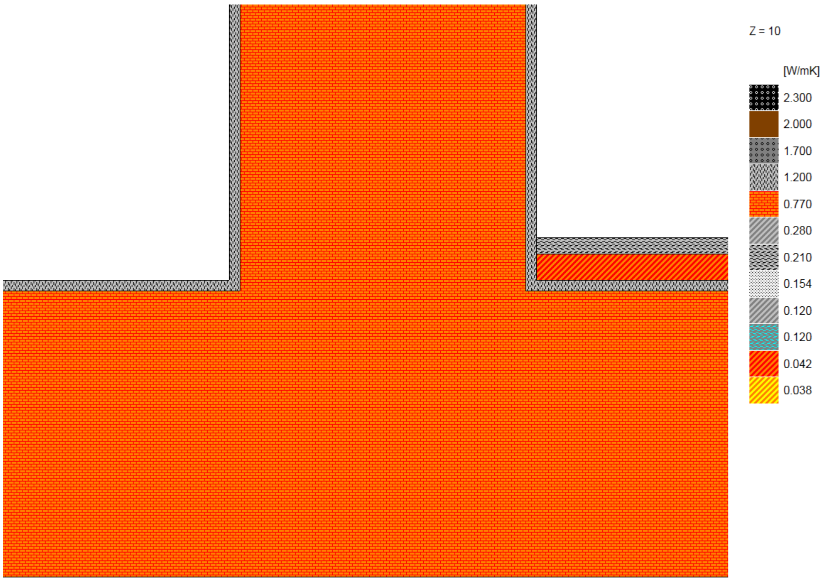
Eaves



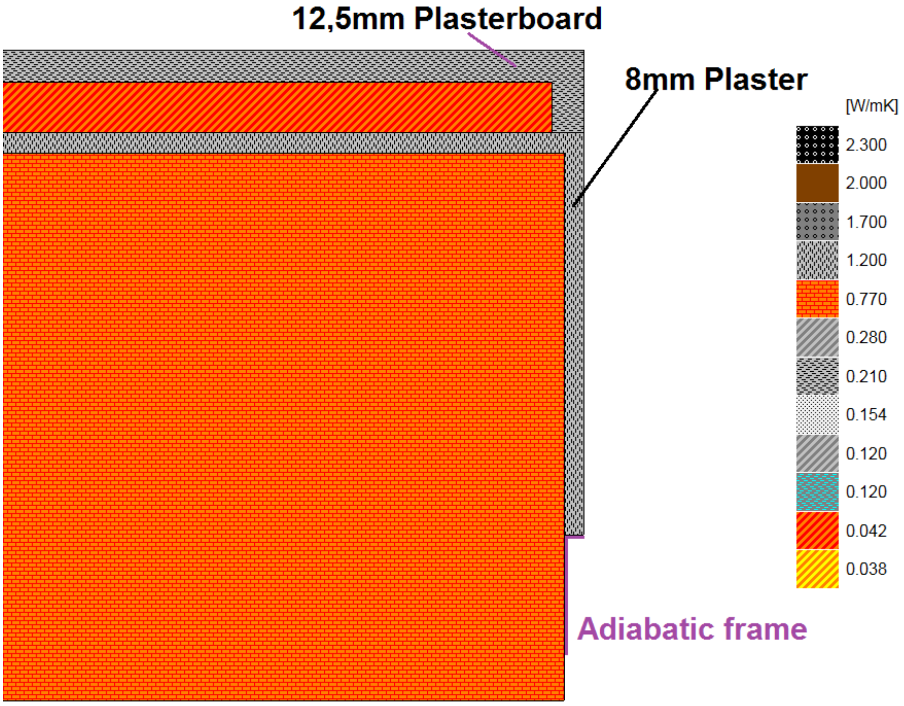
Intermediate Floor



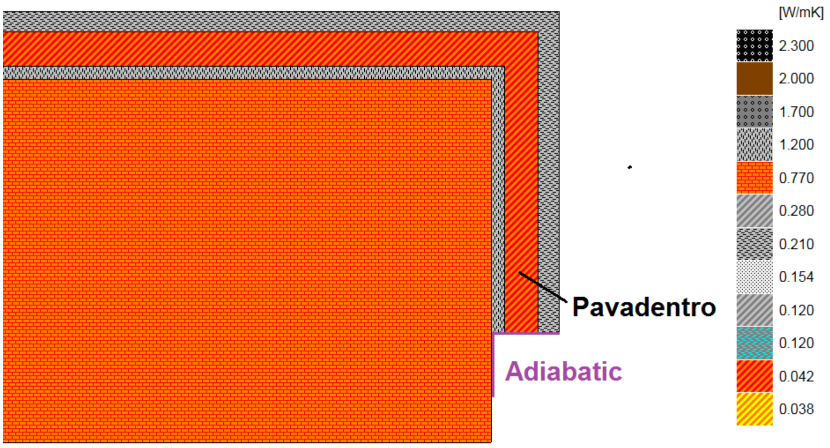
Ground Floor



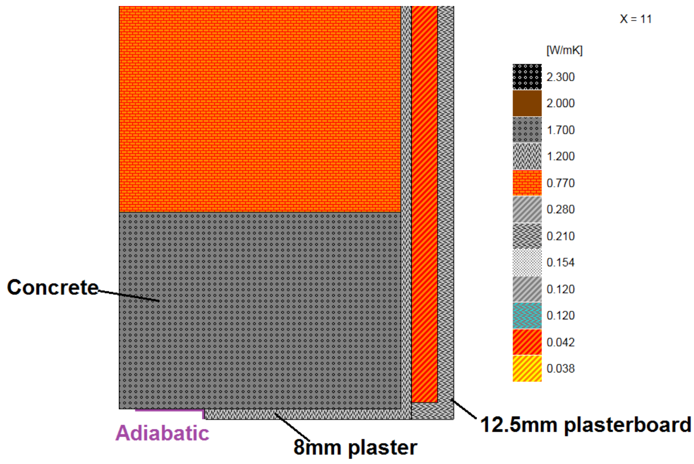
Party wall to uninsulated adjacent house



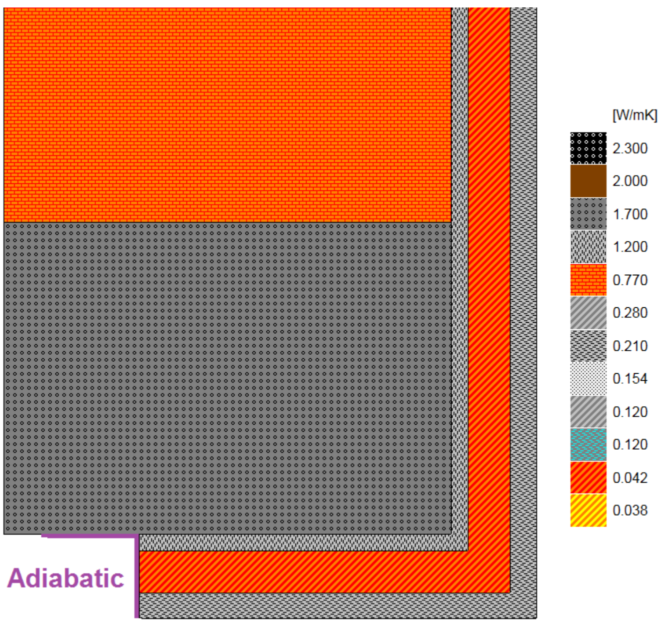
Jamb – Uninsulated reveal



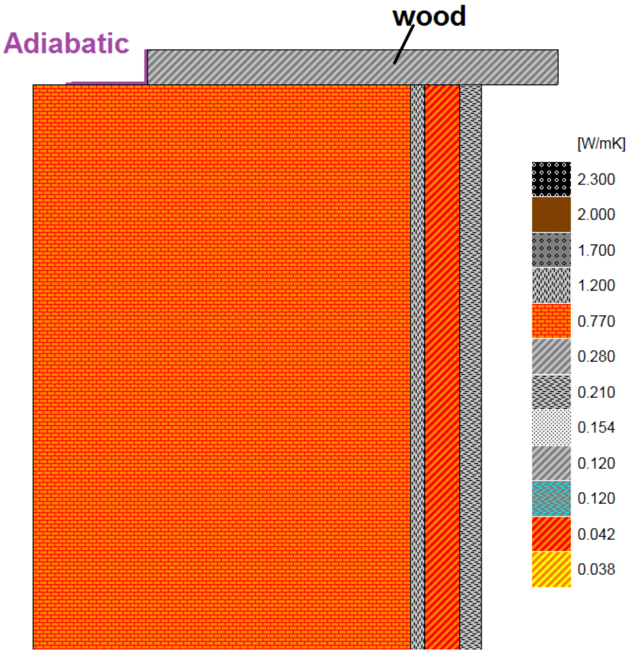
Jamb – Insulated reveal



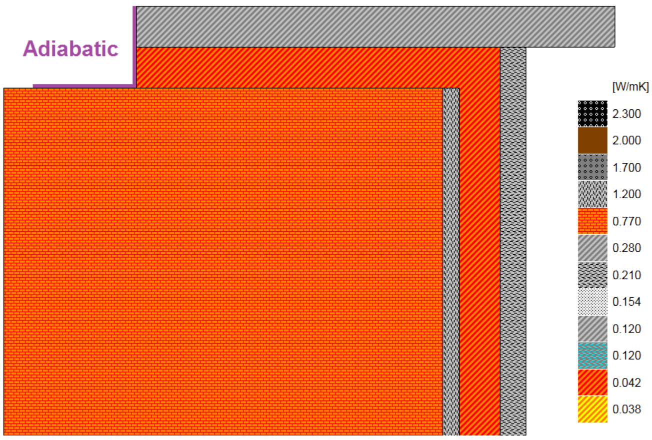
Lintel – uninsulated reveal



Lintel – insulated reveal



Sill – Uninsulated reveal



Sill – Insulated reveal

2. 3D modelling outputs

The three-dimensional model of a centre terraced house can be used to investigate the interactions between the different thermal bridges. TRISCO calculates the heat loss Q Watts, from the central house with an Inside to outside temperature difference of 20°C. The U-values and internal areas of the plane surfaces, the external wall, the ground floor and the roof are used to calculate ΣAU W/°C. As is common practice in thermal bridge calculations, the windows and door and their frames are replaced with adiabatic boundaries. Then the effect of all the thermal bridges combined is found from $\Sigma L\psi = Q/20 - \Sigma AU$.

Description of house – materials, conductivities and areas etc.

Four combinations of wall thickness and Insulation type were investigated:

A) 215mm of brick with wood fibre Insulation λ = 0.042
B) 215 mm of brick with PU Insulation λ = 0.026
C) 500mm of brick with wood fibre Insulation λ = 0.042
D) 500mm of brick with PU Insulation λ = 0.026
The thickness of the internal wall Insulation (IWI) was varied from 0 to 140mm.

Table 1 – Fabric U-values as a function of IWI thickness

	Wall				Ground Floor*		Roof
IWI mm	215 mm brick wood fibre	215mm brick PU	500mm brick wood fibre	500mm brick PU	215 mm brick	500 mm brick	
0	2.194	2.194	1.211	1.211	0.455	0.420	0.212
20	1.008	0.778	0.734	0.604	0.451	0.417	0.212
40	0.681	0.487	0.544	0.413	0.448	0.415	0.212
60	0.514	0.354	0.432	0.313	0.446	0.413	0.212
80	0.413	0.278	0.358	0.252	0.443	0.411	0.212
100	0.345	0.229	0.306	0.211	0.440	0.408	0.212
120	0.297	0.195	0.267	0.182	0.438	0.406	0.212
140	0.260	0.169	0.237	0.159	0.436	0.404	0.212

*The ground floor U-values vary because of the longer heat flow path around the thicker wall.

Table 2 – Internal areas and ΣAU W/°C

	Internal areas m^2			ΣAU W/°C			
IWI mm	Floor	Roof	Wall	215 mm brick wood fibre	215mm brick PU	500mm brick wood fibre	500mm brick PU
0	29.109	29.109	30.889	87.2	87.2	55.8	55.8
20	29.109	29.109	30.889	50.4	43.3	41.0	37.0
40	29.109	29.109	30.889	40.2	34.3	35.1	31.0
60	29.109	29.109	30.889	35.0	30.1	31.5	27.9
80	29.109	29.109	30.889	31.8	27.6	29.2	25.9
100	29.109	29.109	30.889	29.6	26.0	27.5	24.6
120	29.109	29.109	30.889	28.1	24.9	26.2	23.6
140	29.109	29.109	30.889	26.9	24.1	25.2	22.8

There are six of variables affecting the thermal bridging, which take two values:

1) The thickness of the brickwork: 215mm or 500mm

2) The type of IWI: wood fibre $\lambda = 0.042$ or PU $\lambda = 0.026$

3) Whether or not the window and door reveals are insulated with the same IWI.

4) Whether or not the intermediate floor is insulated, with mineral wool $\lambda = 0.038$

5) Whether the loft Insulation stops level with the internal surface of the brick or is extended to cover half the brickwork.

