The Performance of Traditional Buildings: the SPAB Building Performance Survey 2011 Interim Findings

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Abstract:
If we are to reduce CO_2 emissions from the housing sector understanding the performance of our existing older buildings is essential. This paper outlines the first stage of the SPAB Building Performance Survey, which is a two year study of seven pre-1919, owner-occupied dwellings of traditional construction; that is solid wall houses built of permeable fabric that have been identified for various energy saving interventions. A number of aspects of energy performance and environmental behaviour have been monitored whilst the dwellings are in an "unimproved" condition and an assessment of their performance following refurbishment will be made during Winter 2011/2012. The study looks at fabric heat loss in the form of measured and calculated U-values of walls; room, surface, sub-surface and interstitail moisture beheaviour; air permeability; indoor air quality and fabric and comfort risks. The initial results are consistent with previous work carried out by the authors on traditional buildings, identifying an overestimation of the degree of thermal transmissivity and lower air permeabilities than orthodoxy. Low levels of comfort were being experienced and all of the dwellings studied had elevated levels of moisture close to ground level in the walls, In all but one properties interstital dewpoint gradients showed no condensation risk over the monitoring period but reveal anomolies and defects with certain wall structures. It must be emphasised this is only an interim study, a complete picture of these dwellings and the effect of measures carried out will only be obtained once the study is complete.

Keywords:
Air permeability, building fabric, moisture, traditional buildings, U-values.

1 Introduction

Estimates vary as to the total number of pre-1919, solid wall properties there are in the UK, it is thought that 4.8 million houses in England alone date from before this period and that overall these buildings could represent up to one quarter or more of our total existing housing stock.[i] Much of our understand of building performance is based on modern, twentieth century construction materials and practices but given the proportion of existing buildings that pre-date 1919 it is important that we understand the behaviour and performance of older buildings. These buildings consist of solid wall structures and use different often vernacular materials and are defined as being "buildings of traditional construction with permeable fabric that both absorbs and readily allows the evaporation of moisture of traditional types of construction" (Office of the Deputy Prime Minister).

During 2009-10 winter season the Society for the Protection of Ancient Buildings (SPAB) undertook a programme of research into the U-values of traditionally built walls. This resulted in a number of alternative measured *in situ* U-values and cast doubt on conventional U-value calculation practices for traditional walls of certain construction (Rye 2010). As a result of this research work it was also acknowledged that heat loss as quantified by U-value assessment is only a part of a wider set of factors that affect the energy profiles of traditional buildings. In order, therefore, to engage more comprehensively with debates concerning energy efficiency and older buildings more wide-ranging forms of building performance assessment are required. The SPAB Building Performance Survey is an attempt to provide such an assessment by looking at a range of factors that may affect the energy performance and environmental behaviour of traditionally built dwellings. The study consists of seven pre-1919 properties identified as being of traditional construction and scheduled for various forms of energy improvement interventions. Whilst in an 'unimproved' condition, various aspects of the energy performance and environmental behaviour in these seven properties were monitored and recorded. It is expected, once refurbishment work has been completed, that these same buildings will once again be measured during the 2011-12 winter season. When complete this study will present an analysis of the various parameters relating to fabric performance and the environment within these individual properties both before and after refurbishment. It is hoped that this approach will enable an assessment of points of difference and change, beneficial or otherwise within the properties as a result of the energy 'improvement' work. Currently, data from the first season’s ('unimproved') monitoring has been collated and subjected to a preliminary analysis. A final report detailing all the research outcomes will be published after completion of the second monitoring cycle and is expected in the summer of 2012.

2 Literature Review

Though it is generally recognised the fabric of a traditional building performs in a fundamentally different manner to modern buildings, the subject is perceived as complex (Halliday 2009) and there is limited existing research on the actual performance of older buildings.

Concerning whole building energy use, in 2008, Jon Wallsgrove, an architect for the Ministry of Justice, carried out research into the energy consumption of a cross-section of buildings in the Justice's estate. Counter to current orthodoxy, Wallsgrove's research found that the oldest buildings in the study built prior to 1900 used the lowest amounts of energy, 197kW/h per sq. m (2008, p. 18). Although it should be noted that this research pertains to public not domestic buildings.

