# THE SPAB RESEARCH REPORT 2.

# The SPAB Building Performance Survey 2011
# Interim Report

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## Foreword

This report details the interim findings of the SPAB's Building Performance Survey, a research project that looks at the performance of a number of traditional buildings both before and after refurbishment. The report is in two parts, the first part is concerned with the project in general, it sets out the background context for the research, the methods and techniques used to carry out the various investigations and then discusses the overall findings of this work thus far. The second part, called Appendix A, is formed of a collection of reports from the individual properties involved in the study.

# TABLE OF CONTENTS

## 1. INTRODUCTION

During 2009-10 winter season the SPAB undertook a programme of research into the U-values of traditionally built walls. This resulted in a number of alternative *in situ* U-values and cast doubt on conventional U-value calculation practices for traditional walls of certain constructions[1]. As a result of this research work it was 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 SPAB Building Performance Survey has been supported in part by a grant from the Dartmoor National Park Sustainable Development Fund. Seven different properties, four of which are located in and around the Dartmoor area, were identified as being of traditional construction and scheduled for various forms of energy improvement interventions over the coming year (2011-12). During a two week period between January and April 2011, 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 the seven individual properties both before and after refurbishment. It is hoped

[1] The findings of this research are detailed in the SPAB Research Report 1: U-value Report at http://www.spab.org.uk/downloads/TheSPABU-valueReportFINAL.pdf /

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.

The SPAB Building Performance Survey looks specifically at;

- Fabric heat loss through the U-value measurement of wall elements both in the form of *in situ* and calculated U-values,
- Air infiltration through air permeability testing and thermographic survey,
- Moisture; room and wall moisture including wall surface and interstitial moisture behaviour
- Indoor air conditions and comfort levels via the measurement of $CO_2$, interior temperature and relative humidity.

At the time of writing this research project is in process, data from the first season's ('unimproved') monitoring has been collated and subjected to a preliminary analysis. This Interim Report provides details of the projects findings thus far. 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. MONITORING PROCEEDURES & DATA PROCESSING

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.

***U-value measurements***

The *in situ* measurement of the thermal transmissivity (U-value) of the walls in the study follows the method set out in the standard prEN 12494 (currently under revision). The measurement requires 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. This was done using a Hukseflux HFP01 heat flux sensor and a Campbell Scientific CR1000 data logger logging at 10 minute intervals. Simultaneously records are also made of interior and exterior surface and air temperatures for the same period logged every 10 minutes to the Campbell logger and a Gemini TinyTag Plus 2 TGP-4520 data logger respectively. The heat flux and surface temperature information is then combined to provide an *in situ* U-value for the wall in question[2]. 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 referred to in the Building Regulation Approved Documents.

***Moisture measurements***

Moisture within the properties was studied in a number of ways. Most simply the interior relative humidity (RH) and temperature of a room was measured and logged using TinyTag Plus 2 TGP-4520 data loggers at 10 minute intervals. In addition to this the moisture content of the interior surface of the 'monitoring' wall, where the monitoring equipment was installed, was measured using a twin pinned electrical resistance probe and another device measuring material moisture content 40mm back from the interior surface through a capacitance measurement. The two different figures derived for

[2] For further details on the *in situ* U-value methodology used in this research see Rye, C. (2010) *SPAB Research Report 1* or Baker, P. (2011). *Technical Paper 10: U-values and traditional buildings*. Edinburgh: Historic Scotland.

surface moisture measurements were placed together in a comparative graph. The gradients charted in these graphs are purely relational and the scale a nominal one, they do not reflect actual quantities of moisture as two different systems of moisture measurement have been used to gather the data. Interstitial moisture was also 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. This allowed the moisture and temperature at various points through a cross section of the wall to be monitored using prototype ArchiMetrics gradient loggers designed by Cameron Scott. 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. These were outputted as static graphs with the information plotted as average values collected through the monitoring period or as animated graphs which showed the changing relationship between temperature and dewpoint through the wall over time (normally 14 days).

***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. These values were placed in a table alongside interior temperature and RH data for each property. Interior temperature and RH levels over the monitoring period were 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) quoted by Viitanen et al in their paper *Moisture and biodeterioration risk of building materials and structures.* 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.

### *Air Permeability Testing*

This test procedure was carried out using an Energy Conservatory Minneapolis Blower Door Model 3 and following 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). This procedure is used to test newly built dwellings and Approved Document L1A sets a limit for the air permeability of these buildings under the 2010 regulations of $10m^3h^{-1}m^{-2}$ @50 Pa. Comparison to these thresholds was made in each of the dwelling studies.

Using the calculated building volume, the measured air flow can be 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. In order to relate the air changes per hour at 50 Pa to infiltration levels under normal conditions, a widely used (e.g., Ridley et al citing Sherman[3]) approximation is:

$$\textit{Air infiltration at normal pressure} = \frac{\textit{Air permeability@50pa}}{20}$$

[3] Ridley, I. et al, The impact of replacement windows on air infiltration and indoor air quality in buildings. International Journal of Ventilation 1(3) pp 209-218.

CIBSE[4] citing Dubrul identified the divisor should be adjusted for different types of location - for buildings exposed to high winds this could be as low as divided by 10 compared to a sheltered location where the divisor could be 30. However, this advice appears to be widely ignored.

The principle air permeability test was on the full volume of the inhabited space apart from Skipton, where the modern extension was to be demolished as part of the refurbishment process. A number of the studied dwellings had more recent extensions and, where it was practical to isolate, the older part of the building was examined separately. 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 some instances where there was significant infiltration, further examination of particular features of a property such as external doors or loft hatches was carried out.

Additional data was collected on the air flow rates related to individual flues in each property. Since a number of factors govern air flows in chimneys, including convection when in use and the passive stack effect, it was anticipated the data collected would not directly relate to the volume of air moved under normal conditions, but indicate the variation across the group of properties studied.

### *Thermographic Survey*

The thermographic survey work was carried out using a FLIR InfraCAM, kindly loaned to the project by Cumbria Action for Sustainability. The purpose of thermal imaging a building is to identify the thermal weak points of the structure and zones of infiltration.

[4] CIBSE, *Heating, ventilating, air conditioning and refrigeration: CIBSE Guide B*. London: CIBSE (2005).

In order for satisfactory images to be obtained there needs to be a temperature differential between the conditions inside the building and those prevailing in the external environment – a threshold of at least 5°C is required, but the greater the temperature difference, the clearer images appear. Where possible, thermal imaging was carried on both outside and inside the test dwellings. In addition to requiring a temperature difference, external thermal imaging can be problematic for a number of reasons including the impact of solar gain, wet weather, variations in emissivity and the different behaviour of some materials to infrared radiation compared to visible light (for example, glass is opaque to infrared and therefore behaves like a mirror rather than transparent as it appears in visible light). These factors were taken into account in analysis of images.

Inside the building, thermal imaging is less susceptible to weather conditions and the standard practice adopted for the study was to capture images whilst the blower door test was being carried out, exaggerating the air flows through the fabric of the building providing clearer images of areas subject to infiltration.

Throughout the study, the equipment was used on an automatic setting, where the colour range displayed related to the maximum and minimum temperatures within the field of view of the camera, rather than an absolute scale. The colours representing a particular temperature could therefore change between images - the temperature scale at the base of each image should therefore be referred to, together with the temperature displayed in the top left hand corner of each image, which is the recorded temperature at the centre of the cross hair.