6) Whether or not the adjacent houses are insulated with IWI (in both cases it is assumed that the internal temperature of the adjacent houses is 20°C)

Combining all these six variables leads to 64 different situations

The table in the appendix 1 shows the values of $\Sigma L\psi$ calculated with IWI thicknesses of 20mm and 100mm, $\Sigma L\psi_{20}$ and $\Sigma L\psi_{100}$. The overall average value of $\Sigma L\psi_{100}$ is 17.23 W/°C.

The 'worst case' is variant 52, with 500mm of brick, PU insulation, uninsulated reveals, uninsulated intermediate floor, insulated wall head and insulated adjacent house. This gives $\Sigma L\psi_{20}$ = 20.63 W/°C and $\Sigma L\psi_{100}$ = 25.17 W/°C, these represent 35.8% and 50.6% of the total fabric heat loss ($\Sigma AU + \Sigma L\psi$) respectively.

The 'best case' is variant 31, with 215mm of brick, PU insulation, insulated reveals, insulated intermediate floor, insulated wall head and uninsulated adjacent house. This gives $\Sigma L\psi_{20}$ = 10.59 W/°C and $\Sigma L\psi_{100}$ = 10.89 W/°C, these represent 19.6% and 29.5% of the total fabric heat loss ($\Sigma AU + \Sigma L\psi$) respectively.

Effect of changing individual parameters

The second table in the appendix shows the change in $\Sigma L\psi_{100}$ as individual parameters are changed; i.e. D_{Br} shows the change in $\Sigma L\psi_{100}$ as the brick thickness is changed from 215mm to 500mm etc. The ways in which these changes interact with the other parameters is discussed in the sections below.

Table 3 shows the average change in $\Sigma L\psi_{100}$ when each individual variable is changed. It is clear that insulating the reveals is much more significant than anything else.

Table 3 – Average change in ΣLψ100 when each individual variable is changed

Measure	$\Sigma L\psi_{100}$ before W/°C	$\Sigma L\psi_{100}$ after W/°C	Change W/°C	% of mean
Insulating the reveals	21.73	12.74	-8.99	-52.17
Increasing brick thickness	16.14	18.33	2.19	12.73
Insulating the adjacent houses	16.72	17.75	1.03	5.97
Insulating the intermediate floor	17.68	16.78	-0.90	-5.20
Changing IWI from fibre to PU	17.11	17.35	0.24	1.40
Covering the wall head	17.20	17.26	0.06	0.34

Insulation of the reveals

Adding 20mm of IWI to the window and door reveals is by far the most important method for reducing the value of $\Sigma L\psi_{100}$. On average it reduces $\Sigma L\psi_{100}$ from 21.73 W/°C to 12.74 W/°C, a reduction of 8.99 W/°C or a reduction of 41%. Table 4 shows that the thickness of the brickwork, and therefore the depth of the reveals, and the type of IWI, have an effect, with the greatest reduction in $\Sigma L\psi_{100}$ with 500mm thick brickwork and the lower thermal conductivity PU IWI.

Table 4 - Change in ΣLψ100 when reveals are insulated by brick thickness and IWI type

Brick	IWI	Mean	Std. Deviation	N
215	Fibre	-7.21	.015097	8
	PU	-8.58	.017010	8
500	Fibre	-9.05	.177594	8
	PU	-11.12	.203407	8

Figure 1 shows the variation of ΣLψ with IWI thickness, broken down by the brick thickness, IWI type and whether the reveals are insulated; the effect of insulating the reveals is clear. It can also be seen that, with the thicker brickwork and therefore deeper reveals, the value of ΣLψ continues to increase, while with the shallower reveals in the 215mm thick brick, ΣLψ stabilises to a constant value at large IWI thicknesses.

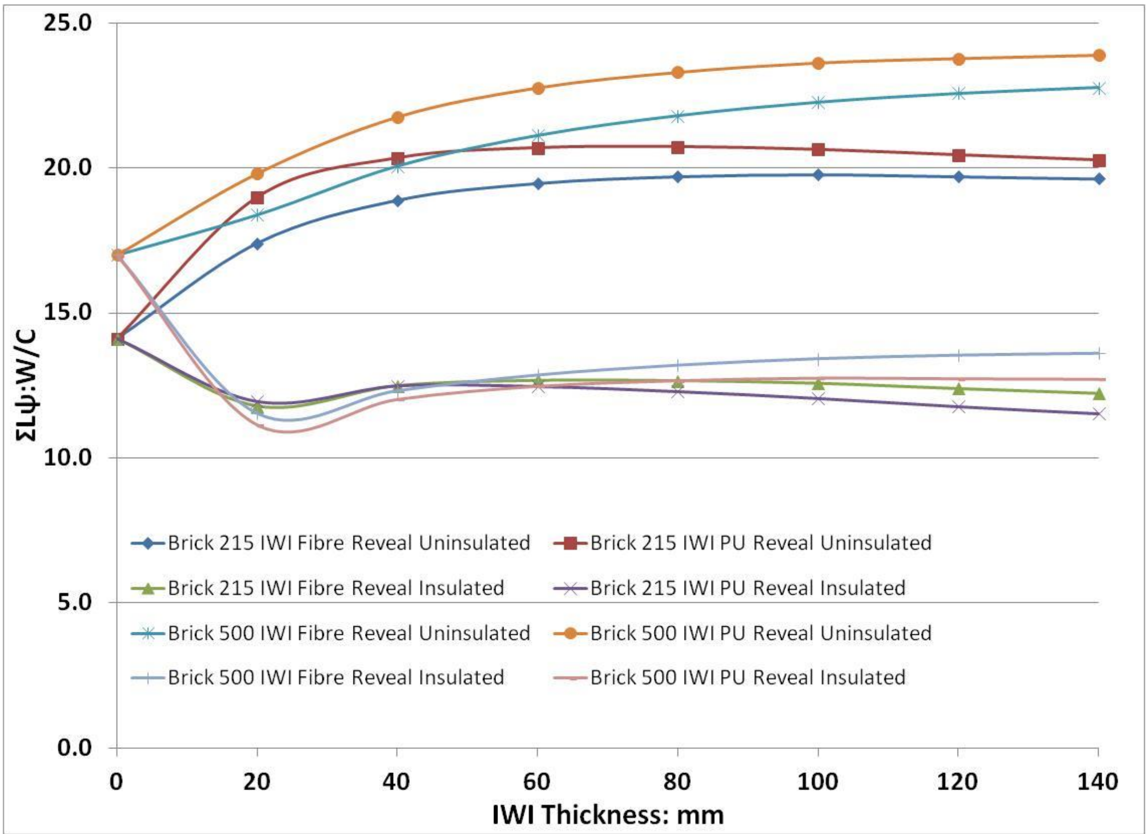


Figure 1 – ΣLψ as a function of IWI thickness by brick thickness, IWI type and reveal insulation

Brick Thickness

Changing the thickness of the brick from 215 to 500mm increases ΣLψ100 by 2.19 W/°C on average. Table 5 shows that this effect is dependent on whether the reveals are insulated. The deeper reveals in the thicker brickwork are an important source of heat loss.

Table 5 – Change in $\Sigma L\psi_{100}$ when brick thickness increased from 215 to 500mm by reveal insulation

Reveal	Mean	Std. Deviation	N
Uninsulated	3.29	.430021	16
Insulated	1.09	.239256	16
Total	2.19	1.167256	32

IWI Type

On average, changing the conductivity of the IWI makes a very small change to $\Sigma L\psi_{100}$. Table 6 shows that the change is affected by the depth of the reveals and whether they are insulated or not.

Table 6 - Change in ΣLψ100 when IWI changed from wood fibre to PU by reveal insulation and brick thickness

Reveal	Brick	Mean	Std. Deviation	N
Insulated	215	-0.53	.031201	8
	500	-0.71	.050503	8
Uninsulated	215	0.84	.028894	8
	500	1.36	.038770	8

Insulation of the intermediate floor

Adding insulation to the intermediate floor reduces $\Sigma L\psi_{100}$ by 0.90 W/K on average. Table 7 shows that the reduction is slightly greater with a 215mm thick brick wall compared to the 500mm brick, which provides some more resistance to heat flow.

Table 7 - Change in $\Sigma L\psi_{100}$ when intermediate floor is insulated by brick thickness

Brick	Mean	Std. Deviation	N
215	-1.09	0.029985	16
500	-0.71	0.069684	16

Insulation of the wall head

Covering half the wall head with insulation reduces $\Sigma L\psi_{100}$ by only 0.06 W/K on average. However there is an interesting effect when the depth of the reveals is taken into account. Covering the wall head cools the wall below, so actually increases heat loss through the deeper uninsulated lintel, thus emphasising the importance of insulating the reveals.

Table 8 – Change in $\Sigma L\psi_{100}$ when wall head covered by brick thickness and reveal insulation

Brick	Reveal	Mean	Std. Deviation	N
215mm	Insulated	-0.057	.008991	8
	Uninsulated	-0.075	.009326	8
500mm	Insulated	0.012	.011444	8
	Uninsulated	0.350	.021165	8

Insulation of the adjacent houses

D_{adj} is close to 0.90 W/°C for the 215mm brick wall and 1.15 W/°C for the 500mm brick wall, with none of the other parameters having an effect. This means there is slightly more heat loss through the junction when the adjacent houses are insulated, because there is less heat reaching the brick from the adjacent house. This is a slightly artificial situation because the calculation assumes that the temperature of the adjacent houses remains constant at 20 °C whether they are insulated or not. In practice they would become warmer when insulated reducing heat loss through the party wall and into the brick.

Figure 2 shows $\Sigma L\psi$ as a function of IWI thickness, for a 215mm wall with wood fibre insulation and the reveals, wallhead and intermediate floor uninsulated.

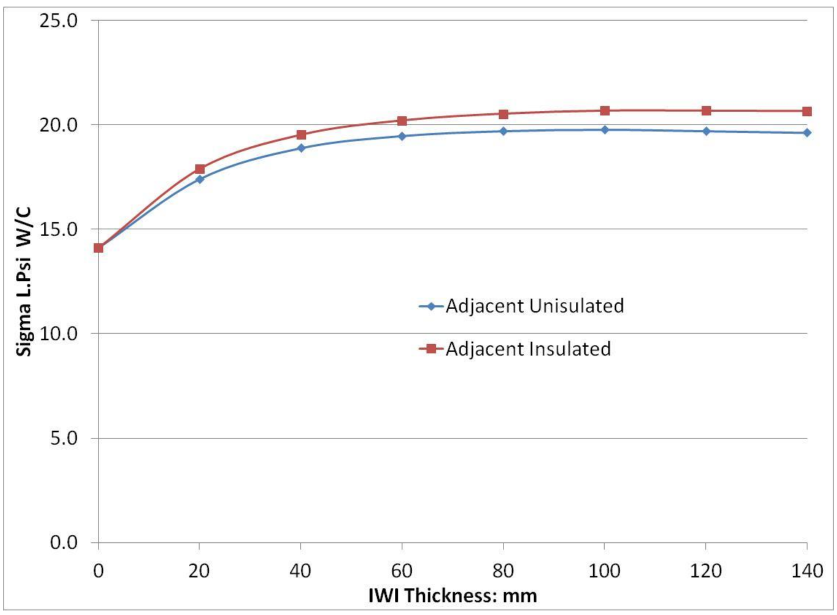


Figure 2 – $\Sigma L\psi$ with and without adjacent houses insulated

Conclusions

It all comes down to insulating the reveals – wall thickness is only relevant because it leads to deeper reveals and IWI conductivity is only relevant because you get more thermal resistance into the reveals with a low conductivity insulation.