Regarding the subject of fabric heat loss, Dr Paul Baker of Glasgow Caledonian University has carried out fabric heat loss (U-value) assessments on behalf of both Historic Scotland and English Heritage and has established meausred in situ U-values of a variety of traditional stone and brick walls (Baker, 2008). Dr Caroline Rye, on behalf of the SPAB, has made a study of the in situ U-values of a variety of solid walls and compared the meausured results with U-values calculated for the same walls following the standard 'Conventions for U-value Calculation BR 443'. A significant discrepancy was found between the two sets of figures where the heat loss of the walls was overestimated by the BR 443 calculation in 73% of the walls in the study (Rye, 2010).

A similiar discrepancy was also found by Baker for the walls assessed in his research (Baker, 2011). This work as well as other research by Dr Baker for English Heritage has caused doubts about the accuracy of the government's approved energy assessment method, Standard Assessment Procedure (SAP) however, at the time of writing this has yet to be published.

Similiary very little measured in situ research has been conducted concerning the beheaviour of moisture beheaviour in traditional buildings. M Aoki-Kramer, B Hubbs, G Finch and J Teetaret have conducted a project concerning hygrothermal beheaviour in a historical museum in Seattle comparing measured and modelled data, however, the construction details are different to UK buildings and thus of little relevance to UK domestic buildings.

With respect to ventilation, Hubbard (2010) has raised questions over the orthodoxy that older buildings will have higher air permeability levels.

The authors (Rye 2011, Hubbard 2010) have identified the need to study dwellings holistically and the SPAB survey provides that vehicle, considering properties both before and after refurbishment.

3 Research Methodology

In order to offer as complete a picture as possible, data was collected on a variety of parameters, some on a whole dwelling basis and others in relation to a particular room or wall. Testing took place during the 2010/2011 heating season and, where not a discrete test, monitoring in an individual property was carried out over a 14 day period.

A room within each property, usually at ground floor level, was singled out as providing a suitable location for the installation of U-value, air quality and interstitial moisture sensors and loggers. A single exterior wall was identified within this room as the site for the application of heat flux sensors to measure U-values and for the placement of four interstitial temperature and humidity sensors implanted at different depths through the wall structure. Exterior air and surface temperature conditions were monitored in proximity to this wall.

3.1 U-value measurements

The *in situ* measurement of the thermal transmittance coefficient (U-value) of the walls in the study follows the method set out in the standard prEN 12494 (currently under revision). The measurement required a heat flux sensor to be attached to the interior face of a wall and voltage difference information from this to be logged at regular intervals. Simultaneously records were also made of interior and exterior surface and air temperatures for the same period and the results then combined to provide an *in situ* U-value for the wall in question (Rye 2010, Baker 2011). As a continuation of the SPAB U-value survey work standard U-values were also calculated for the walls in the study using the U-value calculating software BuildDesk version 3.4. This software follows the protocol for U-value calculations set out in the document BR 443 *Conventions for U-value calculations* by Anderson (2006) referred to in the Building Regulation Approved Documents Part L: Conservation of Fuel and Power

3.2 Moisture measurements

Moisture within the properties was studied in a number of ways:

- Logging of the interior relative humidity (RH) and temperature of the test room.
- The moisture content of the interior surface and sub-surface of the 'monitoring' wall using resistance and capacitance measurements.
- Interstitial moisture was measured by embedding temperature and relative humidity sensors into the body of the wall to a variety of different depths depending on the overall thickness of the wall (4 sensors). This allowed the moisture and temperature at various points through a cross section of the wall to be monitored using prototype ArchiMetrics gradient loggers. Interior and exterior air and surface temperature measurements were used in combination with the values reported from the interstitial sensors to produce plots of temperature and dew point through the wall sections.

3.3 Indoor Air Quality & Comfort/Fabric Risk

Measurements of CO_2 levels in the 'monitoring' room were logged along with RH and temperature readings at 5 minute intervals, compared to the interior temperature and RH data for each property and plotted to give an indication of comfort as well as potential levels of risk to building fabric. Risk to building fabric (and human health) is indicated by three temperature and humidity gradients, these are based on work by Sedlbauer (2001) and cited by Viitanen et al (2003). The gradients represent different levels of ambient humidity required for the start of biological (mould) growth on different substrates, called the limiting isopeth for mould (LIM). LIM0 represents a substrate consisting of an ideal culture medium above this are substrates that consist of biodegradable materials such as timber - LIM1 and porous materials of stone-like character such as brick - LIM2.

