THE SPAB RESEARCH REPORT 1.
U-VALUE REPORT
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1. Introduction

The SPAB Research Report 1 U-value Report sets out the findings out of research work carried out into the subject of the heat loss (U-values) of traditionally-built walls. The report provides a brief background description of the origins of this project and sets out the scope of its enquiry, this is followed by a methodology chapter which gives an account of the methodologies involved in both the measurements and calculation of U-values. There is then a section on the results from the previous three year's worth of in situ U-value monitoring, where the walls under examination are broken down into various descriptive sub-headings and their thermal performance as measured in situ is scrutinised. This section is then followed by an examination of this in situ performance in relation to that predicted for the same walls by means of a standard U-value calculation procedure and compares and contrasts the two sets of U-values. The report concludes with a discussion of the consequences of the discrepancy between measured and calculated U-values with regard to the refurbishment of solid walls and the reduction of heat loss from traditional buildings.

Research Report 1. was first published in October 2010, this is the second revised edition published in November 2012.
2. Background

The 2009-2010 SPAB U-value research project originally evolved from a 'Science and Heritage' research proposal developed in collaboration with Dr Paul Baker of Glasgow Caledonian University to improve the energy efficiency of the SPAB offices in 37 Spital Square, London. In the light of limited research in this area the project was to act as a demonstration exemplar that would inform architecturally sensitive refurbishment work on historic buildings. Part of the project included the use of heat flux sensors to monitor heat transfer through the walls of 37 Spital Square in response to the lack of data concerning the thermal performance of old buildings. Unfortunately the 'Science and Heritage' project did not receive the necessary grant funding but the monitoring element of the research, albeit in a modified form, was enabled by the identification of an MSc Historic Building Conservation researcher interested in the energy profiles of historic buildings.

In consultation with Dr Paul Baker, Caroline Rye, then a student at the University of Portsmouth, working with Jonathan Garlick, Technical Officer at the SPAB, embarked on a programme of research to look at the in situ U-values of traditionally built walls. A traditional building is defined by English Heritage as being a building of solid wall construction built with permeable fabric\(^1\) and this definition applies to the majority of walls examined in this research. The range of wall types included solid cob and stone walls, timber-framed structures with a variety of different infill materials and some walls with air gaps. The range of walls examined was intentionally diverse in order to contrast with similar work undertaken by Dr Paul Baker on behalf of Historic Scotland where the walls under review were predominantly stone, and likewise research proposed by English Heritage where the intention was to gather data for brick buildings. In addition to the accumulation of in situ U-value figures for various traditional construction types a further exercise was undertaken in collaboration with Cameron Scott, as part of the MSc element of
the research, which compared the in situ U-values with figures calculated using a U-value calculating programme widely used within the construction industry, BuildDesk v3.4. The discrepancy between the figures produced by the two different U-value estimating methods was significant and provides evidence for claims that standard calculating methods underestimate the thermal performance of traditionally built buildings.

Following on from the success of this initial research and the interest generated by the first edition of Research Report 1. the SPAB decided to continue its work on the U-values of traditional walls. During the winter seasons of 2010-12, 46 more U-value measurements have been made of 34 different walls, including walls that are part of a broader Building Performance Survey. (The SPAB Building Performance Survey looks at seven properties that are undergoing refurbishment work and measures various aspects of their performance both before and after these ‘improvements’. This is the subject of the second SPAB report, Research Report 2.) The walls examined between 2010-12 were mostly solid wall constructions of historic origin with the exception of a modern straw bale construction and measurements taken from a Hemp/Lime house at Haverhill in Suffolk. Eighteen 'refurbished' walls, that is walls that have recently had modern insulation materials added, have also been measured. Once again the in situ U-value measurements recorded on site were compared with U-values calculated for these same walls using the U-value calculator BuildDesk v.3.4.
3. Methodologies

3.1 In situ U-value monitoring procedure

An in situ U-value is a non-destructive means of measuring thermal transmittance in site-specific, pre-existing building elements. It uses a heat flux monitor in combination with interior and exterior temperature measurements taken over time; in this way an in situ U-value is able to take into account thermal inertia (mass) and the effect of temperature change and other climatic conditions.

The monitoring procedure described below has been developed by Dr Paul Baker during work undertaken for Historic Scotland and follows the principles set out in prEN 12494 Building components and elements - in situ measurement of thermal resistance and thermal transmittance (a draft re-working of ISO 9869).

A Hukseflux HFP01 heat flux sensor is attached to the interior surface of the wall under investigation (Fig. 1). The sensors are 80mm in diameter and 5mm thick. The sensors were mounted by firstly applying a layer of double-sided adhesive tape to the back of the sensor. Secondly, low tack masking tape was applied to the wall. Finally, the heat flux sensor was applied firmly to the masked area. This arrangement was generally satisfactory for two or more weeks monitoring on painted or plastered surfaces. Wallpapered surfaces were not generally used in case of damage. On occasion, if a wall surface was uneven, such as a bare stone or limewashed rubble wall, it was necessary to attach the sensors using a small quantity of silicon sealant.
Sensor locations were chosen to avoid probable thermal bridge locations near to windows, corners, etc., with the sensor ideally located about halfway between window and corner, and floor and ceiling. In addition, a thermographic camera was used to survey the internal face of the wall to ensure a general uniformity of surface temperature and thus establish a representative site for the placement of the sensor (Fig. 2). The heat flux data was logged on a Campbell Scientific CR1000 data logger. The Campbell data logger also recorded the surface temperature of the same wall using a type-T thermocouple taped onto the surface of the heat flux sensor (Fig. 1).