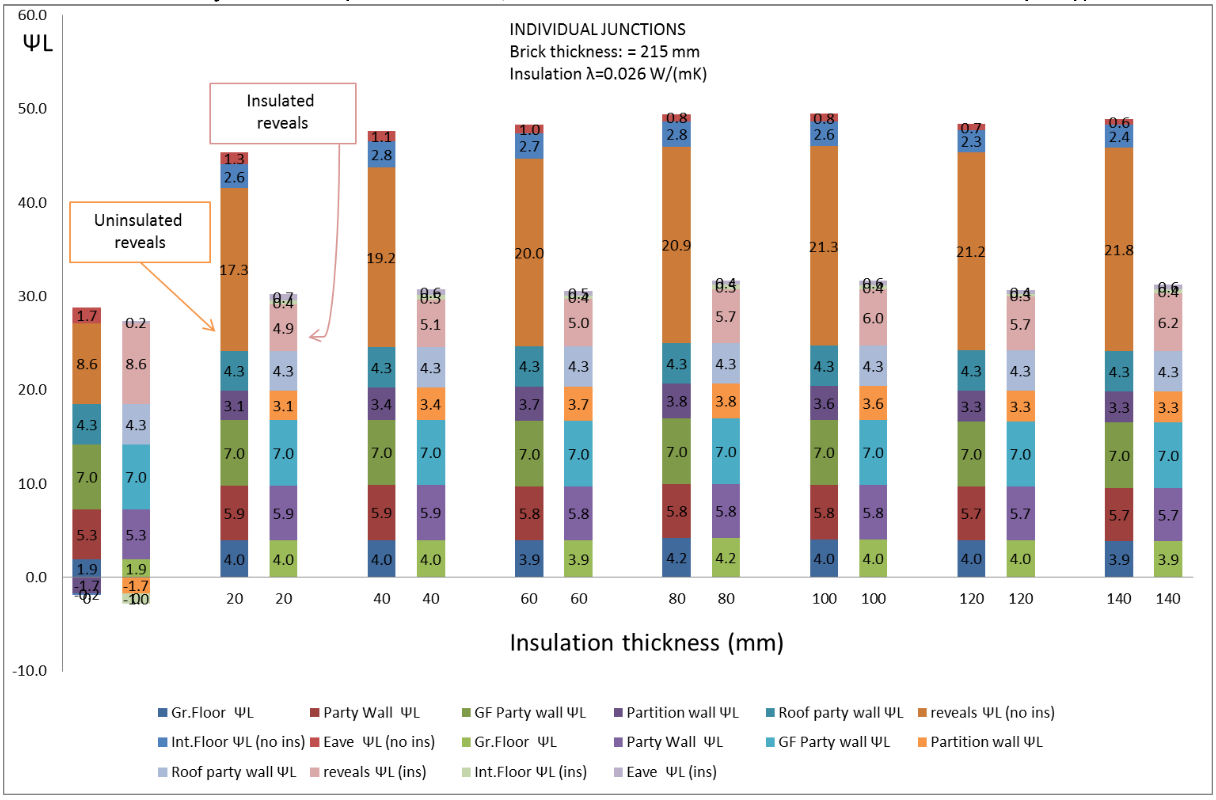
3. 2D analysis of Individual Junctions

2D analysis models each junction separately and then adds these together to achieve the total picture. While it may be slightly less accurate than 3D modelling it makes it easier to identify the effect of different junctions and factors.

The following charts use the same details as the 3D modelling (with minor exceptions) for the terrace model. A comparison between the 3D and 2D modelling is in Appendix 2.

215 mm wall

ΨL of individual junctions (mid terrace, 215mm brick and IWI with λ=0.026 W/(mK))

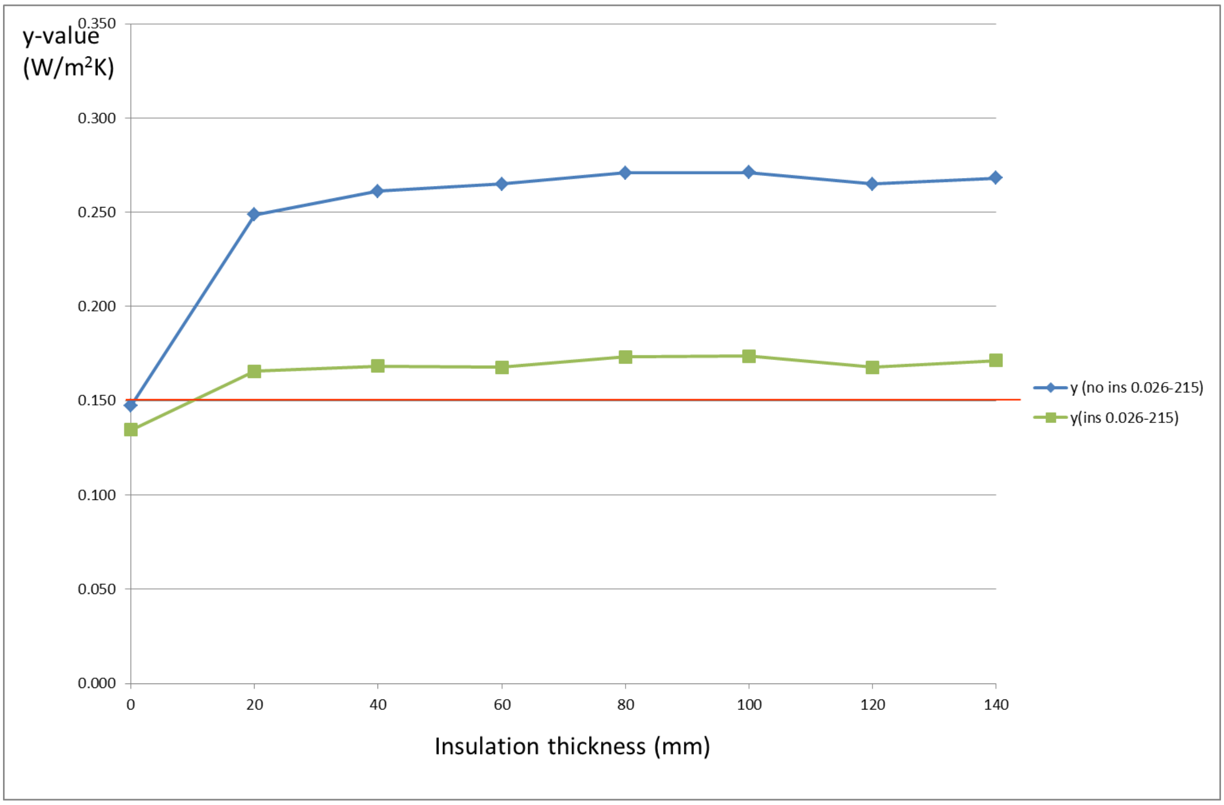


The y-value of individual junctions (mid terrace, 215 mm brick and λ=0.026 W/(mK))

The y-value is calculated dividing the sum of the thermal bridges by the total area of the exposed elements

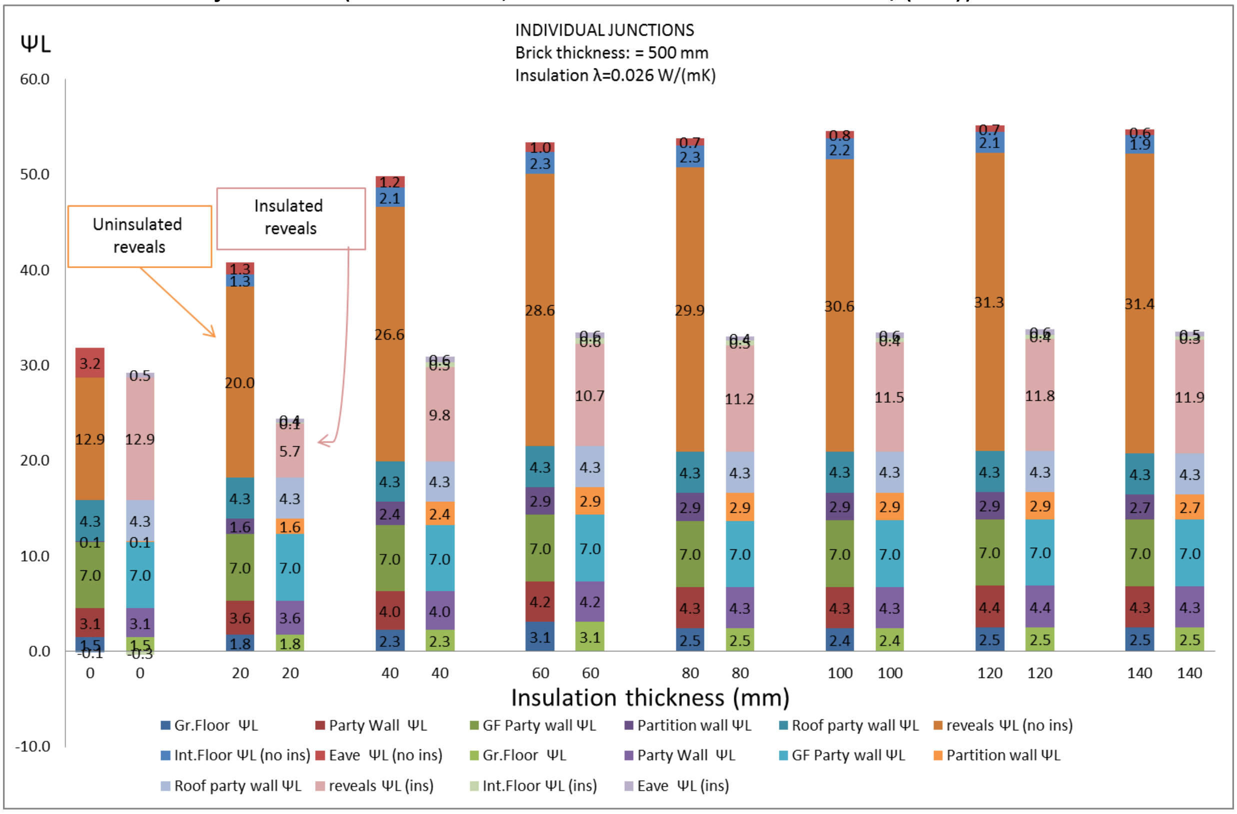
$$y = \frac{\Sigma \Psi L}{A_{exp}}, \quad \text{with } A_{exp} = 182.5 \text{ m}^2$$

The y-value is compared to the default y-value used in part L, y = 0.15 W/(m^2K)



500 mm wall

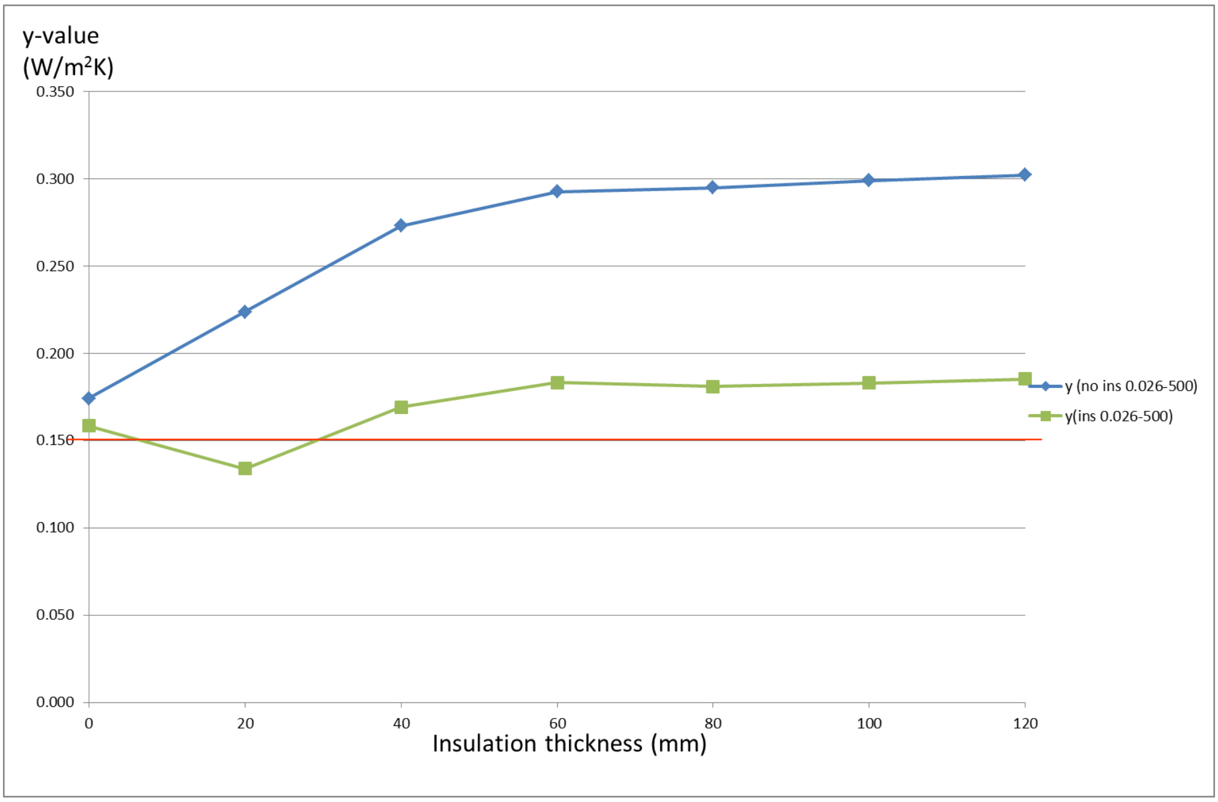
ΨL of individual junctions (mid terrace, 500mm brick and λ=0.026 W/(mK))



The y-value of individual junctions (mid terrace, 500mm brick and λ=0.026 W/(mK))
The y-value is calculated dividing the sum of the thermal bridges by the total area of the exposed elements

$y = \frac{\Sigma\Psi L}{A_{exp}}$, with A_{exp} =182.5 m^2

The y-value is compared to the default y-value used in part L, y = 0.15 $W/(m^2K)$