## 3. RESULTS

The results for each of the different monitored parameters; fabric heat loss, surface and interstitial moisture behaviour, indoor air conditions, and air permeability are reported on a property by property basis. These results are also accompanied by a commentary on the findings for each property and these individual reports can be found in Appendix A of this document.

## 4. DISCUSSION

### *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 (Fig. 1.). This discrepancy is of the same order as that discovered during other SPAB U-value research work, 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.

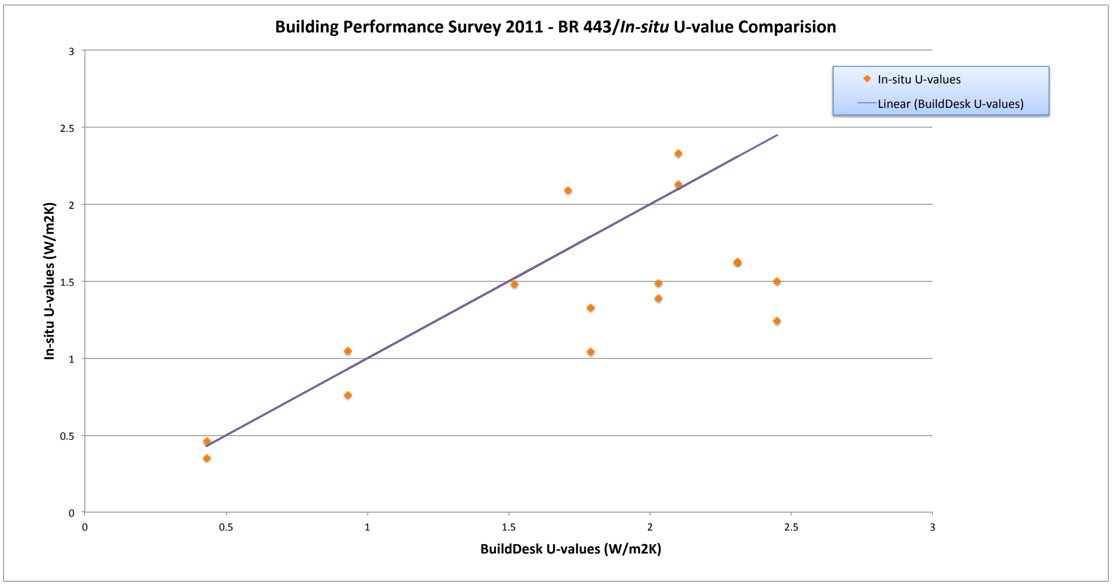



*Figure 1. Comparison of in situ and calculated U-values in the SPAB Building Performance Survey 2011.*

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 Abbeyforegate 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 (1.52 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$^2$K in contrast to a BR 443 calculation of 0.93 W/m$^2$K. 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.

***Air Infiltration***

The results of the air permeability testing are summarised in Table 1.

| | Units | Shrewsbury | Skipton | Lower Brailes | Riddleco-mbe | Ashburton | Drewste ignton | Devon Consols |
|---|---|---|---|---|---|---|---|---|
| **Whole dwelling** | | | | | | | | |
| Internal floor area | $m^2$ | 60 | 190~ | 113 | 86 | 332 | 325 | 161 |
| Habitable building volume | $m^3$ | 134 | 458~ | 263 | 189 | 817 | 759 | 379 |
| Dwelling envelope area | $m^2$ | 185 | 401~ | 285 | 245 | 690 | 708 | 380 |
| Measured air flow | $m^3h^{-1}$ @50 Pa | 2106 | 6789~ | 2478 | 1355 | 15615* | 6139 | 7615 |
| Air permeability test result @50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 11.4 | 16.9~ | 8.7 | 5.5 | 22.6* | 8.7 | 20.0 |
| Air changes per hour @ 50Pa | ach @50 Pa | 15.7 | 14.8~ | 9.4 | 7.2 | 19.1* | 8.1 | 20.1 |
| Estimated ach through infiltration at ambient pressure | ach | 0.8 | 0.7~# | 0.5 | 0.4 | 1.0* | 0.4 | 1.0 |
| **Part of dwelling** | | | | | | | | |
| Description | | Extension | | Original cottage | Original cottage | Original house plus old extn | Barn conversi on | |
| Internal floor area | $m^2$ | 17 | | 96 | 54 | 240 | 235 | |
| Habitable building volume | $m^3$ | 41 | | 224 | 124 | 643 | 552 | |
| Envelope area | $m^2$ | 81 | | 230 | 184 | 514 | 473 | |
| Measured air flow | $m^3h^{-1}$ @50 Pa | 520 | | 2152 | 927 | 11494 | 2804 | |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 6.4 | | 9.4 | 5.0 | 22.4 | 5.9 | |
| Air changes per hour @ 50Pa | ach @50 Pa | 12.8 | | 9.6 | 7.5 | 17.9 | 5.1 | |

*Table 1 Summary of air permeability results.*
*Ashburton whole house figures likely to be inaccurate due to error (refer to report). ~ Skipton – not full area of dwelling (refer to report).
#Skipton – using1/20 approximation (see report).

It should be noted that one building could not be depressurised to a 50Pa differential and an extrapolated result has been used for this building (Ashburton).

Exploring the results further, there was a wide range in air permeability results when considering the complete dwelling, 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 a 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).

Five of the seven dwellings had a secondary test carried out on part of the building. 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. The orthodox view, set out in BRE 1985 and Warm and Oxley 2002, is that a general ventilation rate of 0.4 - 0.5 ach, under normal conditions, is required for dwellings and so the latter figure would be considered excessive.

Air flows @50 Pa for flues were noted in each of the properties. Where a chimney was open, the flows varied from around 30 $m^3h^{-1}$ for Riddlecombe and Skipton where stoves were fitted to 990 $m^3h^{-1}$ for Shrewsbury, where the single open chimney had the effect of increasing the air flow for the complete building under the test conditions by approximately 50%. Though these air flows will not relate to air flow in practice, these tests do offer some means of comparison between flues and properties and show there is a significant variation.

With respect to the thermographic surveys, some general trends were seen, 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.

***Moisture Behaviour - Interstitial Moisture***

When examining the plots of temperature gradient for 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. These differences in the homogeneity of wall construction at Lower Brailes and Skipton were noted on site when core drilling into the body of the walls to install the gradient sensors. With regards to the dewpoint gradients calculated for the different walls, as is to be expected as temperature gradients fall across the wall these begin to converge with the dewpoint gradients. This pattern can be seen in the walls from Skipton, Riddlecombe, Drewsteignton and Lower Brailes. 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 result 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) which will also have the effect of cooling the wall. 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.