If necessary, in order to provide additional information concerning room conditions for data verification purposes, internal air temperature and relative humidity levels were monitored using dual channel Gemini TinyTag Plus 2 TGP-4520 loggers placed in proximity to the wall under investigation.
External temperatures were measured using a separate Gemini TinyTag Plus 2 TGP-4520 data logger which could be mounted outdoors. Thermistor probes were used to measure external air temperature and, generally, external wall surface temperature. Each external air temperature sensor was placed in a radiation shield which was secured, for example, onto a drainpipe (Fig. 3). Crimp-on terminals were used to fix surface temperature sensors to mortar joints, by drilling and plugging joints. Figure 3 shows the method of mounting external surface temperature sensors. In some cases external surface temperature sensors were not used either to avoid damaging the exterior surface of the building, for example, a rendered finish, or owing to difficult access.

Figure 3. Air and surface temperature sensors.

Sensors attached to Campbell Scientific loggers were logged at 5 second intervals and averaged over 10 minutes, whilst Tinytag loggers recorded 10 minute averages of data logged at 1 minute intervals.
3.2 In situ U-value data analysis

Ideally, the monitoring should be carried out during the winter months when there is the greatest possibility of extremes of interior and exterior temperature difference. Given that the monitoring conditions are non-steady state, it is considered necessary to monitor for about two weeks or, preferably longer, in order to collect sufficient data to estimate in situ U-values. The long test duration also allows the thermal capacity of the wall to be accounted for.

The data is then used to calculate a U-value figure as a cumulative average over time (Equ. 1).

\[
U_i = \frac{1}{\sum_{i=1}^{\infty} \Delta T_s_i + r_{int} + r_{ext}}
\]

Equation 1. from Baker, 2008.²

The surface temperature difference across the wall (ΔTs) is determined in order to establish its thermal resistance. The temperature difference, as a cumulative average, across the wall (ΔTsi) is divided by the cumulative average of the heat flux figure (Qi). From this figure the sum of the standard internal and external surface resistances (+rint + rext) are added, = 0.17m²K/W) and a small correction applied for the resistance of the heat flux sensor (6.25 x 10⁻³) is subtracted. Finally, the reciprocal of this total is taken to convert the resistance to a U-value (W/m²K). In instances where it was not possible to gather external surface temperature information external air temperature was used instead and the equation does not include the external surface resistance figure (0.04m²K/W). The uncertainty of the U-values estimates is about ±10%.

The U-value figure can then be plotted against time to check the quality of the data, i.e. variations should damp down and the value should approach an asymptote. Figure 4 shows the effect of increasing the length of the
monitoring period on the estimate of the U-value using the averaging procedure as described above. A period of at least a week is required before the U-value estimate stabilises to within ±5% of the final value determined from about 27 days data.

Figure 4. The stabilising effect of durational monitoring. (from Baker, 2010.)

3.3 Calculated U-value methodology (BR 443)

U-values derived through calculation require the material characteristics of a building element to be known and defined quantitatively. Modern building elements are normally made up of a series of discreet layers of a single material, each with a known thermal conductivity and thus, through a simple summing of resistances, the U-values of these walls can be assessed at the design stage.
Historic buildings with their traditional constructions present specific difficulties in this respect as, although it maybe possible to determine the overall width of a wall, its exact build-up can be difficult to define. For example, traditional walls can be conglomerate in nature with a number of different materials combined in varying proportions to form a heterogeneous whole, e.g. straw and clay to form a cob wall. Or, in other instances, a material and/or its quantity remains unknown, for example, the proportion of mortar, voids and stone involved in the core of a stone wall. In some cases it was possible to define a build-up for the walls involved in the in-situ monitoring as these walls had been the subject of recent survey or building work but in the absence of specific information, in order to compare the in-situ U-value results with calculated figures, it was occasionally necessary to approximate data.

BuildDesk is a U-value calculating software package widely used throughout the UK building industry. BuildDesk calculations are based on the standards set out in the document BR 443 'Conventions for U-value calculations' which underpin building regulation energy conservation legislation and are also the basis of various energy assessment procedures. As a market leader with a robust methodology and good usability, BuildDesk was deemed an appropriate choice of software for the U-value comparison calculations.

The element to be calculated was first defined, in this instance, an external wall with the default internal and external resistances (0.13 W/m²K and 0.04 W/m²K respectively). The various layers involved in the wall build-up were identified and added incrementally, the width of the particular material was entered and a resistance figure for each layer calculated from its thermal conductivity value. The information used in the calculation is sourced either from catalogues of materials that are pre-loaded within the BuildDesk software or alternatively can be entered directly by the user. Some materials used in traditional constructions are not to be found in the catalogues and here it was necessary to create new materials and enter thermal conductivity information for them from a variety of sources. However, there is in general a dearth of
thermal conductivity data for traditional building materials and this contributes to additional uncertainty within calculation processes.

As has been previously stated some traditional constructions can not readily be broken down into separate layers and on some occasions, within the software, it was deemed appropriate to treat these materials as 'inhomogeneous layers' with percentage proportions given for the combined materials. For example, a lath and plaster finish was treated as two layers; a 10mm inhomogeneous layer of 83.33% wood and 16.87% lime and sand plaster and a further layer of 15mm plaster making an overall depth of 25mm. During the early part (2009-10) of this research a further anomaly was encountered when trying to calculate stone walls. The software allowed a separate mortar fraction to be entered when calculating a brick or block wall but this was not possible when specifying stone within the build-up. In effect this meant that the wall was being calculated as if it was a solid slab of stone, without taking into account the thermal effect of the mortar. Partly as a result of this research work this anomaly within the calculating software has been corrected and it is now possible to define a block size and mortar fraction for a stone wall.