Whole building analysis

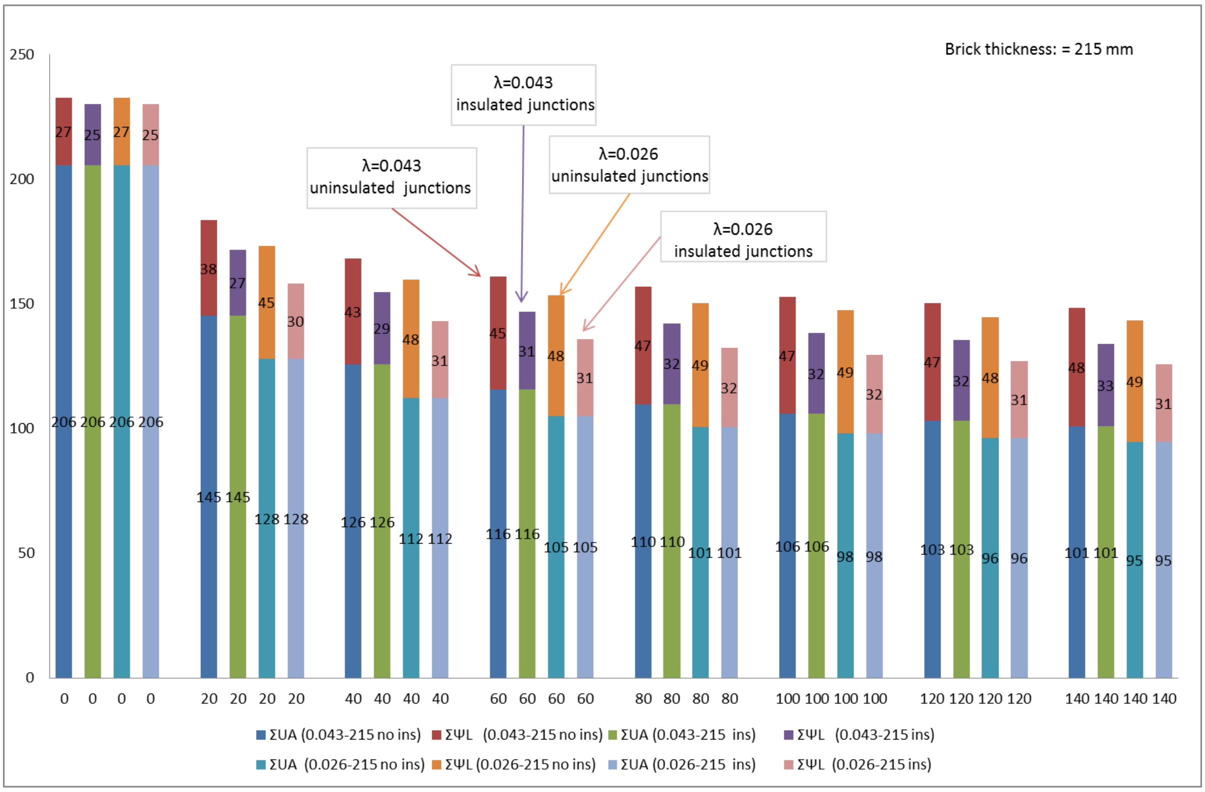
Under "insulated junctions" is included:

- *Insulated lintel, sill, jamb (20mm insulation on the reveals)*
- Uninsulated solid ground floor
- *Insulated intermediate floor (without joists)*
- *Insulated eaves: the joist sits in the middle of the wall plate (100mm), the insulation between joists (80mm thick) and above (88mm thick) is covering half of the wall plate (100mm from the internal surface for 215mm brick and 250mm from the internal surface for 500mm brick).*
- Party wall
- Party wall – eaves
- Party wall – ground floor, neighbouring ground floor uninsulated
- Partition wall

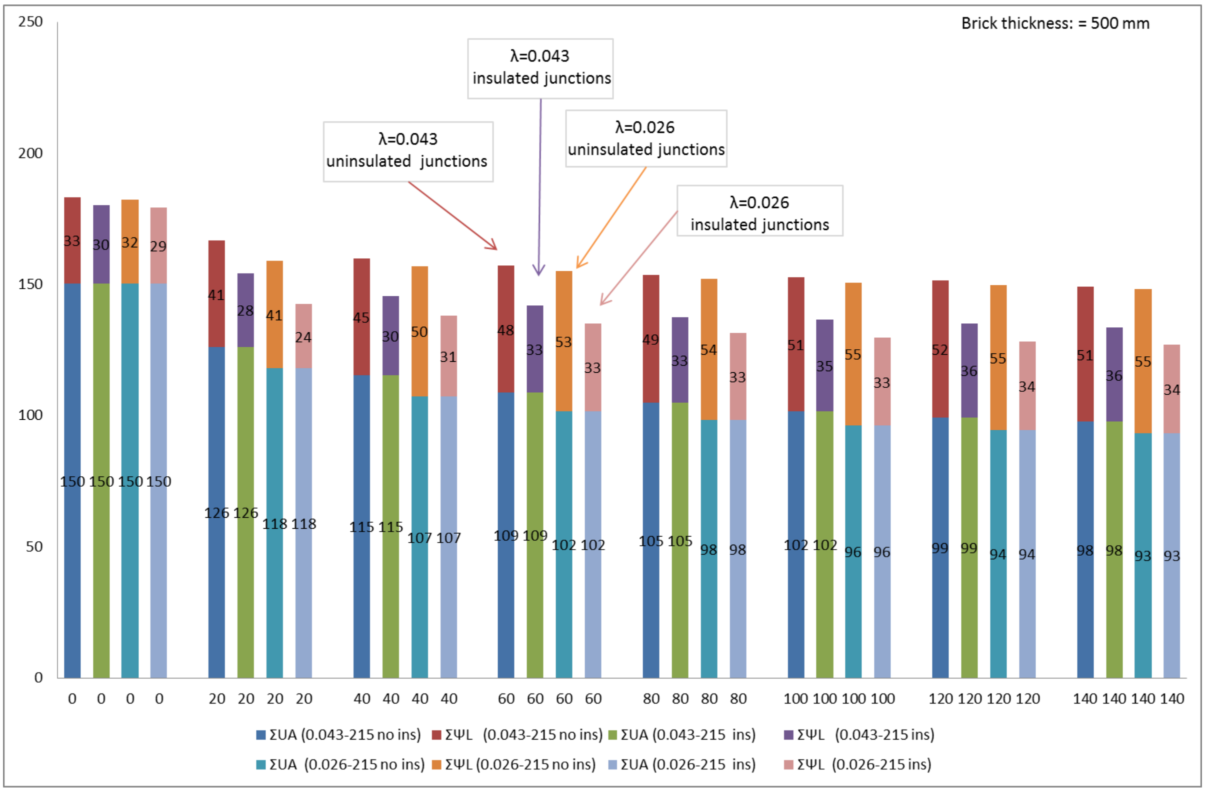
Under "uninsulated junctions" is included:

- *Uninsulated lintel, sill, jamb (no insulation on the reveals)*
- Uninsulated solid ground floor
- *Uninsulated intermediate floor (without joists)*
- *Uninsulated eaves: the joist sits in the middle of the wall plate (100mm), the insulation between joists (80mm thick) and above (88mm thick) is 0mm into the wall from the internal surface*
- Party wall
- Party wall – eaves
- Party wall – ground floor, neighbouring ground floor uninsulated
- Partition wall

Brick thickness = 215 mm



Brick thickness = 500 mm



4. Windows large and small

As it is apparent that reveals are the main factor affecting thermal bridging a key variant is the size and number of windows or to be more precise the linear length of reveal compared to the overall external wall area. In this section we briefly examined the effect of increasing and decreasing just the height of the windows, in order to give an indication of the significance, and to compare what may be a Georgian style town terrace, where the majority of the external wall may be windows (and doors) and a cottage type building which might have very small amounts of windows in comparison with its external wall area.

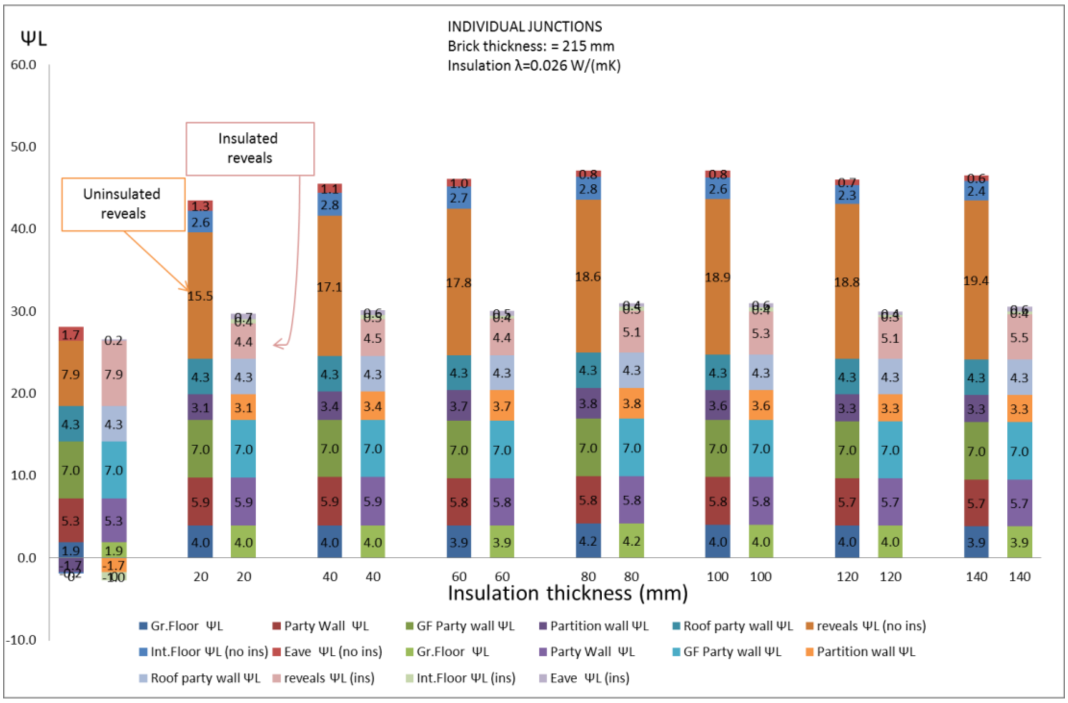
Variations modelled: The total length of lintels is 11.09 m; the total length of sills is 11.09 m. These remain the same.

The total length of jambs is 22.8 m in case of small windows (window height = 0.8 m), 44.4 m in case of large windows (window height = 2 m).

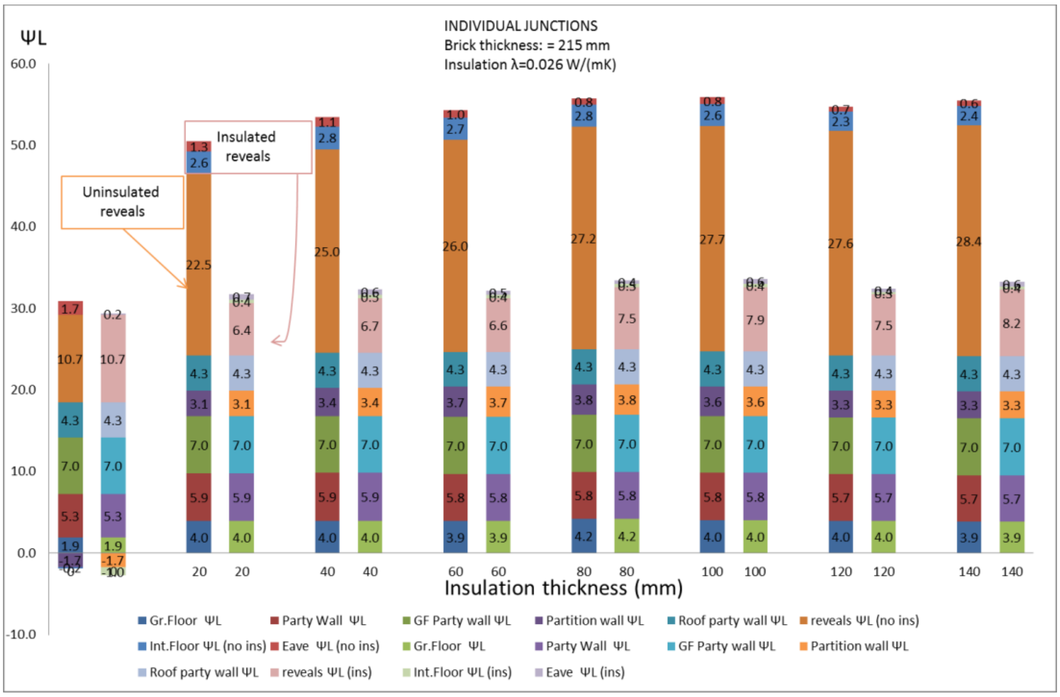
Only one λ value of insulation and only the mid-terrace house type were modelled.