***Moisture Behaviour - Surface Moisture.***

When examining most of the graphs for surface moisture for the seven properties in the building performance survey what is immediately obvious is the reduction in moisture content and stabilization in moisture behaviour that occurs in the measurement profiles 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 permeable materials without damp-proof courses (rising damp). The effect of raised material moisture content at the base of walls due to capillary action (as indicated by the green 40mm deep line on the graphs) on fabric heat loss can be seen in 3 examples from the survey. 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.

| 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 $W/m^2K$ |

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

It is also interesting to note that most of the wall *surface* moisture readings for the properties (indicated by the blue line on graphs within the individual property reports) are quite stable and consistent. Perhaps this is as a result of the drying effect of evaporation which occurs at the surface of the wall? Only one property, Riddlecombe, inverts the relationship normally found between the surface measurements and those taken further back into the wall where the surface of the wall appears to be of 'greater' moisture content than the deeper layer. Here the cob wall was finished with a lime plaster which had then covered with a later gypsum skim which itself looked as if it had been sealed with a coating of dilute pva glue or similar and the wall low down was slightly sticky. Interestingly, overall the wall at Riddlecombe would appear to maybe have a higher than desirable moisture content, it has the lowest dewpoint margin of all the walls studied and parts of the cob material extracted as cores from the walls during sensors installation were wet to touch, see individual report for further discussion of this.

***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.

## APPENDIX A - Individual Property Reports

## 116 Abbeyforegate, Shrewsbury.

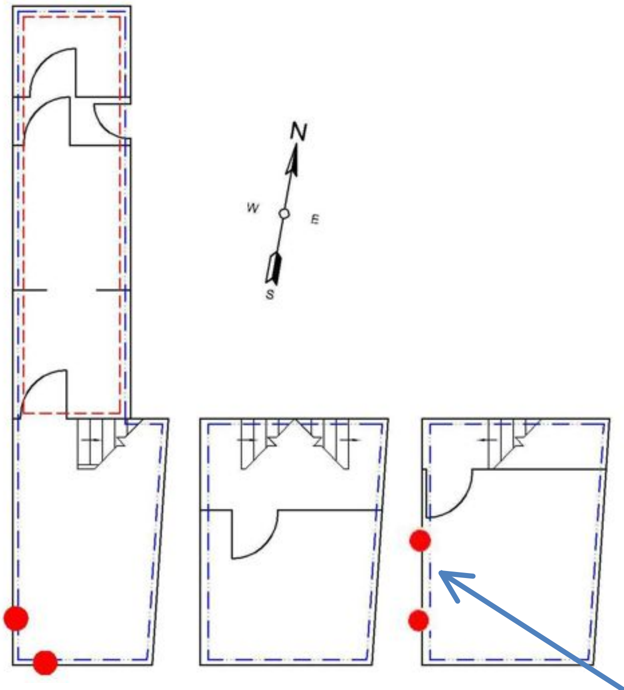
## 2011

Description: End of terrace (originally mid-terrace) house, 2 storeys with attic dormer. Dating from 1820 but with earlier core. Brick with plain tiled roof, with elements of timber-framing and a modern single storey extension at rear accommodating a kitchen and bathroom. Although it appears to be a single double fronted house, number 116 only comprises one half of the building. A central doorway leads through to a passageway between the two dwellings; a blind window sits above this. The gable end has recently been re-rendered.

Occupancy: 1 person.

Floor Area: $60m^2$

*Figure 2 – Plan of 116 Abbeyforegate, Shrewsbury, with ground floor on LHS.* The red dots indicate the locations of the monitoring equipment. The air permeability test perimeter is show in blue, with the secondary test zone shown in red.




*Figures 3 - 6. Showing positions of in situ monitoring equipment at 116 Abbeyforegate, Shrewsbury, 2011.*

U-VALUES

Four *in situ* U-value measurements were made on the gable end walls of the living room and attic bedroom over the period 27th January - 11th February 2011 (Figs. 2 and 3 - 6). The living room measurements incorporate the brick wall with external render finish whereas the measurements taken in the bedroom do not. The results along with standard U-value calculations made following the BR 443 method are shown in Table 3 below.

| **Location** | **Materials/ Build Up** | **mm** | **In-situ U-value** | **BR 443 U-value** |
|---|---|---|---|---|
| South wall Grd floor Sitting Rm 27/01/11- 11/02/11 | Brick<br>Lime Plaster<br>Gypsum skim | 362<br>16<br>2 | | |
| | TOTAL | 380 | 1.48 | 1.52 |
| West wall grd floor Sitting Room 27/01/11- 11/02/11 | Insulating render<br>Brick<br>Lime Plaster<br>Gypsum skim | 40<br>228<br>16<br>2 | | |
| | TOTAL | 180 | 2.09 | 1.71 |
| Bedroom W Gable, N side of chimney 27/01/11- 11/02/11 | Brick<br>Lime Plaster<br>Gypsum skim | 230<br>12<br>2 | | |
| | TOTAL | 248 | 2.13 | 2.10 |
| Bedroom W Gable, S side of chimney 27/01/11- 11/02/11 | Brick<br>Lime Plaster<br>Gypsum skim | 230<br>12<br>2 | | |
| | Total | 248 | 2.33 | 2.10 |

*Table 3. U-value results for 116 Abbeyforegate, Shrewsbury, 2011.*

A comparison of *in situ* and calculated U-value results for the house at Abbeyforegate, Shrewsbury, run contrary to the usual trend seen when comparing the two heat loss measurement methods. Most commonly, in a traditional wall such as this, the calculated method tends to produce U-values of a higher number order (indicating greater heat loss) than an *in situ* measurement. However, in this case, only one *in situ* U-value is greater than its calculated equivalent and only by a small margin.

There is some ambiguity concerning the brick walls at Shrewsbury, this was a mid terrace house which has been transformed into an end terrace due to the removal of the adjoining building to allow the construction of a nearby road. Therefore the dimensions and underlying condition of what is now the west gable wall are hard to define with certainty yet this is only true for the wall at ground and first floor level and above this the brickwork appears untouched as the original terrace only extend to first floor height. Previous work in this area has demonstrated that if the build up of a wall can be well defined (in terms of its materials, their proportions and individual thermal conductivity values) this will produce a calculated U-value that has better correspondence with an *in situ* measurement (see *SPAB Research Report 1: U-value Report*, October 2010). The south facing ground floor wall, the principle monitoring wall for this building, is relatively straightforward and therefore can be defined with some confidence. Indeed, the *in situ* U-value recorded on the south wall of the ground floor, 1.48 W/m$^2$K, corresponds with the calculated U-value for the same wall, 1.52 W/m$^2$K, when the error range of ±10% given for the *in situ* method is taken into account. This suggests that the brick thermal conductivity (lambda or K value) used in this U-value calculation (0.77 W/mK outer leaf, 0.56 W/mK inner leaf) have reasonable correlation to the actual conductivity of the bricks used in this part of the building at Shrewsbury. There is also good correspondence for one of the two *in situ* U-values recorded on the west wall of the bedroom on the second floor, 2.13 W/m$^2$K *in situ* and 2.10 W/m$^2$K calculated. However, the other pair of *in situ* and calculated U-values for this wall is more divergent, 2.33 W/m$^2$K *in situ* compared with the calculated figure of 2.10 W/m$^2$K, furthermore the *in situ* U-value suggests greater heat loss than the calculated value which is contrary to the general trend for traditional buildings. It is difficult to provide an explanation for this other than the wall contains some anomaly or difference which reduces its thermal performance which is not discernable and therefore cannot be taken into account within a calculation. The largest discrepancy for this group of U-values concerns the values produced for the west wall at ground floor level, 2.09 W/m$^2$K *in situ* and 1.71 W/m$^2$K calculated. Once again this pair of U-values invert the usual pattern seen in traditional buildings and shows a greater level of heat loss from the *in situ* U-value measurement. This wall is the most problematic in terms of producing a calculation as its present configuration is quite ambiguous. It is approximately half a brick thick, probably formed mainly of snapped headers as a result of the removal of the adjoining building and had been previously covered with a cement render. This render was cracked and in a poor state so the homeowner had replaced it with an insulating lime-based render. The homeowner reported that after the removal of the cement render the wall was found to be in a parlous state and required random consolidation with lime mortar prior to the application of approximately 40mm of insulating render. Therefore, a U-value figure has been calculated for this wall with a supposed build up of materials but the true nature of the construction at the site of measurement is ultimately obscure. Therefore, once again it is likely that the thermal transmissivity as measured by the in situ U-value for this wall is effect by elements within the wall that increase its heat loss which have not been anticipated and therefore have not been factored into the equivalent U-value calculation.

