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Solid wall heat losses and the potential for energy saving

Classification of solid walls

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Notes

This report is part of a collection of outputs from the BEIS research project investigating the savings achieved with the installation of solid wall insulation. These will be made available on the project web site where a summary of the project can also be found (see http://www.bre.co.uk/swi).

The lead author for this report was Matthew Custard of BRE.

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1 Introduction

Insulating the solid wall housing stock is one of the greatest challenges for energy efficiency policy. Solid wall insulation can be significantly more expensive and intrusive to install than other forms of insulation, making it much less attractive to households and funding organisations. Uncertainties exist around the assumptions used when predicting savings typically achieved following the installation of solid wall insulation. Previous research has identified a gap between calculated savings and actual realised energy savings following the application of solid wall insulation. Typically, the actual savings achieved are lower than predicted. This gap affects the potential energy, cost and carbon savings from solid wall insulation which makes the intervention a less cost-effective measure to install, with potentially significant impacts on Government policy.

Energy models used to predict savings typically use standard assumptions about the performance of the dwelling and the behaviour of the occupants both before and after insulation. The principle methodology used for calculating savings from the Energy Company Obligation (ECO) is Reduced Data SAP (RdSAP). A number of recent studies have suggested that the actual savings from solid wall insulation may be lower than anticipated by modelling using RdSAP. The over-estimation of the savings is addressed in programmes such as ECO by the application of 'in-use factors'[1]. These factors apply a simple percentage reduction in savings after the calculations have been made.

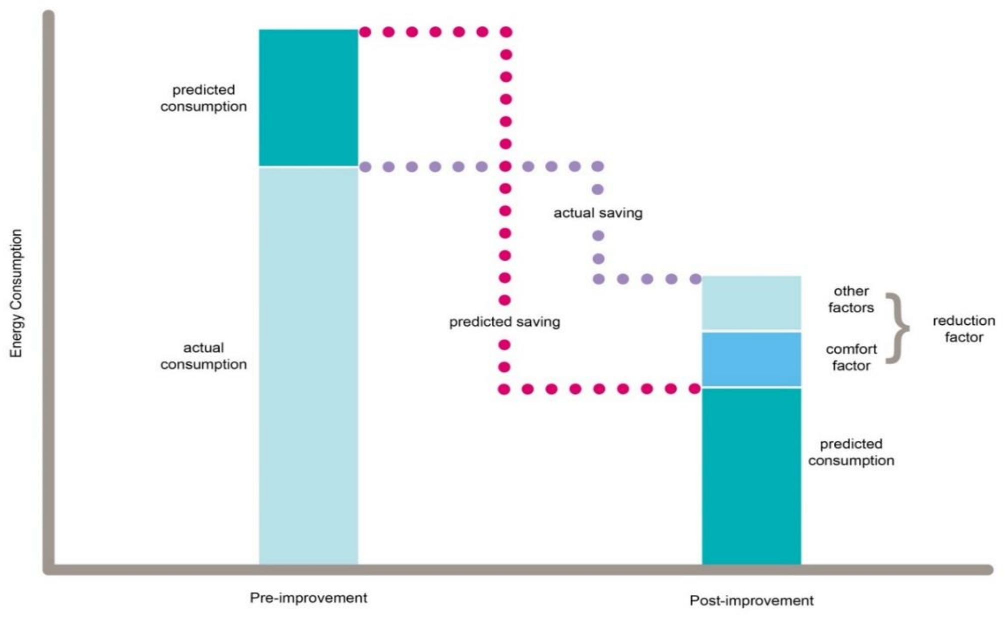

Figure 1 - The gap between predicted and actual energy savings post insulation

[1] https://www.ofgem.gov.uk/ofgem-publications/83100/energycompaniesobligation-measures-pdf

Figure 1 above shows a visual representation of the gap between actual and predicted consumption prior to and following insulation and savings achieved (based on the findings of previous research). A literature review conducted as part of the current project[2] identified that the primary reasons for the gap between the predicted and actual savings are likely to be;

- Inaccurate assumptions regarding the baseline performance of the building envelope and the temperatures in the homes prior to installation;
- Errors in the installation of the insulation and poor workmanship;
- Changes in occupant energy use behaviour once the insulation has been installed.

The BEIS solid wall insulation research programme has looked in detail at the performance of solid walls in England and Wales in both their insulated and uninsulated states. This has been done in order to improve the estimates of savings achieved by installing solid wall insulation. One way to achieve this would be to address the first point in the list above; namely improving estimates of the performance of the solid wall prior to insulation.