215 mm wall in the mid-terrace house type

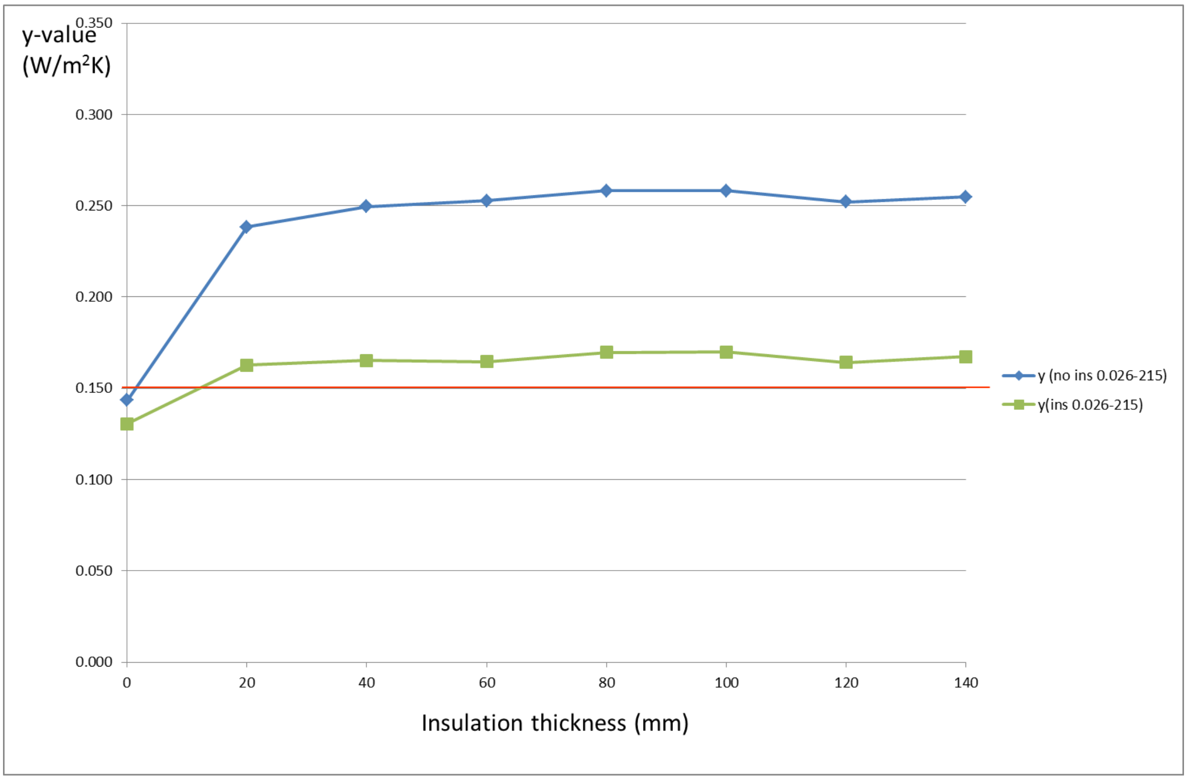
Small Windows: ΨL of individual junctions (mid terrace, 215mm brick and λ=0.026 W/(mK))



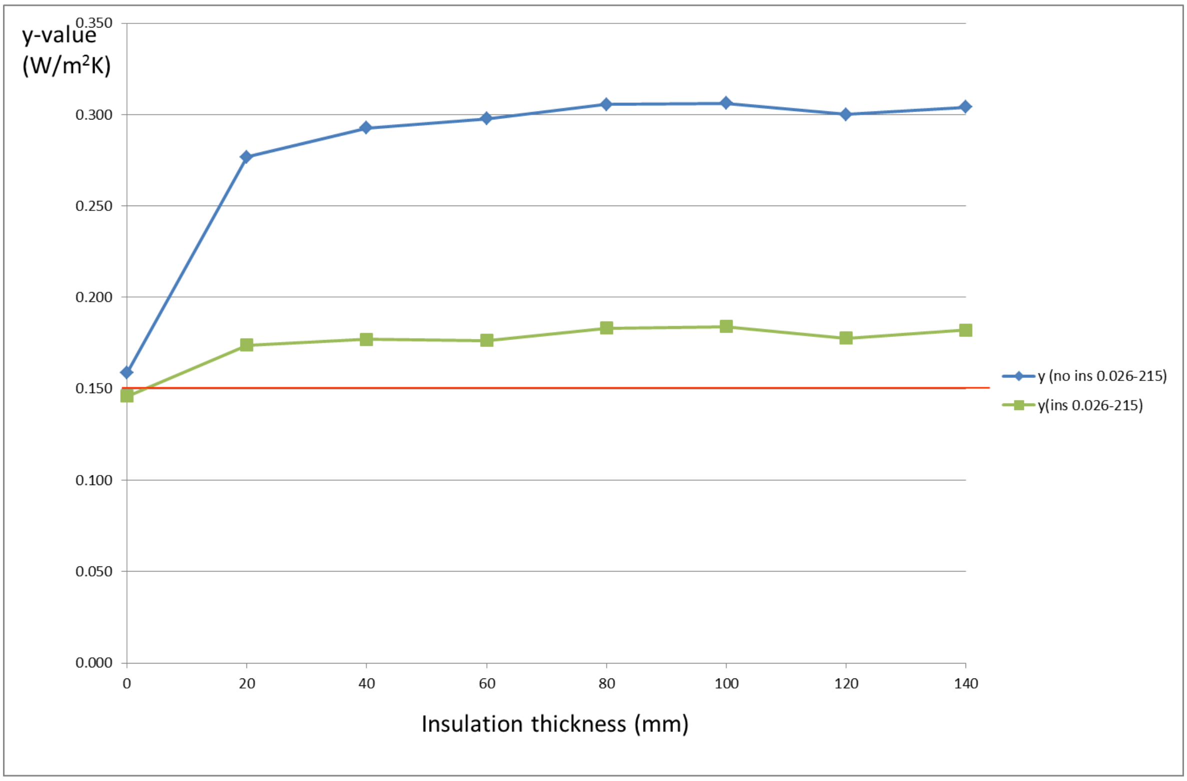
Large Windows ΨL of individual junctions (mid terrace, 215mm brick and λ=0.026 W/(mK))