Overall the south wall shows a good correspondence between the calculated and *in situ* U-values which suggests a degree of confidence in the assumptions made concerning materials and conductivity for the calculated U-value for this wall. However, these assumptions do not provide the same degree of correspondence for some of the west wall which suggests something is different in this construction which is not defined. It maybe that the overall poor thermal performance shown from the *in situ* results for the west wall are a result of changes or material differences made to this wall.

## AIR PERMEABILITY

Air permeability testing was carried out on the complete habitable volume at 116 Abbeyforegate on 26th January 2011. Plaster had been removed from the walls of the first floor room and so a secondary test was carried out on the extension to the rear of the property alone. This test has the provision that windows in the original dwelling were not opened. Both test areas are identified in Figure 2. Interior and exterior conditions at the time of testing are noted in Table 4 and the results of the whole dwelling air permeability test are shown in Table 5.

| | |
|---|---|
| Date of Test: | 26 January 2011 |
| Prevailing weather conditions at time of test: | Sunny with some light cloud. Wind force 0-1. External conditions (shade): 0°C 75% RH (12 noon approx.) |
| Conditions inside dwelling: | Dining area (extension): 16°C 46% RH (approx. 2pm) |

*Table 4. Interior and exterior conditions for air permeability test at 116 Abbeyforegate, Shrewsbury.*

| | Units | Results | Comments |
|---|---|---|---|
| **Whole dwelling** | | | |
| Internal floor area (ground and first floors) | $m^2$ | 60 | |
| Habitable building volume | $m^3$ | 134 | |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 185 | |
| Measured air flow | $m^3h^{-1}$ | 2106 | |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 11.4 | $m^3$ of air per hour per $m^2$ of surface area of the living space. |
| Air changes per hour at 50Pa | ach@50 Pa | 15.7 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

*Table 5. Results for whole house air permeability test at 116 Abbeyforegate, Shrewsbury.*

The air flow measured under the test conditions was 2106 $m^3h^{-1}$. Relating this result to the total surface area of the property (subject to confirmation of room dimensions), Table 5 shows that 116 Abbeyforegate has an air permeability of 11.4 $m^3h^{-1}m^{-2}$ @50 Pa, which is slightly above the limiting air permeability of 10 $m^3h^{-1}m^{-2}$ @50 Pa under Approved Document L1A 2010 for new dwellings. Considering the air flow in relation to the volume of the building, the air change rate at 50 Pa pressure difference is 15.7 ach, representing the number of times per hour the total volume of air in the dwelling will change at this pressure. From Sherman, under normal conditions this would represent an air change rate of around 0.8 ach, which orthodoxy would consider excessive.

The results for the secondary test on extension to the rear of the property alone are shown in Table 6.

| | Units | Results |
|---|---|---|
| **Rear extension only** | | |
| Internal floor area | $m^2$ | 17 |
| Volume | $m^3$ | 41 |
| Surface area of living space | $m^2$ | 81 |
| Measured air flow | $m^3h^{-1}$ @50Pa | 520 |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 6.4 |
| Air changes per hour at 50Pa | ach@50 Pa | 12.8 |

*Table 6. Results for air permeability test on rear extension at 116 Abbeyforegate, Shrewsbury.*

From Table 6, the measured air flow of 520 $m^3h^{-1}$ @50 Pa equates to an air permeability of 6.4 $m^3h^{-1}m^{-2}$ @50 Pa for the extension. This indicates the original dwelling is substantially “leakier” than the extension, but the amount attributable to the current works on the first floor is unknown.

Flues

Under the standard test procedure, chimneys and flues in the dwelling are excluded from the results. Following the main tests, the flues in the property were tested. No flow was apparent from the first floor fireplace. When it was uncovered, the ground floor chimney created an additional air flow of 990 $m^3h^{-1}$. Though it will not directly relate to the air flows through chimneys when in use / not in use, this air flow figure for the building increased by about 50% during the test.

## THERMOGRAPHIC SURVEY

Thermal imaging was carried out inside 116 Abbeyforegate whilst the air permeability test was in progress on 26th January 2011. It was also possible to capture some images of the exterior of the building under normal conditions, though solar gain on the front façade prevented consideration of this part of the building. Inside the dwelling, thermal imaging showed a high level of ingress through the un-plastered areas on the first floor and Figure 7 shows the ingress under the test conditions in the first floor ceiling void.

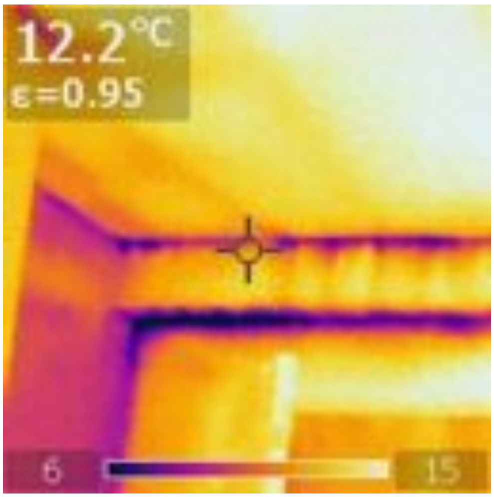



*Figure 7. 116 Abbeyforegate, Shrewsbury - first floor south wall.*

Infiltration around beams and at the junction of the wall to the sloping ceiling on the second floor was identified (Figs. 8 & 9). Leakage around loft hatches and windows was identified, including those in the rear extension. Thermal imaging also provided clues to the underlying building structure. This is illustrated in Figure 10, which shows the timber stud wall structure between the living room and the passageway.