Measuring a wall's U-value currently takes at least 10 days using the recommended methods and therefore is not something that can be done at the time of an energy survey (such as would be undertaken for the production of an EPC). Instead, default values are generally used, with most solid walls assigned a single default U-value of 2.1 W/m^{2}K. The measurements obtained from uninsulated dwellings as part of this research programme provide a rich source of information about the properties of solid walls. These data show that there is a wide range of U-values present in the solid wall housing stock. The use of a default value hides this variation and limits the model's ability to predict savings. If the energy assessor was able to input a better estimate of the wall's performance at the time of the survey, the prediction of savings would be improved.

There are two main methods of achieving this. The first is by measuring the wall. As mentioned this is not feasible using established methods. The BEIS research programme has investigated other more novel techniques for measuring thermal performance of walls more rapidly and this is reported on separately within the suite of publications produced from this programme. In the absence of a rapid measurement device, the other option is to provide a more sophisticated way of estimating the U-value, rather than using the default value of 2.1 W/m^{2}K.

This document presents the structure of a classification system that has been developed using the data collected as part of the research programme. The system would enable assumptions about the thermal performance of a solid wall to be tailored depending upon measureable or observable characteristics. The focus of this classification system is on solid brick walls which make up the great majority of the solid wall housing stock.

There is strong evidence from this and other projects that solid walls tend to perform better than the default assumed value of 2.1 W/m^{2}K and therefore have a lower U-value. Other work in the research programme has sought to establish an appropriate new average U-value for solid brick walls. In the absence of any additional information, energy savings calculations can and should use this new default value. This report looks at how that new average could be adjusted for individual dwellings to enable better modelling of energy use and savings potential.

[2] https://www.bre.co.uk/filelibrary/pdf/other_pdfs/Solid-wall-insulation-literature-review.pdf

2 Constructing the classification system

2.1 Introduction

The solid wall insulation research programme has conducted U-value measurements in 137 dwellings across England and Wales. A number of other measurements and observations were recorded in a subset of 89 cases that together provide a detailed description of the physical properties of solid walls and allow a far more detailed calculation of the U-value to be made than would otherwise be possible. The result of this is that the average calculated U-value (using ISO 6946) is much closer to the average measured U-value than before. These results, along with the methodology for measurement of U-values and the collection of other data are described in the related report, "*The nature of solid walls in situ.*" All reports from the research programme can be found at www.bre.co.uk/swi. The detail has not been reproduced here however the properties of the wall which the fieldwork showed have an effect on the U-value; and which are therefore of relevance to the development of a classification system, are as follows:

- Thermal conductivity of;
    - Brick
    - Mortar
    - Internal finish
- Wall thickness
- Mortar fraction
- Presence of dry-lining
- External finish (render)
- Presence of cavities (including frogs and gaps between bricks)

Some of the factors listed above, such as presence of cavities in the gaps between bricks and the existence and orientation of frogs in the bricks, are not easily measured or observed as part of a non-intrusive survey and are therefore not the focus of this report because an assessor would not be able to deviate from a default value. The other factors can all be measured or inferred from other information.

The calculation of a wall's U-value essentially involves determining the thermal conductivity of each of the materials that make up that wall. The investigations conducted for this research programme identified five main materials that need to be considered. These are;

- Brick
- Mortar
- Plaster
- Render (if present)
- Air (in enclosed air spaces)

If heat is considered to flow one dimensionally, there are several paths that can be identified in a wall that will consist of different materials in different proportions. For example, a pathway may consist of plaster, brick and mortar. It could consist of just plaster and mortar, such as the mortar joint between two stretcher bricks and a header brick (the perpend joint). Our investigations discovered that there will also be pathways containing air pockets, such as within an unfilled frog or in a perpend joint that was not filled with mortar other than for pointing at the wall surface. In all we identified 12 paths within a wall that would contain different combinations and proportions of materials. The combined resistance for; and area of, each of these paths was calculated and the resultant U-value calculated.

The questions for the design of the classification system are;

- “Which properties of the wall should be included?” Determined by;
  - “Which properties have the biggest effect on U-value?” and;
  - “Which properties can be measured and differentiated?”
- “How should they be differentiated?”

The following sections consider these questions for each of the key properties listed previously. The key determinants of thermal conductivity, which is central to so much of the wall’s thermal performance, are the density and moisture content of the materials. Therefore, these two factors have been considered separately.