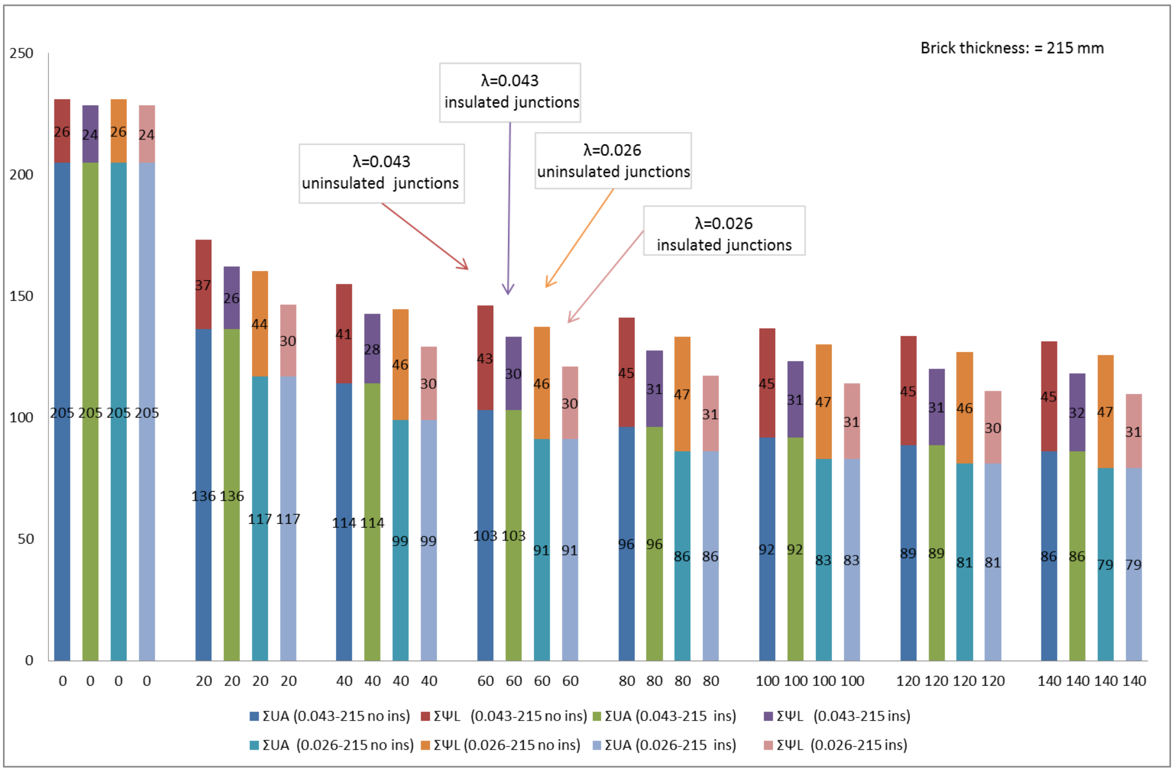
Y-values – Small Windows



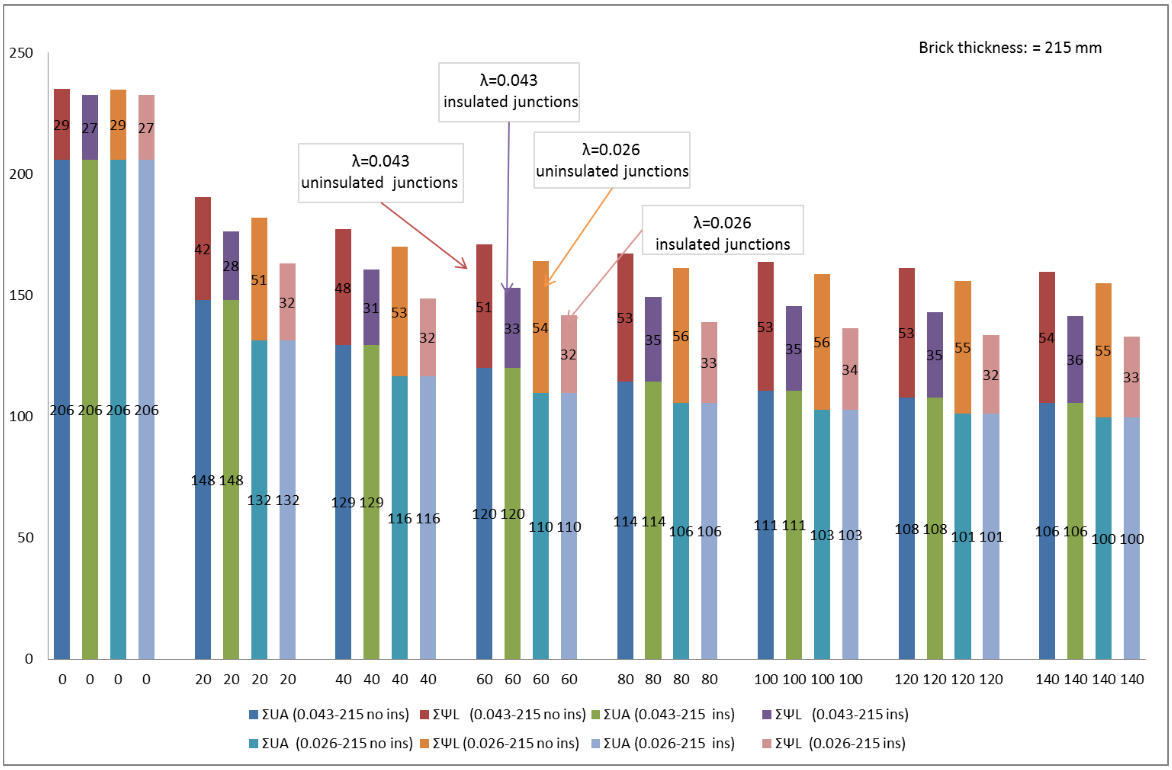
Y-values – Large windows



Whole Building Analysis: Brick thickness = 215 mm – Small Windows

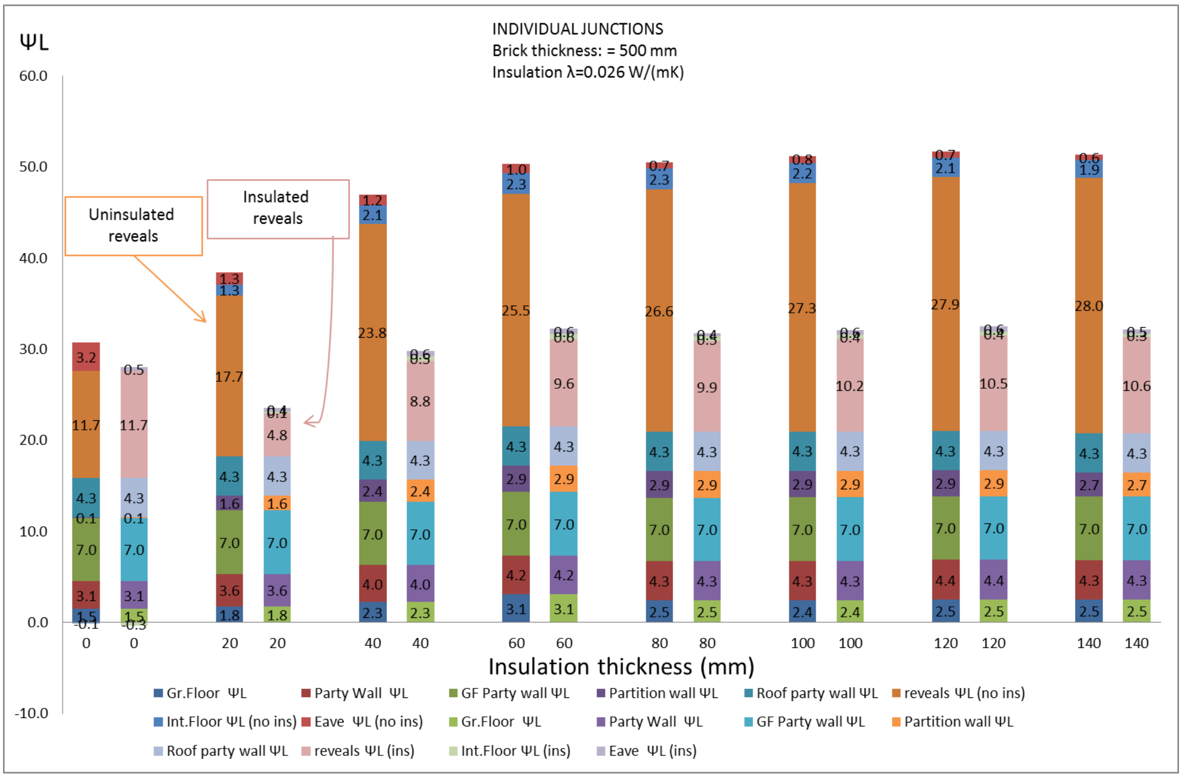


Whole Building Analysis: Brick thickness = 215 mm – Large Windows

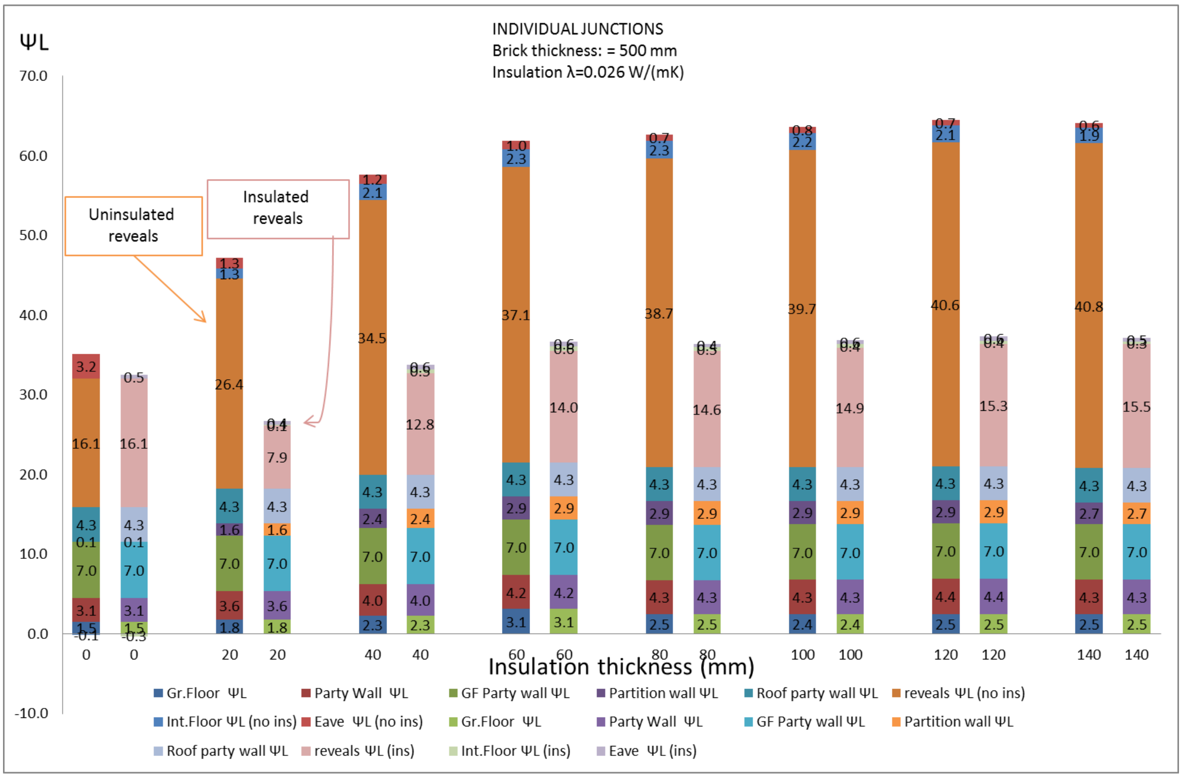


500 mm wall in the mid-terrace house type

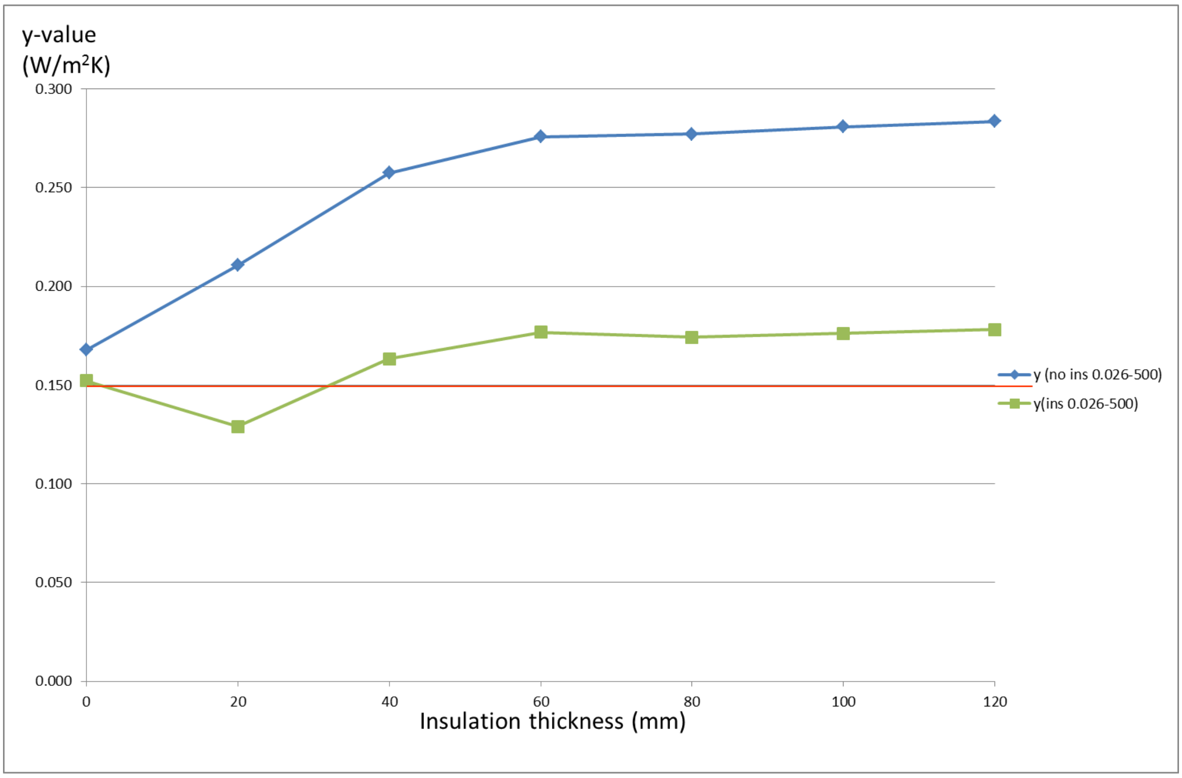
Small Windows: ΨL of individual junctions (mid terrace, 500mm brick and λ=0.026 W/(mK))



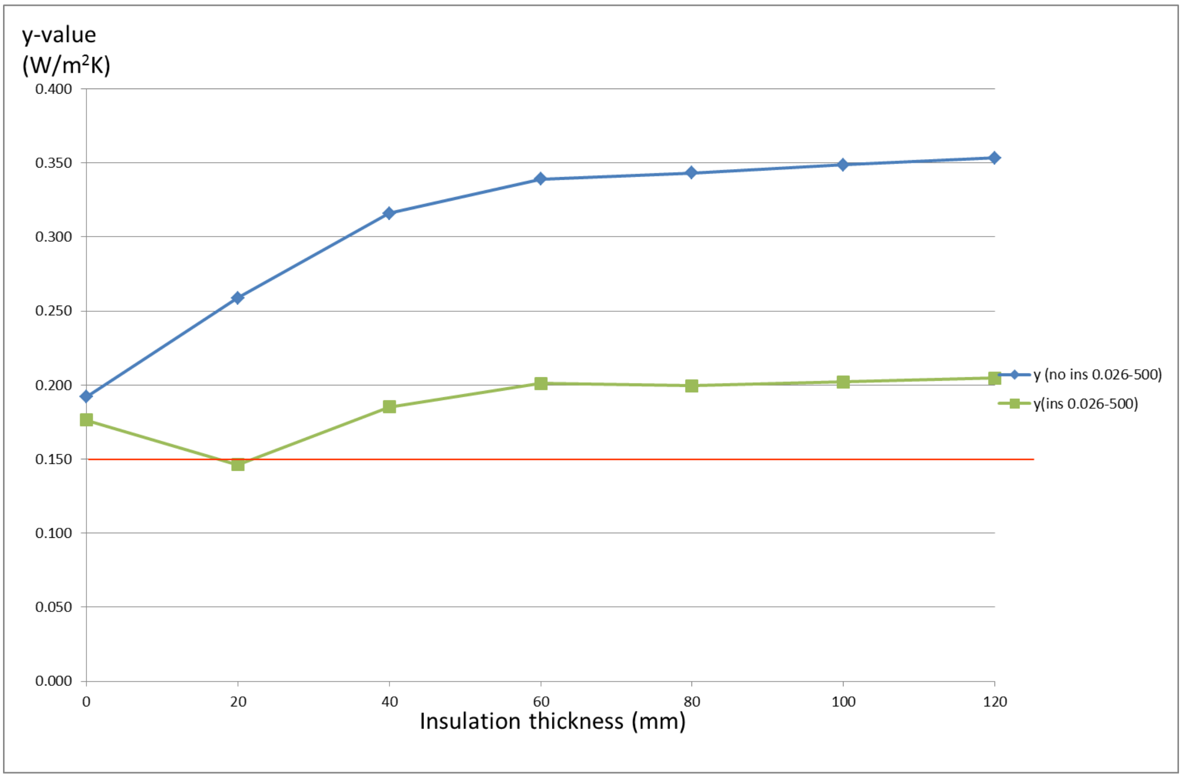
Large Windows: ΨL of individual junctions (mid terrace, 500mm brick and λ=0.026 W/(mK))