*Figure 8. 116 Abbeyforegate, Shrewsbury – second floor, north facing ceiling.*

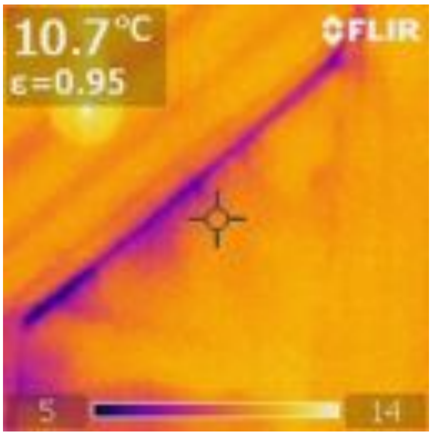



*Figure 9. 116 Abbeyforegate, Shrewsbury - second floor bedroom*

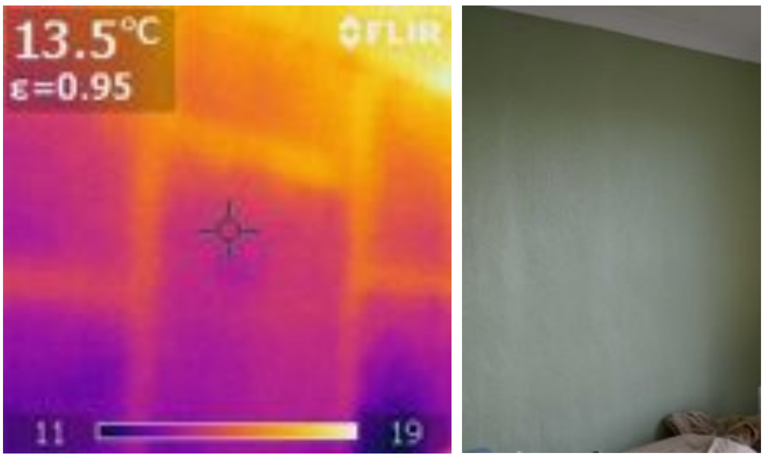



*Figure 10. 116 Abbeyforegate, Shrewsbury - ground floor living room*

## MOISTURE

### Interstitial Moisture

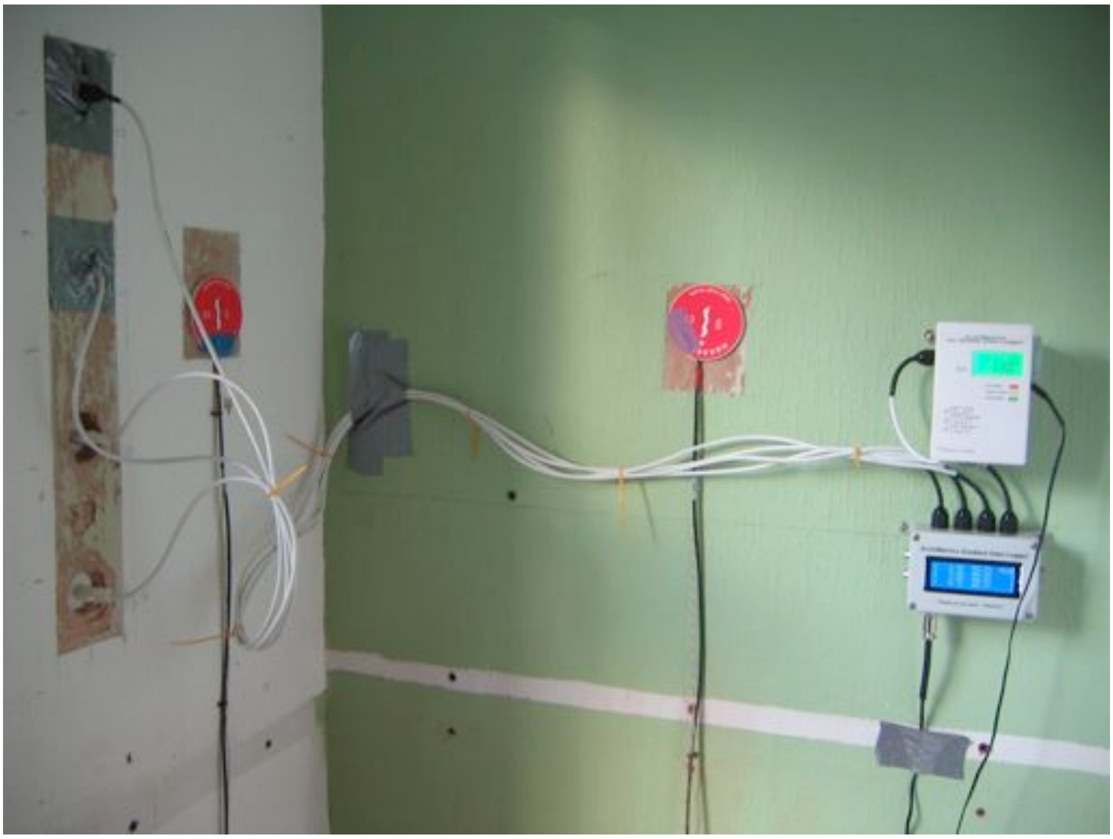


*Figure 11. Interstitial, U-value and IAQ monitoring set up at Abbeyforegate, Shrewsbury, 2011.*

Material moisture measurements were made on the south facing brick wall of the living room at Abbeyforegate (Fig. 11.). Interstitial temperature and relative humidity sensors were located at the heights and depths given in Table 7 and recorded temperature and relative humidity changes at four points within the wall between the period 28th January - 11th February 2011.

| BUILD UP external - internal | SENSOR | HEIGHT from ffl | DEPTH from int sur finish |
|---|---|---|---|
| Brick - 362mm | Sensor 1 | 1875mm | 55mm |
| Lime Plaster - 16mm | Sensor 2 | 1725mm | 150mm |
| Gypsum skim - 2mm | Sensor 3 | 1575mm | 260mm |
| OVERALL = 380mm | Sensor 4 | 1425mm | 340mm |

*Table 7. Interstitial gradient sensor record for Abbeyforegate, Shrewsbury, 2011.*

Figure 12 below shows the average values of each sensor over the monitoring period graphed as separate temperature and dewpoint gradients. The values derived from the relative humidity sensors have been converted to dewpoints in order to indicate the likelihood of condensation forming within the wall.

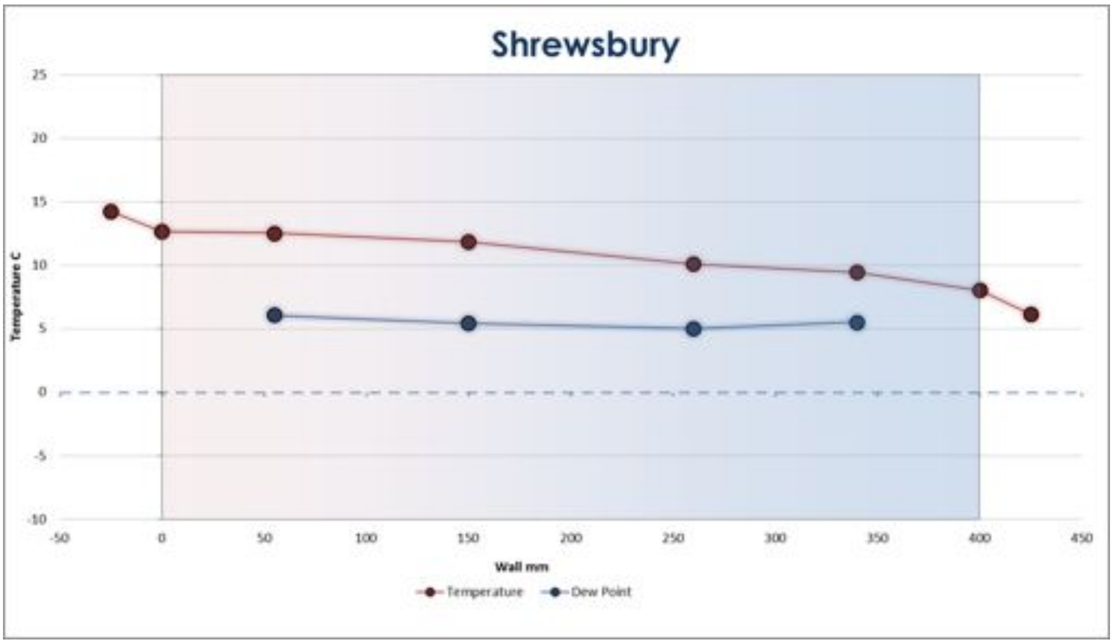



*Figure 12. Temperature and dewpoint gradients for Abbeyforegate, Shrewsbury, 2011*

There is a slight decline in the temperature gradient across the wall from the internal to the external surface shown in Figure 12 and this indicates that the wall has some insulative effect. However the average temperature difference from internal to external surface is only 4˚C. The different gradients plotted between each temperature sensor node indicates that despite the wall being constructed of a uniform material, brick, the wall lacks homogeneity as the degree of heat loss varies between each node.