There is a related question about how the assessor would collect the information at the dwelling. It is important to consider this during the design phase of the classification system because this will affect how the variables are ultimately differentiated.

2.2 Density

The density of a material, along with its moisture content, are key determinants of that material’s thermal conductivity. The denser a material is, the better it is at conducting heat. The four materials under consideration for the classification system are the brick, mortar and the plaster. As part of the fieldwork conducted for this research programme, samples of bricks and mortar were taken form 89 dwellings and tests conducted to ascertain certain properties of those materials. The density of the brick samples was measured and found to be 1,804 kg/m^3 on average. Samples of mortar were also collected from the fieldwork and the average density of those was found to be 1,612 kg/m^3. Plaster and render densities were not measured.

A surveyor cannot easily measure the density of a brick in situ but because of its importance to the determination of thermal conductivity, it was considered important to include density as part of the classification of bricks. For this classification, density has been categorised as low, medium or high. If the assessor is able to differentiate between these categories, the predicted U-value will be more accurate as a result. There are several possible ways that this assessment could be made, although this report does not explore them in detail. The most likely way of differentiating bricks for density would be by visual inspection, looking for visual signs of porosity such as air bubbles and inclusions, possibly coupled with some kind of hardness test such as a scratch test. There is also a possible relationship between brick colour and density however the sample size of the bricks collected as part of this research programme was not large enough to determine this with statistical significance.

Based on the distribution of values in the brick samples measured, the medium density has been assigned the median value of 1,804 kg/m^3, the low density has been assigned 1,650 kg/m^3 and the high density 1,900 kg/m^3. These are based around values that are roughly one standard deviation from the median value, taking into account the skewness of the data. Mortar density has not been varied for this project.

2.3 Moisture content

The other key determinant of thermal conductivity in this setting is the moisture content of the material. The samples of brick that were taken during the fieldwork had their moisture content measured and in addition dust drillings were taken from the mortar. The moisture content of the plaster was not measured during the fieldwork because of the level of disruption and damage to internal finishes that would cause. It was also considered that this would be less variable; at least where the heating was adequate.

As with density, it is not straightforward to accurately measure, in situ, the moisture content for walls of this type and therefore it was decided that, for the classification system, walls would be categorised into low, medium and high. The median moisture content of bricks from field measurements was found to be 0.8% and this was used as the medium value. Moisture content was found to be generally low in the bricks measured and the low value was therefore chosen to be 0.2%. The high value was harder to establish because, although moisture content was generally low, there were some rather high values that skewed the distribution somewhat, with measurements recorded of greater than 15%. A value was chosen for the high category that would reflect this and therefore 5.0% was used.

Mortar was found to be somewhat wetter than brick on average. The corresponding values for mortar are;

- Low – 1.5%
- Medium – 2.8%
- High – 6%

To determine which category an assessor should place a wall in, we envisage some sort of matrix being constructed that uses an assessment based on two factors; the regional weather conditions and the local exposure. The regional exposure can be assessed with reference to the British Standard BS 8104 (British Standards Institution, 1992) which defines four driving rain exposure zones as shown in the diagram below. The local exposure of the dwelling itself can be assessed using the framework set out in the SAP methodology (BRE, 2014) which considers the number of sides of the dwelling that are sheltered.

For a wall to be placed in the 'High' category, we would expect there to be obvious signs of elevated moisture content and that this would be relatively rare. This is reflected in the selection of the 5% value. It is anticipated that most dwellings would fall into the 'medium' category.

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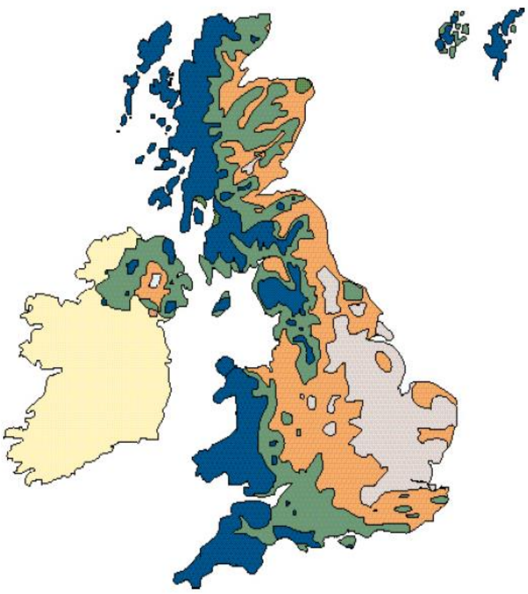


- Buildings that are sheltered by surrounding buildings and trees can be considered to be in an exposure category one lower in 'sheltered' parts. For example: if 'sheltered' in Zone 4 consider it as Zone 3.
- External cladding can improve the exposure rating and give resistance to rain penetration.
- Assess the exposure of the wall using BS 8104.
- See BRE Report 262: 'Thermal Insulation: avoiding risks' for guidance.