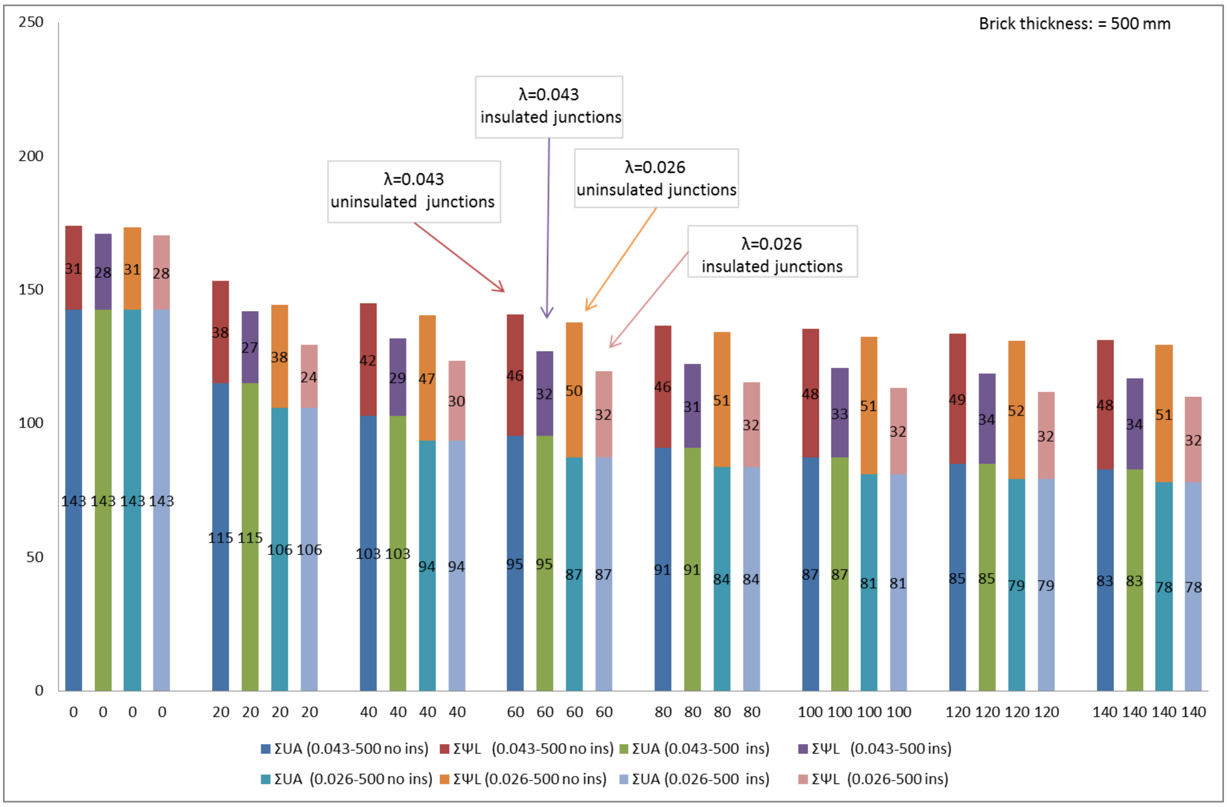
Y-values – Small Windows



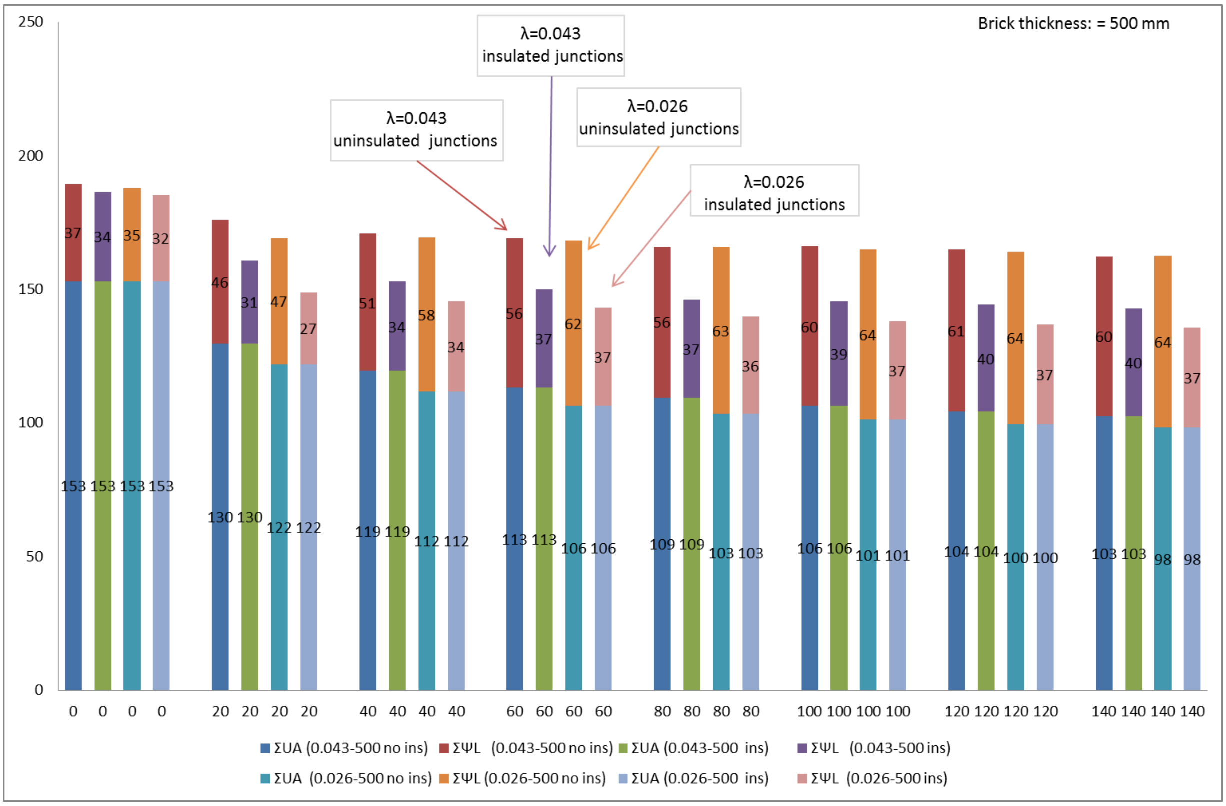
Y-values – Large Windows



Whole Building Analysis: Brick thickness = 500 mm – Small Windows



Whole Building Analysis: Brick thickness = 500 mm – Large Windows



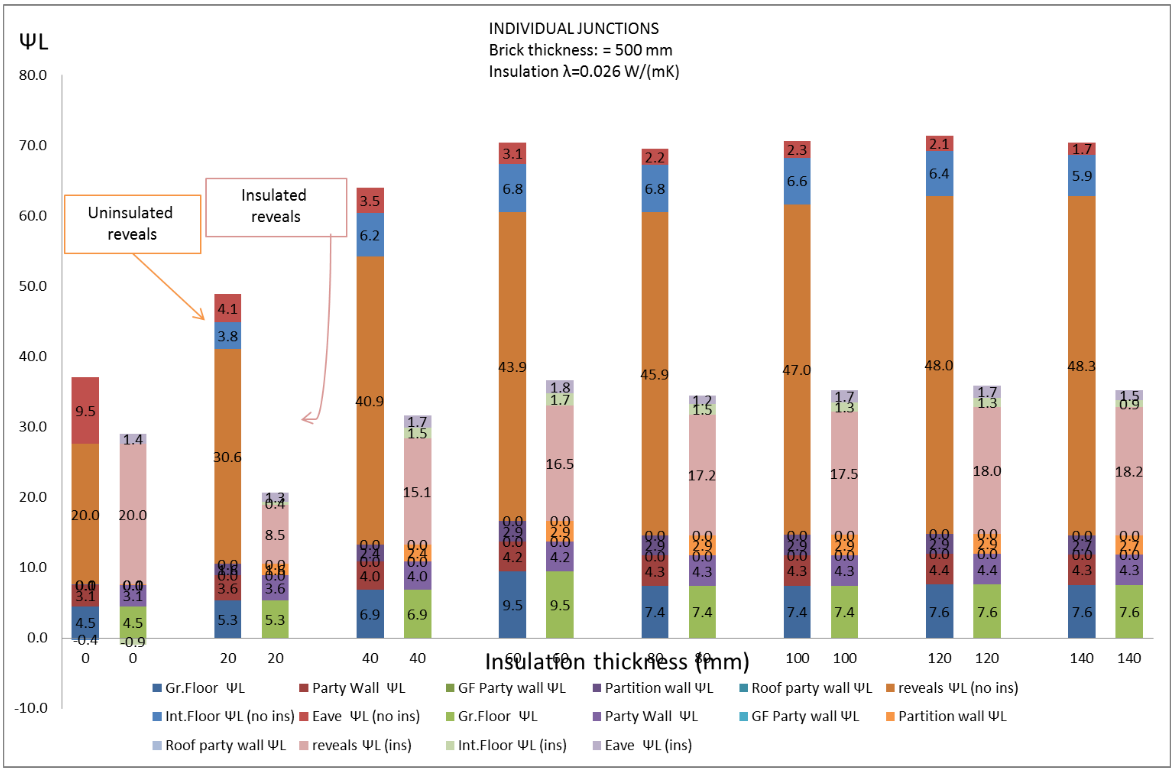
4. Detached house modelling

A simple exercise was done to model the effect of thermal bridging heat loss on a detached house, for comparison with the mid-terrace model. The modelling was done on the following:

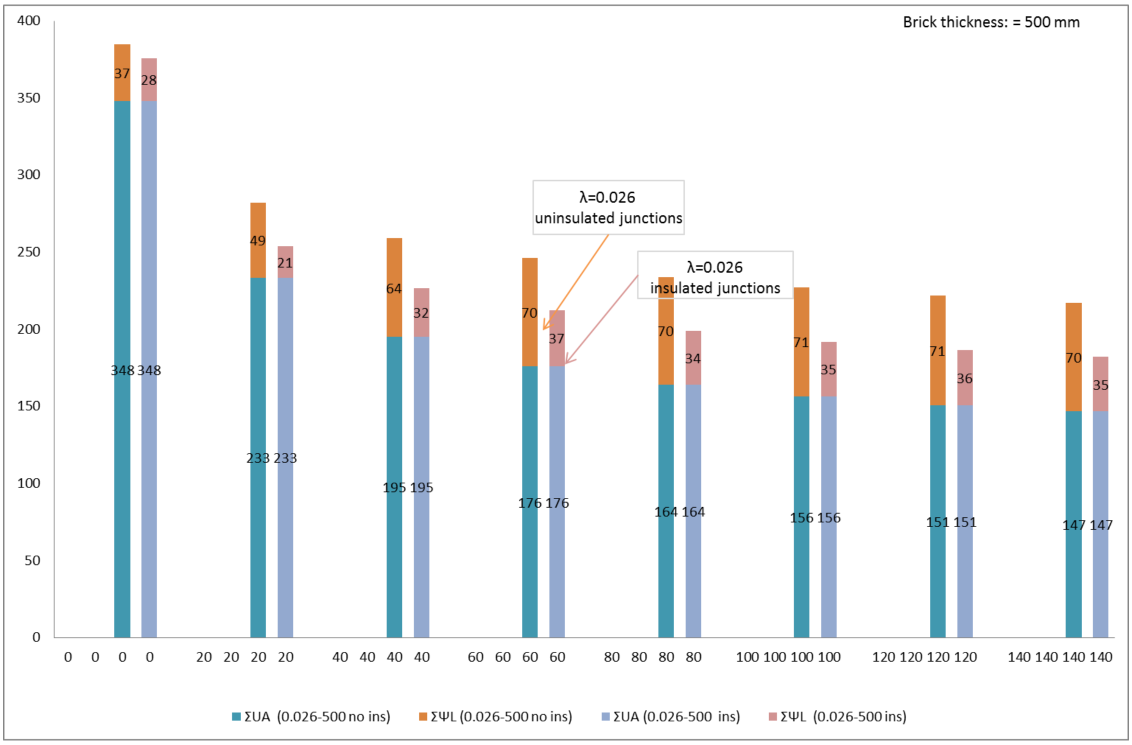
All assumptions were the same as for the mid-terrace house with 500mm wide walls and using an internal wall insulation with λ value of 0.026W/mK with the following exceptions:

1. Floor area is increased to 10m x 8m
2. The Windows were increased from 6 windows and 2 doors to 7 average windows, 6 small windows and 2 doors. The junctions’ lengths increase from 10.86 m to 18.5 m for sills and lintels and from 29.1 m to 41.6 m for jambs.

The individual junctions with and without insulation of reveals



Whole building analysis



Appendix 1

Summary of calculated ΣLψ values for 20mm of IWI and 100mm of IWI

N	Brick mm	IWI Type	Reveals	Intermediate floor	Wall Head	Adjacent House	ΣLψ20	ΣLψ100
1	215	Fibre	Unins	Unins	Unins	Unins	17.43	19.78
2	215	Fibre	Unins	Unins	Unins	Ins	17.91	20.67
3	215	Fibre	Unins	Unins	Ins	Unins	17.06	19.69
4	215	Fibre	Unins	Unins	Ins	Ins	17.54	20.59
5	215	Fibre	Unins	Ins	Unins	Unins	16.46	18.73
6	215	Fibre	Unins	Ins	Unins	Ins	16.94	19.62
7	215	Fibre	Unins	Ins	Ins	Unins	16.09	18.65
8	215	Fibre	Unins	Ins	Ins	Ins	16.57	19.54
9	215	Fibre	Ins	Unins	Unins	Unins	11.81	12.57
10	215	Fibre	Ins	Unins	Unins	Ins	12.29	13.47
11	215	Fibre	Ins	Unins	Ins	Unins	11.47	12.51
12	215	Fibre	Ins	Unins	Ins	Ins	11.96	13.41
13	215	Fibre	Ins	Ins	Unins	Unins	10.83	11.50
14	215	Fibre	Ins	Ins	Unins	Ins	11.31	12.40
15	215	Fibre	Ins	Ins	Ins	Unins	10.49	11.44
16	215	Fibre	Ins	Ins	Ins	Ins	10.97	12.33
17	215	PU	Unins	Unins	Unins	Unins	18.99	20.63
18	215	PU	Unins	Unins	Unins	Ins	19.51	21.54
19	215	PU	Unins	Unins	Ins	Unins	18.69	20.57
20	215	PU	Unins	Unins	Ins	Ins	19.22	21.47
21	215	PU	Unins	Ins	Unins	Unins	17.91	19.54
22	215	PU	Unins	Ins	Unins	Ins	18.43	20.44
23	215	PU	Unins	Ins	Ins	Unins	17.61	19.47
24	215	PU	Unins	Ins	Ins	Ins	18.14	20.37
25	215	PU	Ins	Unins	Unins	Unins	11.96	12.06
26	215	PU	Ins	Unins	Unins	Ins	12.48	12.97
27	215	PU	Ins	Unins	Ins	Unins	11.70	12.01
28	215	PU	Ins	Unins	Ins	Ins	12.22	12.92
29	215	PU	Ins	Ins	Unins	Unins	10.86	10.94
30	215	PU	Ins	Ins	Unins	Ins	11.38	11.84
31	215	PU	Ins	Ins	Ins	Unins	10.59	10.89
32	215	PU	Ins	Ins	Ins	Ins	11.12	11.79
33	500	Fibre	Unins	Unins	Unins	Unins	18.39	22.27
34	500	Fibre	Unins	Unins	Unins	Ins	19.05	23.41
35	500	Fibre	Unins	Unins	Ins	Unins	18.35	22.59
36	500	Fibre	Unins	Unins	Ins	Ins	19.03	23.75
37	500	Fibre	Unins	Ins	Unins	Unins	17.96	21.65
38	500	Fibre	Unins	Ins	Unins	Ins	18.62	22.79
39	500	Fibre	Unins	Ins	Ins	Unins	17.92	21.97
40	500	Fibre	Unins	Ins	Ins	Ins	18.60	23.13
41	500	Fibre	Ins	Unins	Unins	Unins	11.53	13.42
42	500	Fibre	Ins	Unins	Unins	Ins	12.18	14.55
43	500	Fibre	Ins	Unins	Ins	Unins	11.22	13.43
44	500	Fibre	Ins	Unins	Ins	Ins	11.90	14.58
45	500	Fibre	Ins	Ins	Unins	Unins	11.05	12.71
46	500	Fibre	Ins	Ins	Unins	Ins	11.71	13.84
47	500	Fibre	Ins	Ins	Ins	Unins	10.74	12.71
48	500	Fibre	Ins	Ins	Ins	Ins	11.41	13.86
49	500	PU	Unins	Unins	Unins	Unins	19.81	23.63
50	500	PU	Unins	Unins	Unins	Ins	20.55	24.79
51	500	PU	Unins	Unins	Ins	Unins	19.87	23.99
52	500	PU	Unins	Unins	Ins	Ins	20.63	25.17
53	500	PU	Unins	Ins	Unins	Unins	19.29	22.95
54	500	PU	Unins	Ins	Unins	Ins	20.04	24.11
55	500	PU	Unins	Ins	Ins	Unins	19.34	23.30
56	500	PU	Unins	Ins	Ins	Ins	20.11	24.49
57	500	PU	Ins	Unins	Unins	Unins	11.14	12.75
58	500	PU	Ins	Unins	Unins	Ins	11.87	13.91
59	500	PU	Ins	Unins	Ins	Unins	10.89	12.76
60	500	PU	Ins	Unins	Ins	Ins	11.64	13.93
61	500	PU	Ins	Ins	Unins	Unins	10.54	11.95
62	500	PU	Ins	Ins	Unins	Ins	11.28	13.10
63	500	PU	Ins	Ins	Ins	Unins	10.29	11.95
64	500	PU	Ins	Ins	Ins	Ins	11.05	13.12