The dewpoint gradient for the wall at Shrewsbury is unusual as it does not definitively conform to the more standard pattern found elsewhere within this survey where dewpoint and temperature gradient converge towards the exterior face of the wall structure. Here there is a separation between the two, the temperature margin being averaged as 5.49˚C. This is similar to patterns found at Ashburton and Devon Consols and maybe related to low interstitial relative humidity which improves the dewpoint calculation indicating a reduced risk of condensation forming. At Shrewsbury, as with Devon Consols, this is most likely occurring as a result of the air permeability of the wall structures themselves. It was noted during the core drilling required to install the interstitial sensors that air could be felt moving within the wall. This was probably as a result of the poor condition of the external pointing on the front elevation which was admitting air into the body of the wall. The effect of the presence of external air within the body of the brick wall maybe to lower the relative humidity within the structure in two ways; by drying the air through air movement and/or by introducing external air of lower humidity and allowing internal air to be rapidly exhausted through the structure. A reduction in the humidity of the air found within the wall will in turn reduce the risk of interstitial condensation and may thus explain the wide dewpoint margin. It will also however have the effect of cooling the wall and may also be a reason why the *in situ* U-value recorded for this wall shows a poorer thermal performance than that predicted by calculation.

Sensor values for the wall were logged at 5 minute intervals and this information has been animated in order that changes in temperature and dewpoint maybe analysed over time. (To view the interstitial gradients animation for 116 Abbeyforegate, Shrewsbury visit www.archimetrics.co.uk). From the animation it is possible to see the dramatic effect of solar gain on the external surface temperature of the south facing wall and the way that this heat transfers into the body of the construction, at times reversing the heat flow through the wall. Likewise it is also possible to see the effect of heat being inputted into the wall from the warming of the interior space during periods when the central heating is in operation. The beginning of the monitoring cycle coincided with a period of quite low external temperatures, at one point the air temperature fell to around -8˚C. This has a cumulative effect on the wall, particularly during days when no heat contribution is made from solar radiation and during this period the temperature within the wall itself, at sensor 4 positioned 40mm back from the external surface of the wall, dips to 0˚C. Following this cold spell the animation shows a largely horizontal temperature gradient where there is little appreciable difference between internal and external surface temperatures and the absence of any significant heat moving either from the interior to the exterior or visa versa. With the gradients in this configuration the wall is producing no insulative effect. There is no significant temperature differential between interior and exterior conditions during this time partly as a function of the thermal transmissivity of the wall structure and partly because of the quite low internal room temperatures for the living room at Abbeyforegate.

Surface Moisture

On 28th January 2011 two measurements were taken to record the moisture conditions of the interior wall surface of the living room at Abbeyforegate, a resistive measurement of the surface itself and a capacitance reading to a depth of approximately 40mm. Figure 13 plots the two measurements in relation to one another to a height of 2000mm above finished floor level along a nominal moisture scale.

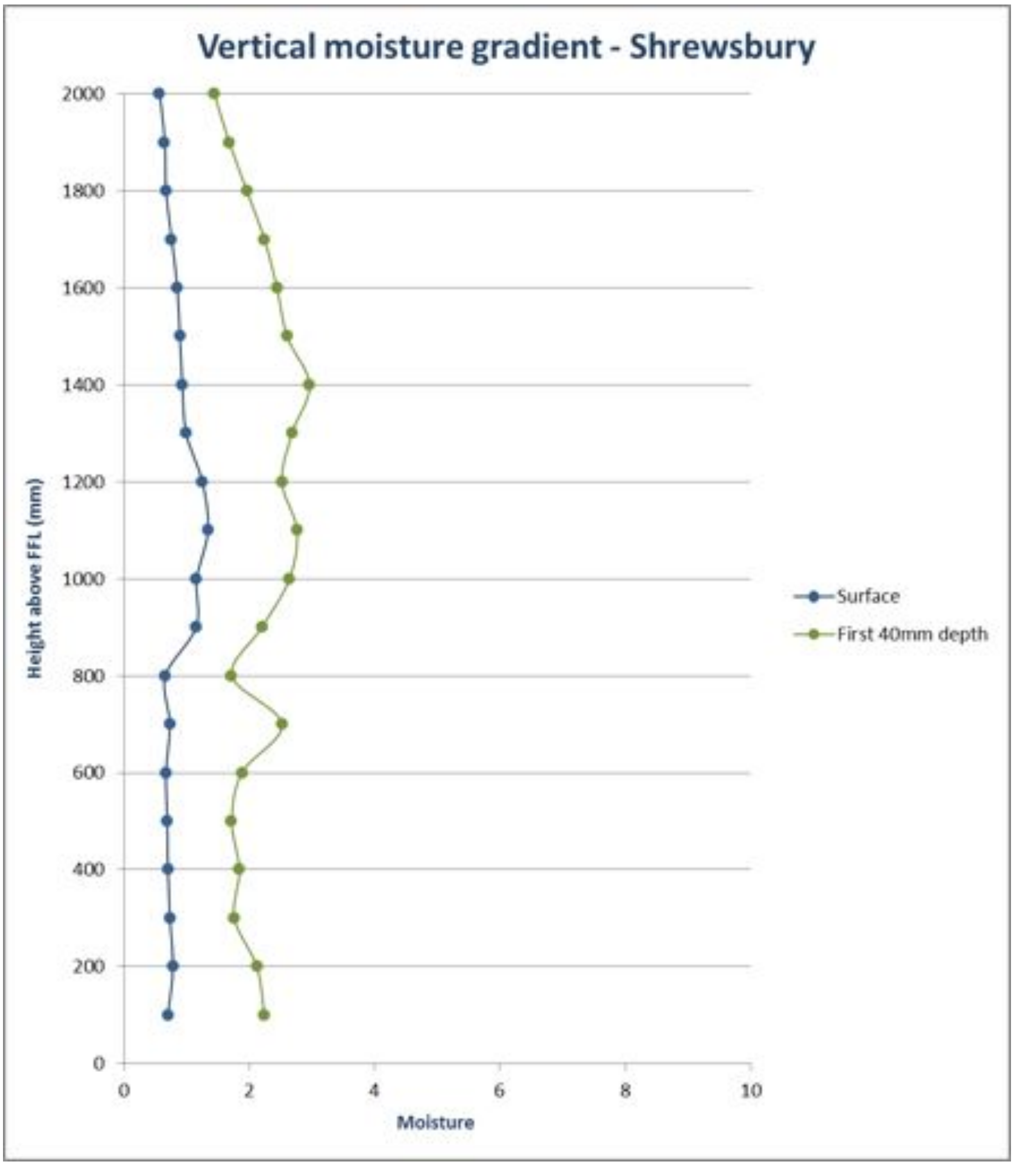



*Figure 13. Surface moisture measurements at Abbeyforegate, Shrewsbury, 28th January 2011.*

Deflections in the profiles of both the surface and the 40mm deep moisture measurements roughly mirror one another. The slight increase in moisture seen at the wall surface 900mm up from finished floor level is also seen as an increase 40mm back from the surface. This could be caused by the window sill which interrupts the wall at a height of approximately 800mm and it maybe that water is tracking along the sill and being drawn into the wall to the extent that it penetrates all the way through to the interior surface. There is no sign at Abbeyforegate of a change in measurements and a reduction in moisture content around the 1000mm/12000mm 'rising damp' level as is seen in other properties within the survey. This suggests that moisture presence due to capillary action is not a factor in this particular wall.