Key to map

Exposure zones	Approximate wind-driven rain (litres/m^2 per spell)
1	Less than 33
2	33 to less than 56.5
3	56.5 to less than 100
4	100 or more

Figure 2 - Wind driven rain map

		Local exposure		
		L	**M**	**H**
Regional exposure	**1**	1	2	3
	2	2	4	6
	3	3	6	9
	4	4	8	12

Green	Low
Amber	Medium
Red	High

Figure 3 - Indicative moisture content matrix

2.4 Wall thickness

A wall's thickness is directly linked to its U-value and is therefore an important characteristic to account for in the classification system. It is also, generally speaking, readily measured by an assessor and so is well suited for inclusion in such as system.

Wall thickness of brick walls will generally be governed by the dimensions of the bricks used, the thickness of the internal finish and external render (if present) and most importantly the construction method used in terms of the number of bricks laid across the thickness of the wall. Most solid brick walls will be built one (header) brick thick. Walls can be built half brick thick, though this is rare in domestic construction. They can also be more than one brick thick, most typically one-and-a-half bricks thick.

There are no discreet categories of wall thickness; it is a continuous measure. The classification system requires categorisation to make a lookup system possible and so each type of wall has been assigned 11 thickness categories. For unrendered walls with a wet plaster finish the categories range from 220 mm to 270 mm. For unrendered walls with a plasterboard internal finish; and rendered walls with a wet plaster finish, the range is 240 mm to 290 mm and for rendered walls with a plasterboard internal finish the range is 260 mm to 310 mm. The thickness of the wall can be measured in a variety of ways ranging from highly precise methods such as digital callipers, through to instruments such as steel rules.

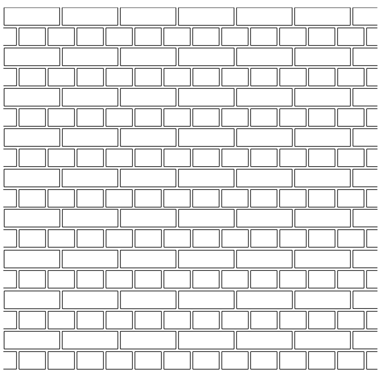
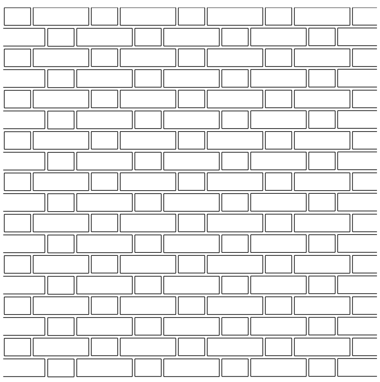
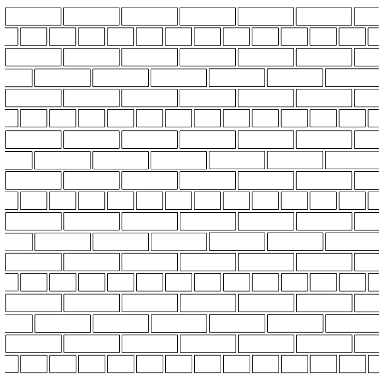
2.5 Mortar fraction

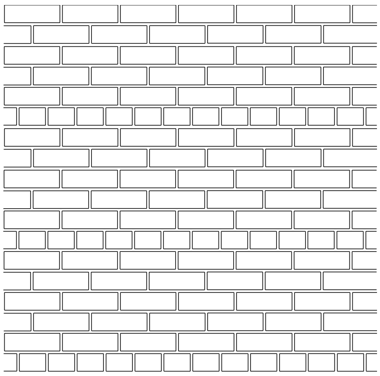
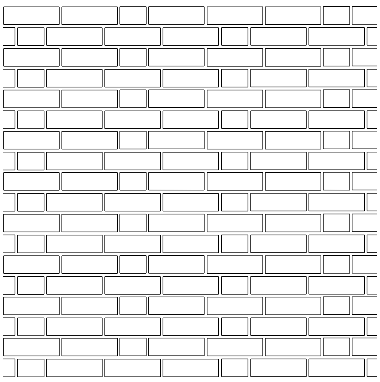
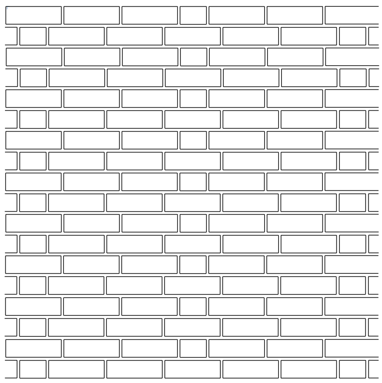
The final characteristic under consideration for the classification system is the ratio of brick to mortar in the wall. This is determined by a number of factors including the gauge of the mortar beds and vertical joints, the dimensions of the bricks and the bonding pattern of the bricks and how they were laid. The gauge or thickness of the mortar joints is easily measured however it varies over the totality of a wall and so an average value has been used for all calculations in the construction of the classification system. This average has been derived from the fieldwork conducted as part of the research programme.