Change in $\Sigma L\psi_{100}$ as each single parameter is changed

N	Brick mm	IWI Type	Reveal	Int floor	Wall Head	Adj House	ΣLψ 100	D_{Br}	D_{IWI}	D_{rev}	D_{int}	D_{head}	D_{adj}
1	215	Fibre	Unins	Unins	Unins	Unins	19.78						
2	215	Fibre	Unins	Unins	Unins	Ins	20.67						0.90
3	215	Fibre	Unins	Unins	Ins	Unins	19.69					-0.08	
4	215	Fibre	Unins	Unins	Ins	Ins	20.59					-0.08	0.90
5	215	Fibre	Unins	Ins	Unins	Unins	18.73				-1.05		
6	215	Fibre	Unins	Ins	Unins	Ins	19.62				-1.05		0.89
7	215	Fibre	Unins	Ins	Ins	Unins	18.65				-1.05	-0.08	
8	215	Fibre	Unins	Ins	Ins	Ins	19.54				-1.05	-0.08	0.89
9	215	Fibre	Ins	Unins	Unins	Unins	12.57			-7.20			
10	215	Fibre	Ins	Unins	Unins	Ins	13.47			-7.20			0.89
11	215	Fibre	Ins	Unins	Ins	Unins	12.51			-7.19		-0.07	
12	215	Fibre	Ins	Unins	Ins	Ins	13.41			-7.19		-0.06	0.90
13	215	Fibre	Ins	Ins	Unins	Unins	11.50			-7.23	-1.07		
14	215	Fibre	Ins	Ins	Unins	Ins	12.40			-7.23	-1.07		0.89
15	215	Fibre	Ins	Ins	Ins	Unins	11.44			-7.21	-1.07	-0.07	
16	215	Fibre	Ins	Ins	Ins	Ins	12.33			-7.21	-1.07	-0.06	0.89
17	215	PU	Unins	Unins	Unins	Unins	20.63		0.86				
18	215	PU	Unins	Unins	Unins	Ins	21.54		0.87				0.91
19	215	PU	Unins	Unins	Ins	Unins	20.57		0.87			-0.07	
20	215	PU	Unins	Unins	Ins	Ins	21.47		0.88			-0.06	0.91
21	215	PU	Unins	Ins	Unins	Unins	19.54		0.81		-1.10		
22	215	PU	Unins	Ins	Unins	Ins	20.44		0.82		-1.10		0.90
23	215	PU	Unins	Ins	Ins	Unins	19.47		0.82		-1.10	-0.07	
24	215	PU	Unins	Ins	Ins	Ins	20.37		0.83		-1.10	-0.06	0.91
25	215	PU	Ins	Unins	Unins	Unins	12.06		-0.51	-8.57			
26	215	PU	Ins	Unins	Unins	Ins	12.97		-0.50	-8.57			0.91
27	215	PU	Ins	Unins	Ins	Unins	12.01		-0.50	-8.56		-0.05	
28	215	PU	Ins	Unins	Ins	Ins	12.92		-0.49	-8.56		-0.05	0.91
29	215	PU	Ins	Ins	Unins	Unins	10.94		-0.57	-8.60	-1.12		
30	215	PU	Ins	Ins	Unins	Ins	11.84		-0.56	-8.60	-1.13		0.90
31	215	PU	Ins	Ins	Ins	Unins	10.89		-0.55	-8.58	-1.12	-0.05	
32	215	PU	Ins	Ins	Ins	Ins	11.79		-0.54	-8.58	-1.13	-0.05	0.90
33	500	Fibre	Unins	Unins	Unins	Unins	22.27	2.49					
34	500	Fibre	Unins	Unins	Unins	Ins	23.41	2.73					1.14
35	500	Fibre	Unins	Unins	Ins	Unins	22.59	2.90				0.32	
36	500	Fibre	Unins	Unins	Ins	Ins	23.75	3.16				0.34	1.16
37	500	Fibre	Unins	Ins	Unins	Unins	21.65	2.92			-0.62		
38	500	Fibre	Unins	Ins	Unins	Ins	22.79	3.16			-0.62		1.14
39	500	Fibre	Unins	Ins	Ins	Unins	21.97	3.33			-0.62	0.32	
40	500	Fibre	Unins	Ins	Ins	Ins	23.13	3.59			-0.62	0.34	1.16
41	500	Fibre	Ins	Unins	Unins	Unins	13.42	0.85		-8.84			
42	500	Fibre	Ins	Unins	Unins	Ins	14.55	1.09		-8.85			1.13
43	500	Fibre	Ins	Unins	Ins	Unins	13.43	0.92		-9.16		0.01	
44	500	Fibre	Ins	Unins	Ins	Ins	14.58	1.18		-9.17		0.03	1.15
45	500	Fibre	Ins	Ins	Unins	Unins	12.71	1.21		-8.94	-0.71		
46	500	Fibre	Ins	Ins	Unins	Ins	13.84	1.44		-8.95	-0.71		1.13
47	500	Fibre	Ins	Ins	Ins	Unins	12.71	1.28		-9.26	-0.72	0.00	
48	500	Fibre	Ins	Ins	Ins	Ins	13.86	1.53		-9.27	-0.72	0.02	1.15
49	500	PU	Unins	Unins	Unins	Unins	23.63	2.99	1.36				
50	500	PU	Unins	Unins	Unins	Ins	24.79	3.25	1.38				1.16
51	500	PU	Unins	Unins	Ins	Unins	23.99	3.42	1.39			0.36	
52	500	PU	Unins	Unins	Ins	Ins	25.17	3.70	1.42			0.38	1.19
53	500	PU	Unins	Ins	Unins	Unins	22.95	3.41	1.30		-0.68		
54	500	PU	Unins	Ins	Unins	Ins	24.11	3.67	1.32		-0.68		1.16
55	500	PU	Unins	Ins	Ins	Unins	23.30	3.84	1.33		-0.68	0.36	
56	500	PU	Unins	Ins	Ins	Ins	24.49	4.12	1.36		-0.68	0.38	1.18
57	500	PU	Ins	Unins	Unins	Unins	12.75	0.69	-0.67	-10.87			
58	500	PU	Ins	Unins	Unins	Ins	13.91	0.94	-0.65	-10.89			1.15
59	500	PU	Ins	Unins	Ins	Unins	12.76	0.74	-0.68	-11.23		0.00	
60	500	PU	Ins	Unins	Ins	Ins	13.93	1.01	-0.66	-11.24		0.02	1.17
61	500	PU	Ins	Ins	Unins	Unins	11.95	1.01	-0.76	-11.00	-0.81		
62	500	PU	Ins	Ins	Unins	Ins	13.10	1.26	-0.74	-11.01	-0.81		1.15
63	500	PU	Ins	Ins	Ins	Unins	11.95	1.06	-0.77	-11.36	-0.81	0.00	
64	500	PU	Ins	Ins	Ins	Ins	13.12	1.33	-0.75	-11.37	-0.81	0.02	1.17

Appendix 2: Comparison of 3D and 2D modelling on individual junctions

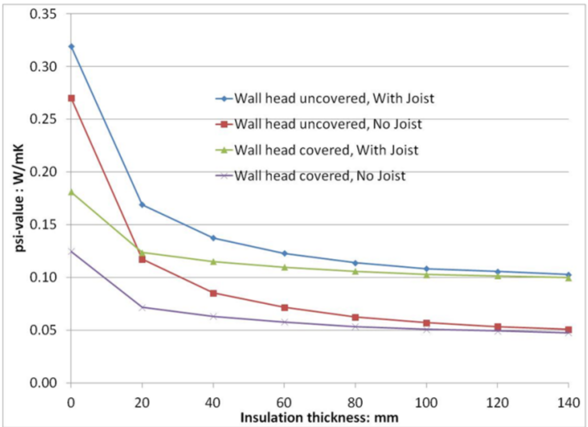
Individual junctions

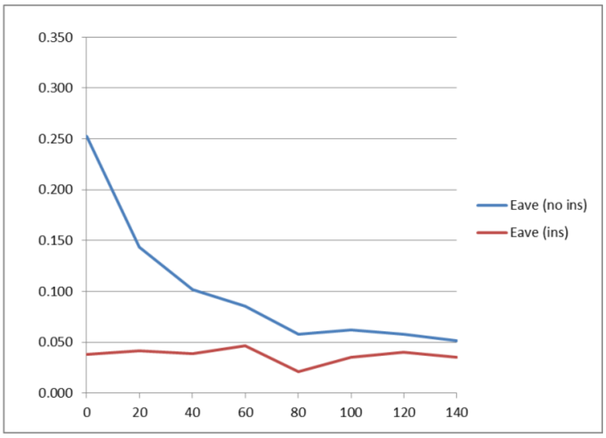
Comparison carried out with brick thickness = 500 mm and λ=0.043 W/(mK).

Eaves

Left: 3D modelling, psi value at eaves.

Right: 2D modelling, psi values at eaves (no joists included).

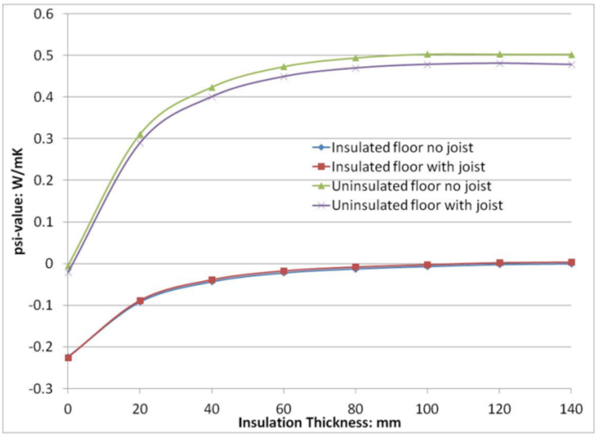


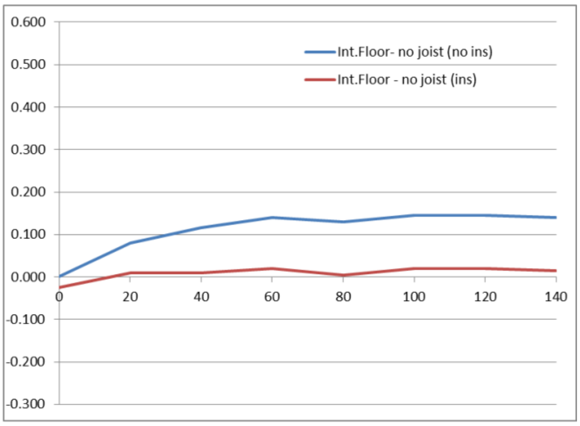


Intermediate floor

Left: 3D modelling, psi value at the intermediate floor.

Right: 2D modelling, psi values at the intermediate floor (no joists included).





Party wall

Blue line: 3D modelling (CS), psi/2 at the party wall; neighbouring wall uninsulated

Red line: 2D modelling (VM), psi/2 at the party wall; neighbouring wall uninsulated.