The BuildDesk U-value calculations for the comparative part of the 2009 -10 research data set were carried out with the help of Cameron Scott of Timber Design Ltd. Further information about values and assumptions made in the calculating process are given in Tables 1 and 2.
4. Results and Discussion

The range of walls monitored was deliberately diverse and included historic walls which had been subject to recent repair and refurbishment and a few modern examples. Specific wall types consisted of mass masonry walls of granite, slate, limestone, gritstone, malmstone and flint (both as ashlar block and rubble constructions) and a section of concrete block repair work. Unfired earth-based materials were monitored either as mass wall constructions in the form of cob walls (earth and chalk) or as part of infilling material for a timber-frame as straw/clay and wattle and daub. Other timber-frame infill materials included brick and more modern infills such as hemcrete, mineral wool, sheep's wool, woodfibre board and reedboard, sometimes layered with the earlier brick material. Measurements were also taken on the timber studs of the frame itself. Almost all of the walls surveyed were solid walls of traditional (i.e. permeable) construction although a few of these walls contained cavities or air gaps formed by the addition of a lining to the interior wall face set off from the wall by battens. Five of these linings were historical consisting of either lime plaster on laths or timber paneling, others were of more recent origin when cavities had been created by fitting an additional layer to the existing wall often as part of an insulation strategy, such as the examples of stone and brick walls drylined with plasterboard, polystyrene sheets or sheep's wool. Most of the walls studied had an internal finish of lime and/or gypsum plaster and either no external finish or an external lime render. Four newly built walls, of hemp/lime, straw bale, straw/clay and a polyisocyanurate 'sandwich' were also examined, two within timber-frame structures. These timber-frame constructions also incorporated cavities in the form of a ventilated air gap behind a weatherboard external finish.

In order to structure the findings and allow some basis for comparison, the sample group has been broken down into two basic wall 'types', homogeneous and heterogeneous. Homogeneous indicates that the wall is
solid and (ignoring internal and external finishes) made predominantly from a single material e.g. limestone. Heterogeneous refers to a wall where the body of the wall consists of more than one material and/or incorporates some form of air gap within its build up. These two groupings can then, to a limited extent, be further ordered in terms of their relative densities, that is subdivided between heavy weight walls made of high density materials and light weight walls of lower densities.

Tables 1 and 2 (p. 14.) detail each wall studied; its location, material build-up and the two U-value figures derived for it, one in situ, the other a BuildDesk calculated value. Also given in these tables are details concerning thermal conductivities and their sources, as well as other assumptions used in the U-value calculation.

There is some uncertainty about a few elements of the build up and wall thickness data within the study. Burrow Farm near Taunton is a multi-period farmhouse built principally of rendered stone and cob which has been the subject of much alteration and repair over the years. A south-west facing bedroom wall (4c) was described as being a wall consisting of a concrete block repair but there was no absolute certainty about this and the in situ value recorded is similar to one achieved for a cob wall of the same width at the same location. On the opposing wall of the same room, a large cavity had been formed by a primitive dry-lining using deep studs placed against the interior face of a thin exterior cob wall to support a lath and lime plaster internal finish. Here it was not possible to say for certain the exact width of the cavity and this figure has been estimated from photographs of the exposed wall head taken during repair work. Abbeyforegate in Shrewsbury is an early nineteenth century three storey house, its was difficult to determine the exact dimensions of the gable end wall of the second floor bedroom, created from a previous partition wall when part of the terrace was demolished, therefore these dimensions have been extrapolated from other wall dimensions found within the house.
### 4.1 Results Tables

#### Table 1. Homogeneous Walls.

<table>
<thead>
<tr>
<th>Location</th>
<th>Material</th>
<th>Description</th>
<th>Density</th>
<th>In-situ</th>
<th>Tearing</th>
<th>BS/EN 12524</th>
<th>Timber Design</th>
<th>Build Desk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stockbridge, Hampshire</td>
<td>Brickwork</td>
<td>Internal wall</td>
<td>1800 kg/m³</td>
<td>0.70</td>
<td>0.65</td>
<td>0.77</td>
<td>0.91</td>
<td>1.00</td>
</tr>
<tr>
<td>Stockbridge, Hampshire</td>
<td>Stone</td>
<td>Inner wall</td>
<td>2500 kg/m³</td>
<td>0.75</td>
<td>0.65</td>
<td>0.77</td>
<td>0.91</td>
<td>1.00</td>
</tr>
<tr>
<td>Stockbridge, Hampshire</td>
<td>Limestone</td>
<td>External wall</td>
<td>1800 kg/m³</td>
<td>0.70</td>
<td>0.65</td>
<td>0.77</td>
<td>0.91</td>
<td>1.00</td>
</tr>
<tr>
<td>Stockbridge, Hampshire</td>
<td>Limestone</td>
<td>Internal wall</td>
<td>2500 kg/m³</td>
<td>0.75</td>
<td>0.65</td>
<td>0.77</td>
<td>0.91</td>
<td>1.00</td>
</tr>
<tr>
<td>Stockbridge, Hampshire</td>
<td>Granite</td>
<td>External wall</td>
<td>2500 kg/m³</td>
<td>0.75</td>
<td>0.65</td>
<td>0.77</td>
<td>0.91</td>
<td>1.00</td>
</tr>
<tr>
<td>Stockbridge, Hampshire</td>
<td>Granite</td>
<td>Internal wall</td>
<td>2500 kg/m³</td>
<td>0.75</td>
<td>0.65</td>
<td>0.77</td>
<td>0.91</td>
<td>1.00</td>
</tr>
<tr>
<td>Stockbridge, Hampshire</td>
<td>Limestone</td>
<td>Internal wall</td>
<td>2500 kg/m³</td>
<td>0.75</td>
<td>0.65</td>
<td>0.77</td>
<td>0.91</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Formation of dense walls is a key aspect of sustainable building practices, ensuring both structural integrity and thermal efficiency. The use of high-density materials like limestone and granite not only enhances durability but also contributes to the overall energy efficiency of the building, aligning with modern eco-friendly architecture goals.
## Table 1. Homogeneous Walls cont.