The classification system allows the user to specify mortar fraction. There are six different brick configurations included which account for the great majority of solid brick walls in the UK and which will all have different ratios of brick to mortar. These are:

- English
- Flemish
- English garden wall (3 courses of stretchers)
- English garden wall (5 courses of stretchers)
- Flemish garden wall (3 stretchers)
- Flemish garden wall (5 stretchers)

These are represented graphically below.

		
English bond	Flemish bond	English garden wall (3 courses)

		
English garden wall (5 courses)	Flemish garden wall (3 stretcher)	Flemish garden wall (5 stretcher)

2.6 Internal finish

As mentioned, the density and moisture content of the internal finish were not measured in the dwellings visited. It was deemed that the key distinction to be made when considering internal finish was the type of finish present. Insulating wet plaster solutions are available on the market but are uncommon and not picked up with the sample visited as part of this fieldwork. Therefore, the only distinction made in the categorisation system is between wet plaster applied directly to the brickwork and plasterboard, affixed to the wall using wooden studwork or plaster dabs.

Plasterboard, regardless of its fixing method, will have a narrow air cavity between it and the brick surface. Providing that this air cavity is isolated from the general environment of the dwelling interior, this will serve as an extra insulating layer. Plasterboard is readily identifiable by an assessor as compared to wet plaster it will sound hollow when tapped.

Insulating internal finishes, such as insulating wet plaster and insulation-backed plasterboard, have not been considered as part of this study because of the focus on unimproved solid brick walls. The same applies to insulating external finishes, such as insulating render.

2.7 External render

The presence of render is perhaps the easiest feature of a wall for an assessor to determine and is therefore included in the classification system. In addition, the presence of render on all external walls will normally mean that other features such as brick type and bonding pattern cannot be assessed. Therefore, it is important for the classification system to recognise this feature and to assume values for those features that cannot be assessed. The system does not differentiate between types of render, it merely recognises its presence or absence.

2.8 Populating the classification table

The classification system is essentially a large lookup table containing U-values for each combination of the properties of walls discussed above. The table is populated by inputting the values specified into a calculation (compliant with ISO 6946) for each of the combinations listed and then entering the resultant U-value into the correct cell in the lookup table. The table below summarises the values chosen for each of the categories used.

Table 1 - Summary of variables and options in classification system

Density	Moisture content (brick)	Moisture content (mortar)	Wall thickness	Mortar fraction	Internal finish
Low – 1,650 kg/m^3	Low – 0.2 %	Low – 1.5 %	220	English bond	Wet plaster
Medium – 1,805 kg/m^3	Medium – 0.8 %	Medium – 2.8 %	Then 5 mm increments up to	Flemish bond	Plasterboard
High – 1,900 kg/m^3	High – 5 %	High – 6 %	310	English garden wall (3 stretcher courses)	
				English garden wall (5 stretcher courses)	
				Flemish garden wall (3 stretchers)	
				Flemish garden wall (5 stretchers)	

3 Using the classification system

The concept of the classification system is for an assessor to collect a restricted number of data items that can be entered into a lookup system which will tell them what the calculated U-value should be for the wall they have specified. This value can then be entered into an RdSAP software application to override the default U-value. There are 1,426 different combinations of values from the variables specified in Table 1 above. These have been collated in a look up table. An extract from the table is shown below.