3.4 Air Permeability Testing

This test procedure followed the methodology outlined in ATTMA Technical Standard L1 (2010), with any permanent points of ventilation covered or closed, such as boiler flues, chimneys, extractor fans and trickle vents. The pressure in the building was reduced to 50 Pascal (Pa) below the external air pressure using a blower door. The volume of air flow through the testing fan was then measured and related to the complete internal surface area of the test volume of the building, providing an air permeability result in m^3 of air per hour per m^2 of surface area of the living space ($m^3h^{-1}m^{-2}$ @50 Pa). Using the calculated building volume, the measured air flow was converted to a figure of air changes per hour (ach @50 Pa), which is easier to relate to but has the disadvantage of losing the relationship to the surface area of building fabric.

3.5 Thermographic Survey

Infra-red imaging was use on the dwellings in order to identify the thermal weak points of the structure and zones of infiltration. Where conditions permitted, thermal imaging was carried on both outside and inside the test dwellings, but these were restricted by issues such as a limited temperature differential (a ΔT of greater than 10^oC is ideal), solar gain and the emissivity of the surfaces being observed.
Interior images were taken whilst the air permeability testing was being carried out, exaggerating the air flows through the fabric of the building providing clearer images of areas subject to infiltration.

4 Findings and Discussion

The dwellings studied under the SPAB Building performance Survey are outlined in Table 1.

Table1. The SPAB Building Performance Survey 2011- description of dwellings

Property	Shrewsbury	Skipton	Lower Brailes	Riddle-combe	Ashburton	Drewst-eignton	Devon Consols
Floor area (m^2)	60	210	113	86	332	325	161
Approx. Age	Earlier than 1820	1790	19^{th} Century	19^{th} Century	Early 19^{th} Century	19^{th} Century	Mid 19^{th} Century
Type	End terrace with rear extension.	Detached with 19^{th} and 20^{th} century additions	Mid-terrace with 20^{th} Century extension	Semi-Detached with early and late 20^{th} Century additions	Mid-terrace (at least 3 stages of building)	Detached barn conversion with 1970s extension.	Mid-terrace
Constru-ction of external walls of dwelling	Brick	Sandstone rubble	Hornton stone (no rubble core)	Cob with cement render	Limestone rubble and timber frame	Granite	Clay-slate rubble with slate hung or rendered exterior
Number of occupants	1	5	1	5	5	2	1
Building work in progress?	Yes	Yes	No	No	Yes	No	No

4.1 Fabric Heat Loss (U-values)

When all the *in situ* U-values gathered during the 2011 monitoring season are subject to comparison with their calculated equivalents, a discrepancy between the two sets of figures is found (see Fig. 1).