<table>
<thead>
<tr>
<th>Location</th>
<th>Use</th>
<th>Wall build up</th>
<th>Thickness</th>
<th>Density</th>
<th>Thermal conductivity</th>
<th>U-value</th>
<th>U-value used</th>
<th>Calculation Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>North wall grd floor Sitting Rm east end</td>
<td>render</td>
<td>Timber stud</td>
<td>100</td>
<td>100</td>
<td>0.06</td>
<td>0.76</td>
<td>BS EN 12524</td>
<td>BS/EN 12524</td>
</tr>
<tr>
<td>South wall 1st fl Bedroom</td>
<td>render</td>
<td>Lint lath &amp; plaster</td>
<td>350</td>
<td>350</td>
<td>0.15</td>
<td>0.76</td>
<td>BS/EN 12524</td>
<td>BS/EN 12524</td>
</tr>
<tr>
<td>Clapham, London</td>
<td>South wall - west</td>
<td>Timber stud</td>
<td>90</td>
<td>90</td>
<td>0.06</td>
<td>0.76</td>
<td>BS/EN 12524</td>
<td>BS/EN 12524</td>
</tr>
<tr>
<td>Hottest</td>
<td>East Wall 1st Fl Bedroom - high</td>
<td>Lime plaster</td>
<td>100</td>
<td>100</td>
<td>0.15</td>
<td>0.76</td>
<td>BS/EN 12524</td>
<td>BS/EN 12524</td>
</tr>
</tbody>
</table>

## Table 2. Heterogeneous Walls.

<table>
<thead>
<tr>
<th>Location</th>
<th>Use</th>
<th>Wall build up</th>
<th>Thickness</th>
<th>Density</th>
<th>Thermal conductivity</th>
<th>U-value</th>
<th>U-value used</th>
<th>Calculation Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hottest</td>
<td>South wall - south</td>
<td>Lime plaster</td>
<td>100</td>
<td>100</td>
<td>0.15</td>
<td>0.76</td>
<td>BS/EN 12524</td>
<td>BS/EN 12524</td>
</tr>
<tr>
<td>Hottest</td>
<td>South wall - west</td>
<td>Lime plaster</td>
<td>100</td>
<td>100</td>
<td>0.15</td>
<td>0.76</td>
<td>BS/EN 12524</td>
<td>BS/EN 12524</td>
</tr>
<tr>
<td>Childrey, Oxfordshire</td>
<td>Bedroom - north</td>
<td>Lime plaster</td>
<td>100</td>
<td>100</td>
<td>0.15</td>
<td>0.76</td>
<td>BS/EN 12524</td>
<td>BS/EN 12524</td>
</tr>
<tr>
<td>Hottest</td>
<td>South wall - east</td>
<td>Lime plaster</td>
<td>100</td>
<td>100</td>
<td>0.15</td>
<td>0.76</td>
<td>BS/EN 12524</td>
<td>BS/EN 12524</td>
</tr>
</tbody>
</table>

Note: BS/EN 12524 is the reference to the British Standard for the calculation of U-values. BS EN 12524 is the equivalent European standard. BS 6946:1999 is the British Standard for the calculation of U-values.
<table>
<thead>
<tr>
<th>Location</th>
<th>Principal component</th>
<th>Wall Build-Up Material</th>
<th>Thickness</th>
<th>Surface Similarity</th>
<th>Calculated U-value</th>
<th>X-value used</th>
<th>X-value source</th>
<th>Calculation Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bury St Edmunds, Suffolk</td>
<td>Brick &amp; Woodfibre</td>
<td>Insulating render 90</td>
<td>200</td>
<td>Insulated</td>
<td>1.47</td>
<td>BS EN 12524</td>
<td>Manufacturers</td>
<td></td>
</tr>
<tr>
<td>South wall &amp; floor, Sitting Room</td>
<td>Brick &amp; Woodfibre</td>
<td>Insulating render 90</td>
<td>200</td>
<td>Insulated</td>
<td>1.34</td>
<td>BS EN 12524</td>
<td>Manufacturers</td>
<td></td>
</tr>
<tr>
<td>South wall &amp; floor, Office</td>
<td>Woodfibre</td>
<td>Insulating render 90</td>
<td>200</td>
<td>Insulated</td>
<td>1.29</td>
<td>BS EN 12524</td>
<td>Manufacturers</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- X-values used are based on manufacturers' data and specifications.
- U-values are calculated using standard methods and current British standards (BS/EN 12524).
- Surface similarity considerations are taken into account for accurate U-value calculations.

**Sources:**
- BS/EN 12524: European Standard for building energy performance.
- BS EN ISO 6946: European Standard for building energy performance.
- Timber Design: BS/EN 12524 manufacturers' data.

**Material Specifications:**
- Insulating render: Various densities and compositions as per manufacturers' data.
- Woodfibre: Insulation material typically used for energy-efficient walls.
- Brick: Various types and thicknesses, with different insulating render applied.

**Additional Details:**
- The U-values are indicative of the performance of the wall constructions and are crucial for energy-efficient building designs.
- The surface similarity factor accounts for the thermal properties of the external surfaces, affecting overall U-value calculations.
4.2 Uncertainties

There are three *in situ* U-value results which are widely divergent from those measured on similar materials in the study. The U-value of 0.76 W/m²K for a 615mm thick granite wall recorded at Higher Uppacott (5c) seems extremely low. Conversely, the value 2.26 W/m²K for a 510mm cob wall recorded at Oxenholm Farm (7b) seems high and at this location there is the possibility of thermal bridging affecting the final result due to poor sensor placement in close proximity to an intermediate floor (Fig. 5). Example 9b from a house in Farringdon in Oxfordshire gives a figure of 1.05 W/m²K for a limestone rubble wall. When plotted against similar wall types this figure does not conform to an overall trend and therefore may possibly be treated as an outlier or is the result of a high proportion of mortar and voids within that particular wall construction (Fig. 6).

Figure 5. Cob sensor placement at Oxenholm Farm (7b).
4.3 In situ results - Homogeneous Walls

Given the wide variety of wall constructions and the range of wall thicknesses, no simple cross comparisons can be made between material types and thermal performance. However, the results do reveal some interesting observations regarding the relative performance of different materials and constructions.

4.3.1 Heavyweight Homogeneous Walls

![Graph showing U-values/Wall Thickness 2009-12 - heavy weight homogeneous walls](image)

Figure 6. In situ U-values for heavyweight homogeneous walls 2012.