## INDOOR AIR QUALITY & COMFORT/FABRIC RISK

*Figure 14. Close up of heat flux sensor and loggers at Abbeyforegate, Shrewsbury 2011.*

Table 8 provides a summary of the indoor conditions surveyed within the living room/office on the ground floor at Abbeyforegate (Fig. 14.). The figures represent average values recorded over the monitoring period 28th January - 11th February 2011.

| PROPERTY | $CO_2$ (ppm) | Temp (˚C) | RH (%) |
|---|---|---|---|
| Shrewsbury | 702 | 15 | 50.6 |

*Table 8. Indoor Conditions at Abbeyforegate, 28th January -11th February 2011.*

Parameters surveyed were $CO_2$, air temperature, and relative humidity levels. The individual indoor temperature and relative humidity readings were plotted against an index of human comfort and fabric risk. The results for Abbeyforegate can be seen in Figure 15.

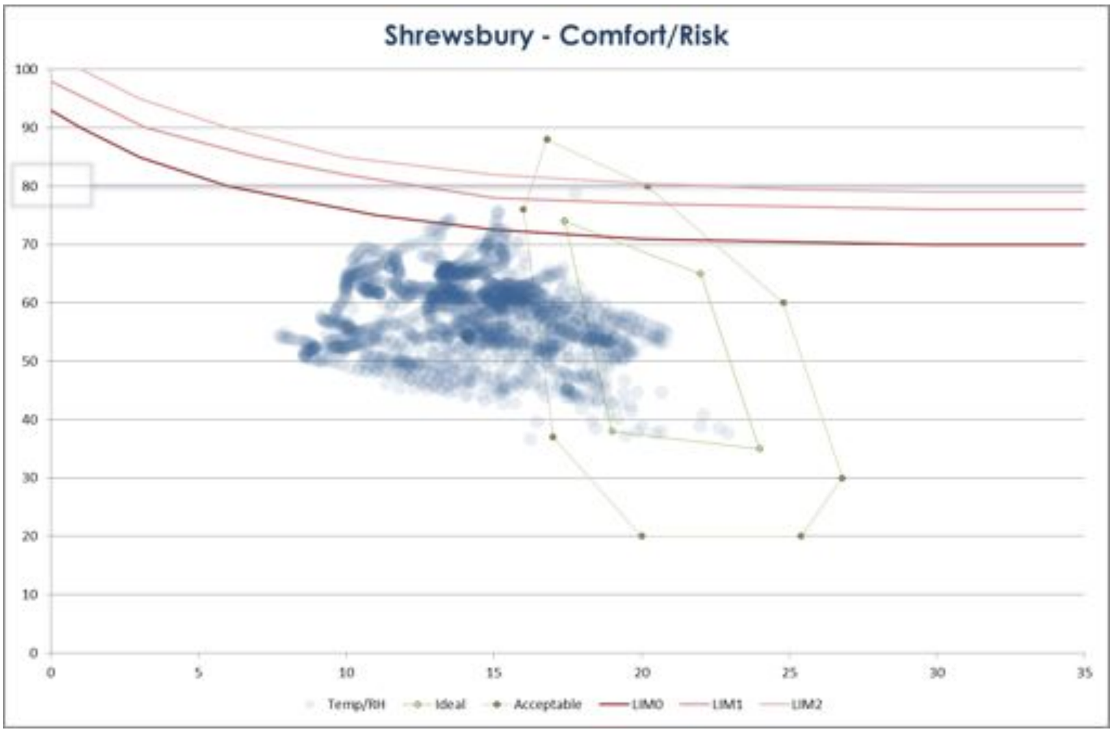



*Figure 15. Comfort/Risk Analysis for Abbeyforegate, Shrewsbury, 2011.*

As is shown in Figure 15, the majority of the temperature/relative humidity measurements fall outside of the parameters deemed ideal for human comfort and mostly outside of the polygon that describes the acceptable limits. However, these conditions do not to seem to imperil the fabric of the building to any great extent as all but a few of the temperature/relative humidity readings sit below the limiting isopeths for mould gradients which mark the tolerance thresholds for various material types (LIM 0 - ideal culture medium, LIM 1 - timber, LIM 2 Masonry).

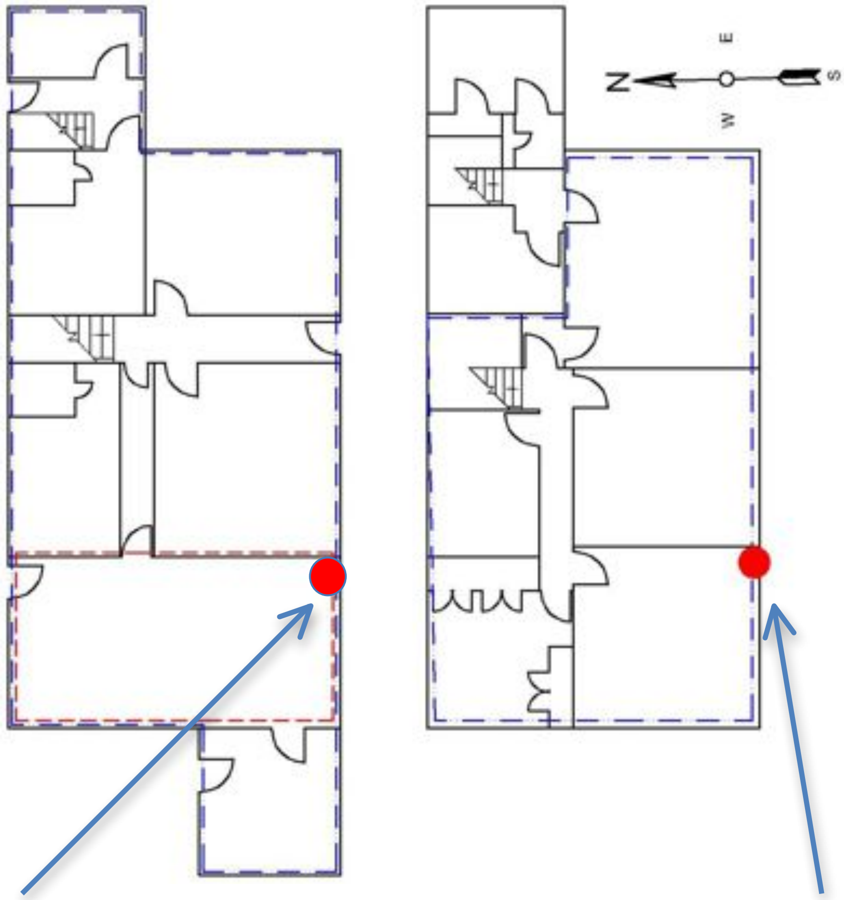
# White House Farm, Stirton, Skipton
# 2011

Description: Grade II listed farmhouse dating from 1790 of local squared sandstone rubble construction with slate stone roof. The walls comprised principally of gritstone set in a lime mortar and contain a distinct rubble core comprising of other stone types including flint. The original building has been extended twice, a nineteenth century extension full depth to the left side of the original and a 1957 addition in brick and render half depth to the right of the original. The property has functioned as two separate dwellings but was reinstated as a single dwelling in March 2010.