				Thickness					Median					
Bonding	Density	Moisture	Dry-lining	220	225	230	235	240	245	250	255	260	265	270
FGW5	L	L	N	1.73	1.70	1.68	1.66	1.63	1.61	1.59	1.57	1.55	1.53	1.51
FGW3	L	L	N	1.73	1.70	1.68	1.66	1.64	1.61	1.59	1.57	1.55	1.54	1.52
EGW5	L	L	N	1.74	1.71	1.69	1.67	1.64	1.62	1.60	1.58	1.56	1.54	1.52
EGW3	L	L	N	1.74	1.72	1.70	1.67	1.65	1.63	1.61	1.59	1.57	1.55	1.53
English	L	L	N	1.76	1.74	1.72	1.69	1.67	1.65	1.63	1.61	1.59	1.57	1.55
Flemish	L	L	N	1.75	1.73	1.70	1.68	1.66	1.64	1.62	1.60	1.58	1.56	1.54
FGW5	M	L	N	1.82	1.80	1.78	1.75	1.73	1.71	1.69	1.67	1.65	1.63	1.61
FGW3	M	L	N	1.83	1.80	1.78	1.75	1.73	1.71	1.69	1.67	1.65	1.63	1.61
EGW5	M	L	N	1.83	1.81	1.79	1.76	1.74	1.72	1.70	1.68	1.66	1.64	1.62
EGW3	M	L	N	1.84	1.82	1.79	1.77	1.75	1.73	1.70	1.68	1.66	1.64	1.63
English	M	L	N	1.86	1.84	1.82	1.79	1.77	1.75	1.73	1.71	1.69	1.67	1.65
Flemish	M	L	N	1.85	1.83	1.80	1.78	1.76	1.73	1.71	1.69	1.67	1.65	1.63
FGW5	H	L	N	1.88	1.86	1.83	1.81	1.78	1.76	1.74	1.72	1.70	1.68	1.66
FGW3	H	L	N	1.88	1.86	1.83	1.81	1.79	1.77	1.74	1.72	1.70	1.68	1.66
EGW5	H	L	N	1.89	1.87	1.84	1.82	1.80	1.77	1.75	1.73	1.71	1.69	1.67
EGW3	H	L	N	1.90	1.87	1.85	1.83	1.80	1.78	1.76	1.74	1.72	1.70	1.68
English	H	L	N	1.92	1.90	1.87	1.85	1.83	1.80	1.78	1.76	1.74	1.72	1.70
Flemish	H	L	N	1.91	1.88	1.86	1.83	1.81	1.79	1.77	1.75	1.73	1.71	1.69

Figure 4 - Extract from U-value lookup table

A prototype Excel front end has been created that allows the user to enter the values measured. The resulting U-value is displayed. This is shown below.

Bonding	Density	Moisture	Dry-lining	Wall thickness
FGW5	L	L	Y	220
FGW3	M	M	N	225
EGW5	H	H		230
EGW3				235
English				240
Flemish				245
Rendered				250
				255
				260
				265
				270
				275
				280
				285
				290
				295
				300
				305
				310

Flemish	M	M	N	250	FlemishMMN	U-value:	1.771486

Figure 5 - Prototype U-value lookup facility

In the absence of any other information, the assessor can use default (medium) values as shown in the table above. The resultant U-value for these values is 1.77 W/m^{2}K. This corresponds to the median value observed in the fieldwork meaning that if defaults are used throughout, an assessor would record a U-value equivalent to the stock average based on the best knowledge and information currently available.

4 Next steps

There are three main areas for development of the classification system. The first is around verification. The system should be tested with walls of a known U-value. These should be independent of the walls measured as part of this study. This exercise will demonstrate the classification system's ability to predict U-values from the information collected by the assessor.

The second area for development is around how the information should be collected by the assessor. This was not the primary focus of this study, although some consideration was given to the feasibility of collecting the information because there is no point including a variable that cannot be measured, regardless of its importance to the wall's U-value. Some of the characteristics under consideration are easily measured, such as wall thickness and presence of dry-lining. Others, such as density and moisture are more difficult. Thought must be given to effective ways of estimating these properties and these must be verified through experimentation and testing.

The third area of development is to expand the capabilities of the tool beyond the current range of values and walls that they represent. For example, the thicknesses effectively only encompass one header brick thick walls.

Once these areas have been addressed, the tool has the potential to facilitate more accurate estimates of solid wall U-values, and therefore better estimates of the savings that can be achieved by insulating them.

5 References

BRE. (2014). *The Government's Standard Assessment Procedure for Energy Rating of Dwellings.* Crown Copyright.

British Standards Institution. (1992). *BS 8104:1992 Code of practice for assessing exposure of walls to wind-driven rain.* BSI.