In general, in homogenous walls built of heavyweight materials e.g. stone/brick/cob, U-values seem to decline in relation to wall thickness (Fig. 6). From Figure 6 it may also be possible to identify certain 'ranges' of performance for particular materials.
Stone Walls

Figure 7. 2009 - 2011 Limestone in situ U-values.

For example, if 9b Farringdon (1.05 W/m²K @ 480mm) is treated as an outlier, it is possible to identify a range of values for limestone walls of similar construction. This trend was indicated in the data gathered from the first year's U-value survey (2009-10) and has been strengthened by the addition of more data from the 2010-11 monitoring work (Fig. 7).

Similarly, if 5c Higher Uppacott (0.76 W/m²K @ 625 mm) is treated as an outlier another gradient can be plotted for the results of granite walls. As might be expected for a denser material, this 'range' sits just above the limestone gradient. However, the gradient for granite walls is less satisfactory than the range identified for limestone walls as the points of correspondence with the trend line are fewer and more divergent, therefore, more data for granite walls is required to give more confidence in a performance range for this material (Fig. 8).
Previously it had been thought that the figure for the cob wall from Oxenholm (7b - 2.26 W/m²K @ 510mm) was questionable due to possible sensor placement error (see page 17.). Subsequently, more in situ U-value data has
been gathered for cob walls, both earth and chalk, and this would seem to confirm the 7b Oxenholm U-value as erroneous (Fig. 9).

However, the extra data from the 2010-11 survey for walls between 450-500mm shows a cluster around a U-value of 1.00 W/m²K and seems to confirm that a section of wall which had been questionably described as a concrete block repair within a cob walled farmhouse, 4c Burrow Farm, is actually likely to be a cob construction. The other cob U-value which is also around the 1.00 W/m²K mark (1.05 W/m²K, 23a, The Firs, Riddlecombe) is unusual as this wall is considerably thicker, being 680mm wide, than the other walls surveyed. At this property moisture was found within the body of the wall and it may be that this U-value is the product of increased thermal conductivity due to the presence of water within the wall (see SPAB Research Report 2).

The U-values plotted for brick walls shown in Figure 9 once again demonstrate the relationship between increased wall thickness and declining U-values where the highest U-value, 2.48 W/m²K is actually for a brick infill panel within a timber-frame, effectively a wall half a brick thick (1c, Blewbury). Conversely, lower U-values are achieved from a group of much thicker walls measured at New Court, Trinity College, Cambridge. These walls are in total 600mm thick (consisting of 22.5" brick walls with a variety of internal and external finishes) and measured U-values of between 0.64 - 0.78 W/m²K (26a - 26e). With the addition of these measurements from the walls at Trinity College it may be possible to see a range for brick walls emerging (Fig. 10).
The measurements which diverge from the range of U-values described by the trendline plotted in Figure 10 can perhaps be explained by variations in brick density due to methods of manufacture and the raw materials used (both of which are related to age of brick and geographical location) or anomalies within the wall build ups themselves. The two U-values which sit below the trendline (12a, Spital Square, 0.76 W/m²K & 29a Rectory Grove, 0.88 W/m²) are both taken from buildings in London of a similar age and were noted to consist of quite soft bricks which suggests material of lower density and thus potentially greater thermal resistivity. However, two of the U-values which sit above the trendline are from the gable end wall in Abbeyforegate Street, Shrewsbury of much thinner section, 248mm (20c & 20d - 2.13 W/m²K & 2.33 W/m²K). As has been previously mentioned (p. 13.) there is some uncertainty as to the exact dimensions of this gable end wall as well as its build-up as it was formed from what had previously been a partition wall when a section of the terrace was demolished to make way for a by-pass during the 1970s. Therefore given a thinner wall section of around 110 - 120mm (a snapped header for example) the U-values recorded for this wall would straddle the trendline as it is currently plotted. However, as with the previous trend graphs
for stone walls, more data is required to provide real confidence in the ranges described for the different wall materials under examination.

There is as yet very limited in situ U-value data for flint and sandstone wall materials within this study. The three U-values for sandstones, 1.45 W/m²K for Malmstone (11b, Huckers Cottage), 1.63 & 1.62 W/m²K for Millstone Grit (21a & 21b, White House Farm) invert the normal trend as the lower value is for a thinner wall. This reflects the diversity of sandstone materials in general and their widely varying densities which makes establishing a range for this material type, even with increased sample numbers, problematic.

**4.3.2 Lightweight Homogeneous Walls**

![U-values/Wall Thickness - lightweight homogeneous walls 2012](image)

Figure 11. In situ U-values for lightweight homogeneous walls 2012.

The other walls contained within the 'homogeneous' grouping could be categorised as 'lightweight' walls constructed of less dense materials some of which may not be typical of traditional walls per se (Fig. 11). These materials are in some cases incorporated as panel infills within timber frame structures,
such as the straw/clay example and some are of modern origin, such as the polyisocyanurate and mineral wool walls. There are also two U-values taken from the timber studs of the timber-frames themselves. In general less dense materials incorporate more trapped air and therefore have an insulative effect reducing heat loss. Because of this the relationship of increased wall thickness and decreased U-values found amongst heavyweight walls is not replicated within the lightweight walls in the study. The lowest U-values here come from straw/clay (11b, Huckers Cottage, 0.28 W/m²K @ 398mm), polyisocyanurate (2a, Blewbury, 0.14 W/m²K @ 168mm) infills and a Straw Bale wall (16a, The Walled Garden, 0.16 W/m²K @ 435mm) across a range of wall thickness. Other U-values measured between 0.50 - 1.00 W/m²K are for mineral wool (24c & 24d, Ashburton, 0.46 & 0.35 W/m²K) and hemcrete (1g, Blewbury, 0.87 W/m²K) both used as infills within timber-frames and also two U-values of 0.40 W/m²K and 0.47 W/m²K for a solid wall of hemp/lime measured at Haverhill. All these U-values are relatively low in relation to the heavier weight walls, as are the figures for timber studs at Blewbury, 1.66 & 1.49 W/m²K (1d & 1f) and are a function of the thinness of these walls in relation to the reduced density of their construction material.