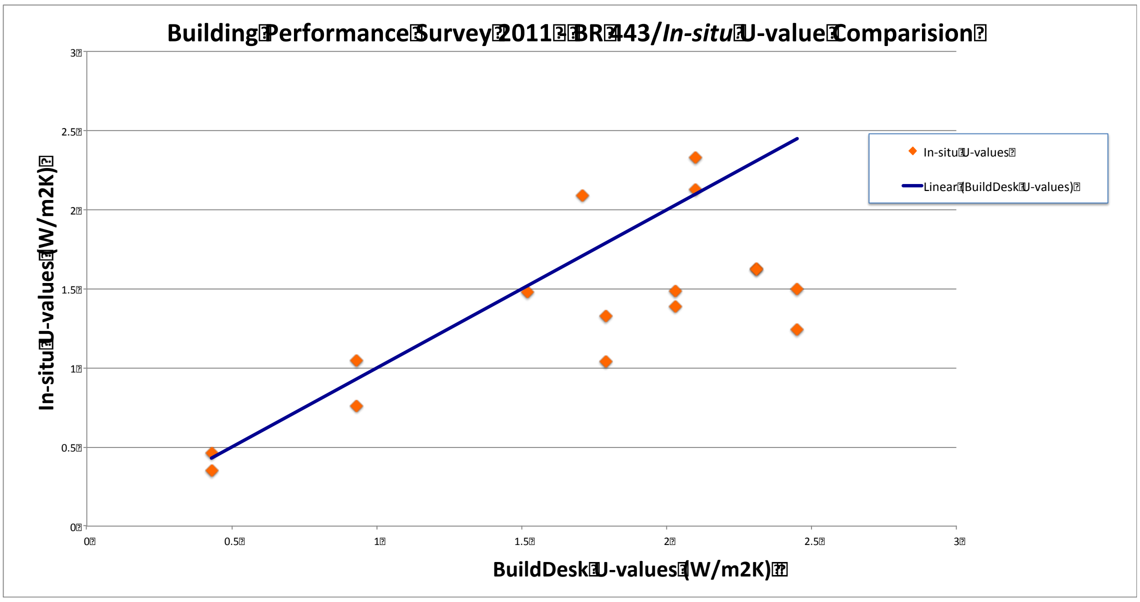

Figure 1. Comparison of in situ and calculated U-values in the SPAB Building Performance Survey 2011.

This discrepancy is of the same order as that discovered during other SPAB U-value research work (Rye 2010), that is to say the calculated U-values overestimate the degree of thermal transmissivity that occurs in these traditionally built walls. In the case of this sample group of 15 *in situ* readings 69% were over estimated by the BR 443 U-value calculation. As has been discussed in the U-value Research Report previously referenced the discrepancy between the two sets of figures is more significant in stone built walls of indeterminate nature and less pronounced in well defined walls. For example, the materials involved in the south-facing wall at Shrewsbury could be clearly identified as brick and the depth of build up was easily defined, this resulted in an *in situ* U-value (1.48 W/m^{2}K) and a calculated U-value (1.33 W/m^{2}K) of close correspondence, within the ±10% margin of error given for the *in situ* measurement method. Likewise, the cob wall at Riddlecombe principally consisted of a single, very homogenous material, therefore given a likely thermal conductivity (K or lambda value) based on material density the U-value calculated (0.93 W/m^{2}K) has reasonable correspondence with the measured *in situ* U-values (1.05 & 0.93 W/m^{2}K). When a wall construction more closely conforms to modern methods of construction, such as the build up of discrete layers found in timber-frame infills and/or utilises modern materials with more robust thermal conductivity data, a good correlation between calculated and *in situ* U-values is found. This was the case for the timber frame at first floor level at Ashburton which returned *in situ* U-values of 0.46 and 0.35 W/m^{2}K for a mineral wool fibre infill between studwork and a calculated U-value of 0.43 W/m^{2}K. Inversely much greater discrepancies between *in situ* and calculated U-values can be found in the stone walls involved in the study; at Skipton (*in situ* 1.62 & 1.63 W/m^{2}K, calculated 2.31 W/m^{2}K) Lower Brailes (*in situ* 1.39 & 1.49 W/m^{2}K, calculated 2.03 W/m^{2}K) and Drewsteignton (*in situ* 1.24 & 1.50 W/m^{2}K, calculated 2.45 W/m^{2}K). The reasons for this are outlined in the *SPAB Research Report 1 - U-value Report* and are likely to originate from the problematic nature of performing a standard calculation for an existing stone wall as this process requires a level of quantification often impossible to achieve for an existing stone wall. Often an operator is unable to provide a full definition of all the types and quantities of materials; stone types, mortar and voids, involved in the wall build up and is obliged to use generalised thermal conductivity information. In addition to this the default mode of the calculating software oversimplifies the wall structure and presumes that the wall is built of solid stone. A standard U-value is a measure of thermal transmissivity in the steady state, where it is presumed that heat flows only in one direction from the interior to the exterior. In actuality, especially with materials of significant density or thermal mass, heat flows can reverse and the storage effect of the mass walls can make a positive contribution to interior temperatures. An *in situ* U-value, as a quasi-dynamic method, is able take into account the contribution made by thermal mass to reducing the overall heat loss of a building element, and this is another reason that the *in situ* U-values show an 'improved' thermal performance for mass stone walls when compared with calculated U-values. It is interesting to note occasions when the U-values in the survey reverse the general trend, that is when the *in situ* values demonstrates greater thermal transmissivity than that predicted by a standard calculation. This occurs in the cob house at Riddlecombe where the *in situ* U-value recorded for the lower part of the wall was 1.05 W/m^2K in contrast to a BR 443 calculation of 0.93 W/m^2K. Although not widely different the poorer performance indicated by the *in situ* U-value may be due to the increased presence of moisture in the lower part of the wall, something that is confirmed by the moisture measurements taken at Riddlecombe. This property is covered with a cement render which is cracked and in poor condition, it is likely that this is allowing water to penetrate the cob wall, particularly at lintel and sill junctions, increasing the moisture content of the material and thus increasing its thermal conductivity. The same inversion of the *in situ*/calculated trend is seen for the brick wall at Shrewsbury which recorded an *in situ* U-value of 1.48 W/m^2K as opposed to a calculated U-value of 1.33 W/m^2K. This discrepancy maybe explained not by high moisture content but by air infiltration through the wall structure itself.