4.4 In situ results - Heterogeneous Walls

The identification of walls as 'heavyweight' or 'lightweight' becomes more problematic when discussing the heterogeneous walls sampled within this study. This is particularly the case when secondary lightweight additions have been made to existing heavyweight walls to reduce heat loss thus changing the nature of these walls. Perhaps unsurprisingly, given its preeminence as a building material within the UK, there are a substantial number of brick walls within the study, as well as a few stone walls, which feature an additional layer or layers of material, most of which also incorporate some sort of a cavity or air gap. Four of these heterogeneous brick walls with cavities are historic; the wainscot paneled wall at Spital Square and three of the walls measured at New Court, Trinity College which have a lath and plaster lining.
similar lining was found on a thin cob wall at Burrow Farm. Other heterogeneous walls are the result of modern interventions made in order to reduce heat loss through the walls. There are also three examples of stone walls which have both been 'drylined', one at Higher Uppacott which uses a lining for damp-proofing, another at Bradford on Avon which has a plasterboard drylining addition and a test wall installed as part of the SPAB Building Performance Survey on a granite wall at Drewsteignton, Devon. The chart below (Fig. 12) shows the range of brick and stone walls with secondary additions and cavities.

![U-values for heterogeneous walls with air gaps](image)

**Figure 12.** *In situ* U-values for lightweight heterogeneous walls with air gaps 2012.

The historic examples of brick wall linings (timber paneling at Spital Square, 12b = 0.71 W/m²K and lath and plaster at New Court, 26f = 0.59 W/m²K & 26g = W/m²K) all measure fractionally lower U-values than un-lined equivalent walls at the same locations and in general represent some of the lower U-values given in Figure 12. By referring to the U-value ranges plotted for Limestone and Granite walls shown in Figure 8 it is possible to see that the addition of a plasterboard drylining for the limestone wall at Bradford on Avon

(8b, 196mm = 0.97 W/m²K) provides a U-value well below the figure predicted for a wall of equivalent thickness without a drylining, approximately 1.9 W/mK. However the same cannot be said for the Granite example from Higher Uppacott where the U-value of 1.07 W/m²K recorded for a 803mm wall seems quite high when matched against the trendline plotted for Granite walls in Figure 8.

Overall, variations in the thicknesses of the air gaps found for these walls and crucially whether the air present within them can really be said to be 'still' or otherwise will have a significant influence on the thermal conductivity of the wall as a whole. As will the thickness of any material that is incorporated within the build up specifically for the purposes of insulating the wall. Therefore it is difficult to make meaningful comparisons for this particular sub-grouping of walls.

There are some walls which have received an additional treatment without the incorporation of an air gap or cavity where brick walls have been subject to either external or internal insulation using expanded polystyrene, insulating lime render, reedboard, woodfibre board or hemcrete. Some of the walls that do not incorporate any form of air gap combine two materials as panel infills for timber-frames; one being the traditional treatment of wattle and daub and others more modern interventions such as the addition of reedboard or hemcrete to existing brick and timber stud work or another example where the original panel infill material has been replaced with sheep's wools combined with a woodfibre board (Fig. 12).
Although most of the walls shown in Figure 13 feature some form of refurbishment the exception to this are the two measurements for Wattle and Daub infill panels (1e & 3a) which inevitably record quite high U-values (2.03 and 1.69 W/m²K) being of thin wall section and consisting principally of a heavyweight material (clay/daub). The two walls with the lowest U-values either comprise of entirely lightweight and therefore highly insulating materials (13a & 13b, 0.35 and 0.19 W/m²K) or are a combination of a thick granite wall 580mm and a substantial addition of a lightweight insulating material 100mm PIR (25c = 0.16 W/m²K). Once again, however, due to the range of materials involved in the build-ups of these walls and the relative proportions of heavy and lightweight elements comparison between individual walls becomes largely irrelevant. Perhaps of more significance is the consideration of refurbished walls in general and a discussion of these walls is included in the next section of this report.
4.5 *In situ* Discussion

It is not really possible to make precise comparisons between materials and performance due to the diversity of wall thicknesses and variety of treatments featured within the survey. A few measurements have, however, been taken both 'before' and 'after' the addition of insulating layers to a particular wall as part of the SPAB Building Performance Survey (see Research Report 2). Furthermore, this particular study is concerned with the measurement of heat loss through walls and the walls are quantified solely in these terms. There are, however, other factors that effect the performance and behaviour of solid walls, in particular that of moisture and no account of adverse moisture behaviour is made within this analysis either within 'original' or refurbished walls (see, once more, the SPAB Research Report 2 for an analysis that takes account of this). Therefore, where some form of comparison is attempted these limitations should be bourn in mind.

![U-values for homogeneous & heterogeneous walls](image)

Figure 14. *In situ* U-values for homogeneous and heterogeneous walls 2012.

It is perhaps not surprising that the walls in this study that fall within or under the threshold value of 0.30 W/m²K from the current Building Regulations *Approved Document L1B Conservation of Fuel and Power* are all recent constructions or refurbishments (Fig. 14). Disregarding wall thickness, the lowest U-value figure achieved overall was from a wall made principally of...
polyisocyanurate board 0.14 W/m$^2$K (2a) closely matched by a straw bale construction 0.16 (16a). Other walls with very low U-values were a new timber-frame construction with Straw/Clay infill panels, 0.28 W/m$^2$K (11a) and three refurbished walls; a granite wall insulated with polyisocyanurate (PIR) board, 0.19 W/m$^2$K (25c) a brick wall insulated with sheep's wool, 0.30 W/m$^2$K (14a) and sheep's wool as a timber-frame infill material combined with woodfibre board, 0.19 W/m$^2$K (13b).

4.5.1 Refurbished Walls

More meaningful perhaps is an analysis of refurbished walls, that is to say where the interventions have taken place that have resulted in heterogeneous walls, with or without a cavity or air gap, specifically undertaken in order to reduce heat loss through these walls (Fig. 15.).

![Refurbished Solid Walls 2012](image)

Figure 15. *In situ* U-values for refurbished walls 2012.

In general the same trend of U-values decreasing with wall thickness can be observed, the exception being perhaps the Cob wall at Riddlecombe which despite its thickness would seem to retain a relatively high U-value (23c =
0.72 W/m²K). This is the wall that has been observed to be wet and indeed the pre and post-refurbishment U-values for this wall show little change in measured heat loss. It is possible that the damp condition of the wall is increasing its thermal conductivity or that the insulation provided by the external render, which is only 40mm thick, is not having a significant effect on the thermal behaviour of the wall, this is discussed in more detail in SPAB Research Report 2. Similarly, albeit for a much thinner wall, the brick wall in Shrewsbury, 20b also treated with an external render would seem to record a U-value (2.09 W/m²K) that sits above the general trend for refurbished walls. The chart shown in Figure 15 contains walls that incorporate both lightweight and heavyweight materials in different proportions therefore there can be a considerable range of U-values seen for walls of similar thicknesses. For example, the 225mm wall from Tyland Farm, which has U-values of 0.19 and 0.35 W/m²K (13a & 13b) consists entirely of lightweight insulating materials used as new infill panels within an historic timber-frame. The 273mm wall recorded at Cholsey consists largely of brick (230mm) and is therefore predominantly a heavyweight wall with the thin addition of lightweight reedboard for insulation, it subsequently provided U-values of 1.06 and 1.16 W/m²K. Therefore no simple equivalences should be drawn between wall thickness and potential refurbished wall U-values as each circumstance will determine the possibilities of what materials can be deployed to best effect taking into account numerous factors including historic fabric, loss of interior room space and general buildability.

4.5.2 Timber-frames.

It is perhaps also useful to look at performance and treatments for particular types of building. Measurements taken within the timber-framed houses in Blewbury, Oxfordshire show poor thermal performance from traditional infill materials: 2.48 W/m²K for 102.5mm brick (1c); and a marginally improved 2.03 W/m²K for 103mm wattle and daub (1e). As is to be expected, the timber stud element of the frame achieves a better performance with a figure of 1.49
W/m²K for a 100mm stud (1f). These U-values are primarily a function of the thinness of the walls (U-values tend to decrease with increased wall thickness) and the relative densities of the materials involved. Mass infill materials, hemcrete and straw/clay, which can be used as infill in timber frame buildings, perform better than the traditional materials; hemcrete with a value of 0.87 W/m²K at 150mm (1g) and Straw/Clay at 0.28 W/m²K @ 300mm (11a). However these materials are used in greater proportions to form thicker walls and are more lightweight (less dense) than traditional infill materials. Other materials that exhibit low U-values within panel infills are modern insulation materials and are extremely lightweight; sheep's wool and woodfibre board, 0.19 & 0.35 W/m²K (13a & 13b), polyisocyanurate (PIR) board, 0.14 W/m²K (2a) and mineral wool, 0.46 and 0.35 W/m²K (24c & 24d) (Fig. 16).

Figure 16. In situ U-values for timber-frame infill panels 2011.

4.5.3 Refurbished Timber Frame Walls.

A number of walls within the study group had been subject to some form of 'refurbishment' motivated by concerns of improving the wall's thermal
performance. The use of a secondary layer, such as hemcrete or reedboard, in combination with a timber-frame infill of brick or the timber of the frame itself, improves thermal performance. A brick panel at the house in Blewbury recorded an *in situ* U-value of 2.48 W/m²K (1c) whilst a similar panel at the same location which had been covered with 20mm of reedboard provided a U-value of 1.12 W/m²K (1a). With a 100mm timber stud, 20mm of reedboard achieve a figure of 0.57 W/m²K (1b) whilst a similar uninsulated stud measured 1.66 W/m²K (it should be remembered that these U-values have been measured at different locations with the same building and therefore are not directly comparable. Fig. 17).

![U-values for refurbished timber-frame walls](image)

Figure 17. *In situ* U-values for refurbished timber-frame walls 2011.

### 4.6 In situ Average U-values

An average *in situ* U-value of 1.31 W/m²K was calculated for all the 39 heavyweight homogeneous walls in the study, that is to say walls that could best be defined as 'traditional' pre 1919 solid walls made of permeable materials (e.g. solid walls of stone, brick or cob). This U-value sits below the lower end of the range of U-values for unfilled cavity walls of 1.4 - 1.9 W/m²K.
identified by Hens et al\textsuperscript{5} in a study of brick cavity walls. A further average \textit{in situ} U-value of 1.36 W/m\textsuperscript{2}K was calculated solely for the 32 solid stone or brick walls in the study or 1.42 W/m\textsuperscript{2}K for the 21 stone walls and 1.24 W/m\textsuperscript{2}K for the 11 solid brick walls. These figures are lower than the U-values given for stone (2.4 & 2.1 W/m\textsuperscript{2}K) and brick walls (2.1 W/m\textsuperscript{2}K) in Table S6: \textit{Wall U-values for England and Wales} in Appendix S of the Standard Assessment Procedure (SAP) 2009 document used in the calculation of SAP ratings for existing buildings (RdSAP)\textsuperscript{6}.

4.7 BuildDesk/BR 443 Comparison Results

![All U-value results 2009-2012 - BR 443/\textit{In-situ} U-value comparison](image)

Figure 18. BuildDesk/\emph{in situ} U-value comparison 2012.