4.2 Moisture Behaviour - Interstitial Moisture

When examining the plots of temperature gradient through the walls in the survey it can be stated that, in general, the steeper the gradient from interior to exterior the greater the insulative effect of the wall. It is also possible to determine the degree of homogeneity of particular wall constructions depending upon the consistency of gradient between the four temperature sensing nodes. Lower Brailes exhibits the same gradient between all 4 sensing nodes suggesting a very homogenous wall built of similar materials and compact construction, as does, perhaps unsurprisingly, the cob wall at Riddlecombe. In contrast the rubble wall construction found at Skipton which includes a variety of stone types, plentiful mortar and a central core/void of loose rubble is clearly identified by the different gradients found between each sensing node and the particularly steep gradient between sensors 2 - 3 which straddled the rubble core. For four properties (Skipton, Riddlecombe, Drewsteignton and Lower Brailes), the temperature and dewpoint gradients follow convention, starting to converge as the temperature drops. However the three other walls at Shrewsbury, Ashburton and Devon Consuls exhibit a different pattern where there is a wide margin of separation between the temperature and dewpoint gradients through the full thickness of the wall. This possibly indicates the effect of influences within the wall structures that reduce the interstitial RH and through reduced humidity reduce the risk of interstitial condensation at any point within the wall. At Shrewsbury and Devon Consols this reduced relative humidity could be as a results of air ingress into and through the wall due to the poor condition of internal or external finishes (interior limewash at Devon Consols and exterior pointing at Shrewsbury). At Ashburton the wide dewpoint/temperature margin is more likely a result of the extreme vapour permeability of the mineral wool infill material rather than air movement.

4.3 Moisture Behaviour - Surface Moisture

When examining the surface moisture pattern across the studied group of properties, consistently there is a reduction in moisture content and stabilization in moisture behaviour over and above the height of 1000mm/1200mm above finished floor level. Variations and increases in moisture content beneath this level probably indicates the effect, via capillary action, of groundwater rising into solid walls built of porous materials without damp-proof courses (rising damp). The effect of this phenomenon on fabric heat loss can be seen in 3 examples - Lower Brailes, Riddlecombe and Drewsteignton (table 2) all exhibited raised moisture levels below the 1000mm/1200mm 'rising damp' level and *in situ* U-values measured above and below this level on these walls indicated greater thermal transmissivity for the lower sections.

Table 2. The effect of raised material moisture content at the base of walls due to capillary action – Lower Brailes, Riddlecombe and Drewsteignton.