When comparing the \textit{in situ} U-value figures for the sample walls with the figures calculated for the same walls using the U-value calculating software BuildDesk v3.4, a significant discrepancy was found. In 77\% of cases the BuildDesk software overestimated the U-value in relation to the \textit{in-situ} figure (Fig. 18).
U-values calculated using BuildDesk are mostly widely divergent from the *in situ* figures when calculating solid stone walls, with only two of the sixteen sample walls showing a close correlation (Fig. 19).

Figure 19. BuildDesk/*in situ* U-value comparison discrepancies for stone walls 2011.

Figure 20. BuildDesk/*in situ* U-value correspondence 2012.
Eleven walls in the survey returned calculated U-values that either matched (in one case) or had close correspondence, i.e. were within 0.05 W/m²K of the U-value that had been measured for the same wall (Fig. 20). Some close correspondences between BuildDesk BR 443 figures and in situ U-values occur when calculating walls consisting of quite simple build-ups. Because these walls are simple to define when they are accompanied by accurate thermal conductivity value for the single principal construction material the result can be a U-value calculation which matches one measured from the same wall. Good correspondence is also achieved for some refurbished walls as, even though in these cases the wall build-ups might be quite convoluted, here the insulating material, as a later addition with a specific measured thermal conductivity, is a known quantity. The same can also be said for some walls that, although they may not specifically include insulating materials the presence of a cavity or air gap of known dimensions that successfully traps air has an insulative effect. In both instances, once again, this allows the wall to be well defined for the purposes of carrying out a U-value calculation and this accurate definition of the principal thermal characteristics of the wall can result in a U-value which closely matches its measured equivalent. Further details of these corresponding walls and their build ups are given in Table 3.
As can be seen from Figure 20 and Table 3 the ability to provide an accurate definition of a wall element ensures a better correspondence between measured \textit{in situ} and calculated U-values. This is often in contrast to many
existing stone walls where, although the overall thickness of the element may be known, the different proportions of materials involved in its construction, including mortar, voids and other non visible characteristics, as well as the random nature of their amalgamation often defy accurate description. The calculation of U-values for traditional walls is further problematised by the lack of basecase thermal conductivity data for most UK vernacular building materials. Furthermore, due to the diverse geology of these Islands such data as does exist may potentially be very location specific. When considered en masse these factors can mean that in some instances there can be significant uncertainty with regard to a calculated U-value for a traditional wall.
5. Conclusions

To date (Nov 2012) this study has looked at the in situ U-values of 77 walls built mainly of traditional materials and construction. It has then compared these figures with U-values calculated using the U-value calculating software, BuildDesk v3.4. based on the standard BR 443 Conventions for U-value Calculations

5.1 In situ U-values

The study suggests that it maybe possible to begin to build-up a general trend of U-values for walls of traditional construction. A range of U-values for Limestone and Brick walls is developing, however, more data is needed to reinforce the figures already established and provide greater certainty. Likewise, more data is needed in order to reinforce and provide greater certainty for other material types featured within the study, such as granite and cob.

Some materials, often found in thinner wall sections, record high U-values indicating greater heat loss. A secondary layer within a wall which either traps a layer of still air or includes a lightweight (and thus less thermally conductive) insulating material, or both, can reduce the U-values measured for a refurbished wall (see Drewsteignton 25a, 25b, 25c & Shrewsbury 20a, 20b, 20e & 20f). Or result in U-values that sit below a particular expected range for equivalent walls with no additions, such as the examples of the timber paneled brick wall at Spital Square (12b) or the dry-lined ashlar stone wall in Bradford on Avon (8b). However, this study has only looked at the phenomena of heat loss through these walls quantified as a U-value. There are other factors concerning the overall performance of a wall which should be taken into account during the application of a secondary insulating layer to a traditionally-built wall, principally that of moisture transfer. More research work is required in order to better understand this area and this is, in part, the
The purpose of the SPAB Building Performance Survey (see The SPAB Research Report 2.).

5.2 Measured & calculated U-value comparison

Significant differences between the and the calculated U-value figures were found with the calculating software overestimating the U-value in 77% of cases. In overestimating the U-value BuildDesk/BR 443 underestimates the thermal performance of the walls in the sample group, as indicated by their in situ figures. Furthermore, averages of the in situ U-value data used in this study produced figures that were lower (indicating reduced heat loss) than those shown on U-value Tables used in the assessment of the energy performance of existing dwellings (RdSAP). This is significant as, in part, U-value calculations are the basis for much building energy assessment and building energy legislation and policy. Therefore, this study suggests that conventional industry practices are unable to represent accurately the thermal performance of traditionally built walls. Ultimately, this could have negative consequences for traditional buildings as the poorer calculated U-values may result in misguided priorities with regard to energy saving alterations or suggest the need for interventions which, depending on their manner of execution, maybe deleterious to the fabric and longevity of the building, as well as to human health.

The calculation of U-values for traditionally built stone walls are particularly problematic using the BR 443 calculating method. The reason for this is that features of traditionally built stone walls, including their construction methods and potential ambiguity, are not considered within the BR 443 guidance nor are such things easily incorporated into calculating software programmes such as BuildDesk v3.4. In addition, within the software, there is a paucity of thermal conductivity data for individual stone types. Traditionally built historic buildings tend to be built of the local vernacular material and are therefore of greater geologically diversity than the material types provided for within
standard thermal conductivity tables. There is a need to increase the range of available thermal conductivity data to reflect this diversity.

In general, the reason for the discrepancy between measured in situ and calculated U-values is likely to be the fundamental difficulty of providing an accurate definition for the purposes of making a calculation for a wall made up of inadequately identified materials, of dubious quantities, with doubtful root thermal conductivity values. Inversely, the calculated figure for a U-value tends to correspond more closely with the in situ figure when more information is known about the build-up of that particular wall and a specific thermal conductivity can be given. A correlation between the calculated and in situ figure is also more likely when the wall can be described in discrete, known, layers as this construction method corresponds more closely with modern building methods. Therefore, due to the inherent difficulties of defining the precise material properties of traditionally constructed walls an in situ figure will in many instances be more representative of actual thermal performance than a calculated one.
6. References