PROPERTY	Below 1200mm	Above 1200mm
Lower Brailes	1.49 W/m^2K	1.39 W/m^2K
Riddlecombe	1.05 W/m^2K	0.76 W/m^2K
Drewsteignton	1.50 W/m^2K	1.24 W/m^2K

4.4 Comfort Levels and Fabric Risk

When all seven plots of internal temperature and RH for the survey properties are examined it is possible to see that conditions in the majority of the rooms studied fall outside of the identified comfort zones. Perhaps this is not surprising as all these properties have been identified by their occupants as in some way 'inadequate' particular with regard to their current interior temperatures, hence the need for refurbishment. Most inhabitants describe their refurbishment schemes as 'energy efficient' and are largely motivated by the desire to create more comfortable dwellings with effective and efficient heating systems. With regard to the risks to building fabric, it would appear that as currently configured none of the humidity conditions within the properties surveyed provide the conditions required for mould growth on building fabric, although many temperature and humidity clusters do sit in close proximity to the LIM0 line indicating the possibility of mould growth developing on an 'ideal' medium. Following refurbishment, given improved internal temperatures one might expect these clusters to relocate further away from the LIM0 limiting factor. However this will depend on the exact methods deployed to improve energy efficiency within these seven properties and the results should prove interesting in respect of both overall comfort and fabric risk.

4.5 Air Permeability

Under the testing process, it was possible to depressurize the dwellings to a 50Pa differential in all except one case. The exception was Ashburton and an extrapolated

result has been used for this property. For the whole dwelling, there was a wide range in air permeability results when, from 5.5 $m^3h^{-1}m^2$ @50 Pa at Riddlecombe to 22.6 $m^3h^{-1}m^2$ @50 Pa for Ashburton. With exception of Devon Consols, the other dwellings with high air permeability had an element of the dwelling with refurbishment in progress. Of particular note is Skipton, where a test was carried out on part of the dwelling excluding the area being refurbished and a substantially lower air permeability was achieved (7.7 $m^3h^{-1}m^{-2}$ @50 Pa). The results for Lower Brailes, Riddlecombe and Drewsteignton compare favourably to the limiting air permeability under Approved Document L1A 2010 for new build dwellings(10 $m^3h^{-1}m^2$ @50 Pa) and are lower than orthodoxy (Hubbard 2010). Five of the seven dwellings had a secondary test carried out on part of the building (it should be noted that a limitation of this secondary test is that it was not commonly possible to ensure the doors and windows of the untested part of the building were all open to the outdoors and it should therefore only be treated as an indicator). In one case, a modern extension appears to be more "leaky" than the older part of the building (Drewsteignton), with two further properties, Lower Brailes and Riddlecombe, providing a broadly similar result. In the case of Shrewsbury, the work in progress on the building is likely to have increased the air permeability of the original part of the dwelling, exaggerating the difference between the two stages of the building.
The air changes per hour at 50Pa for the whole dwellings vary between 7.2 ach @50 Pa for Riddlecombe and 20.1 ach @50 Pa for Devon Consols. Translating to air changes per hour at ambient pressure, these will range from under 0.4 ach to 1 ach, of which the latter orthodoxy would consider excessive (Hubbard 2010).

4.6 Thermographic surveys

Some general trends were evident from the thermographic surveys, particularly with respect to ingress in floor / ceiling voids and windows, door surrounds and loft hatches. However, some properties had specific defects - Devon Consols demonstrated a problem of significant ingress through the body of the slate-hung wall and at Lower Brailes, ingress around service and waste pipes was noticeable. Thermal imaging also offered clues to underlying building structure which was not visually evident.

5 Conclusion and Further Research

The key research objective for this project is to compare building performance before and after "improvement", so this interim paper offers an incomplete view, evaluating the dwellings only in their un-improved state. From the studied buildings, the following key observations can be made:

- Generally, there is an overestimation of the degree of thermal transmissivity in the traditionally built walls studied.
- With regard to interstitial moisture, only four properties follow convention, with a convergence of temperature and dewpoint as temp drops through the wall.
- Surface moisture readings show raise moisture levels below the 1.20m 'rising damp' level although these are often only revealed in the sub-surface rather than surface measurements of the wall. In a number of cases this is reflected in a greater thermal tranmissivity for the lower section of wall.

- Conditions in the majority of the rooms studied fall outside of the identified comfort zones.
- Air permeabilities recorded for a number of the dwellings were lower than orthodoxy and a number of common points of ingress were identified.

Though the study is as yet incomplete, it has added to the body of information available in this field and subjects for further research will be identified once the second stage of the project has been completed.

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[i] Data taken from the English House Condition Survey accessed at: http://www.communities.gov.uk/housing/housingresearch/housingsurveys/englishhousecondition/ehcsdatasupporting/ehcsstandardtables/