Occupancy: Family of 5

Floor Area: 201m$^2$ (excludes utility and extension to be demolished)

*Figure 16. Plan of White House Farm, Skipton, with ground floor plan on LHS.*
The red dot indicates the location of the monitoring equipment. The air permeability test area is shown in blue, with a secondary test zone in red.



*Figures 17 & 18. Positions of in situ monitoring equipment at White House Farm, Skipton, 2011.*

U-VALUES

Between 10th - 24th February 2011 two *in situ* U-value measurements were taken on the south wall of the first floor bedroom (Figs. 16 - 18). The results along with standard U-value calculations made following the BR 443 method are shown in Table 9.

| **Location** | **Materials/ Build Up** | **mm** | **In-situ U-value** | **BR 443 U-value** |
|---|---|---|---|---|
| South Wall 1st Floor Bedroom - low | Gritstone Rubble<br>Lime Plaster<br>Cement skim | 549<br>3<br>20 | | |
| | Total | 572 | 1.63 | 2.31 |
| South Wall 1st Floor Bedroom - high | Gritstone Rubble<br>Lime Plaster<br>Cement skim | 549<br>3<br>20 | | |
| | Total | 572 | 1.62 | 2.31 |

*Table 9. U-value results for White House Farm, Skipton, 2011.*

There is good correspondence between the two *in situ* U-values established for the wall, 1.63 W/m$^2$K and 1.62 W/m$^2$K which lends confidence to the figures but a large discrepancy between the *in situ* U-values and the calculated U-value of 2.31 W/m$^2$K. This divergence corresponds with similar discrepancies found for stone walls in other studies. 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 i.e. inability to provide a full definition of all the materials and voids involved in the wall build up, the use of generalised thermal conductivity information and the oversimplification of the wall structure by the calculating software. Given the problems previously identified and following best practice guidance the *in situ* U-value can be taken to be the more accurate assessment of thermal transmittance for this wall at White House Farm.

## AIR PERMEABILITY

The air permeability testing was carried out at White House Farm on 10th February 2011, with a subsequent test on part of the building on 10th March 2011. Due to difficulties with isolating the extension from the remainder of the building, the rear bedroom adjacent to the extension also had to be excluded from the test area (Fig. 16).

At the time of testing, all plaster had been removed from the Dining Room walls and excavation and partial replacement of the floor had taken place. There was concern that lack of plaster would give a disproportionate reading and this room should be excluded from the test zone. Due to the layout of the building, it was not practical to carry out a test which either excluded this room or measured this room in isolation. In order to give a flavour of the level of ingress if all walls were plastered, the only option was to consider the kitchen in isolation (carried out on 10th March 2011). This test was not ideal as there is likely to be leakage from the rooms above and the doors and windows in the remainder of the house were not opened. Interior and exterior conditions at the time of testing are noted in Table 10 and the results for the air permeability test on 10th February are shown in Table 11.

| | |
|---|---|
| Date of Test: | 10 February 2011 9am onwards;<br>10 March 2011 9am onwards |
| Prevailing weather conditions at time of test: | 10 February (air permeability and thermal imaging): Sunny. Wind force 1-2. Dry, but had been wet on previous day.<br>10 March (air permeability only): Bright, showers, gusting increasing to force 5 through day (exceeding TM1 spec.) . External conditions 9$^{o}$C 68% RH (approx. 1pm) |
| Conditions inside dwelling: | 10 February: Kitchen - 17$^{o}$C 62% RH<br>10 March: Kitchen – 13$^{o}$C 68% RH (approx. 12noon) |

*Table 10. Interior and exterior conditions for air permeability test at White House Farm, Skipton.*

| | Units | Results | Comments |
|---|---|---|---|
| **Dwelling (10 February 2011)** | | | |
| Internal floor area (ground and first floors) | $m^2$ | 190 | Excludes extension, utility room and rear bedroom adjacent to extension. |
| Habitable building volume | $m^3$ | 458 | |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 401 | |
| Measured air flow | $m^3h^{-1}$ | 6789 | |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 16.9 | $m^3$ of air per hour per $m^2$ of surface area of the living space. |
| Air changes per hour at 50Pa | ach@50 Pa | 14.8 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

*Table 11. Results for the air permeability test on 10 February at White House Farm, Skipton*

Table 11 shows air flow measured for the property at 50Pa was 3997 $m^3h^{-1}$. Relating this figure to the surface area of the defined volume this equates to an air permeability of 16.9 $m^3h^{-1}m^{-2}$ @50 Pa, which is higher than the limiting air permeability under Approved Document L1A 2010 for new dwellings of 10 $m^3h^{-1}m^{-2}$ @50 Pa.

Relating the dwelling volume to the measured air flow, the air change rate at 50Pa is 14.8 ach, representing the number of times the total volume of air in the building will change at this pressure difference. Using the *rule of thumb* of 1/20 based on Sherman and applied to the other test buildings, this equates to an air change rate of 0.7 ach, above the orthodox view of 0.5 ach (BRE 1985, Warm & Oxley 2002). However, it should be noted that a divisor lower than 20 should be applied due to White House Farm's more exposed location (CIBSE), but for comparison 1/20 has been employed.

The results for the test on 10th March on the kitchen only are shown in Table 12. The substantially lower air permeability result (7.7 $m^3h^{-1}m^{-2}$ @50 Pa) does confirm that ingress into the dining room through the un-plastered walls is likely to be a significant factor, artificially increasing the results for the whole dwelling.

| | Units | Results |
|---|---|---|
| **Kitchen only (10 March 2011)** | | |
| Internal floor area | $m^2$ | 28 |
| Habitable building volume | $m^3$ | 64 |
| Surface area of living space | $m^2$ | 107 |
| Measured air flow | $m^3h^{-1}$ | 824 |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 7.7 |
| Air changes per hour at 50Pa | ach@50 Pa | 12.9 |

*Table 12. Air permeability results for kitchen only test on 10 March 2011 at White House Farm, Skipton.*

Flues

Under the standard test procedure, chimneys and flues in the dwelling are excluded from the results. When checked, there was no flow associated with either of the fireplaces in the bedrooms, indicating they are likely to have been capped. Excluding the oil fired range in the kitchen, there are multifuel stoves fitted in the Lounge and Dining Room. When the vents for these were opened, they showed flows of 32 and 24$m^3h^{-1}$ respectively.

THERMOGRAPHIC SURVEY

Thermal imaging was carried out inside White House Farm whilst the air permeability test was in progress on 10th February 2011. Images of the exterior of the building were also taken under normal conditions.

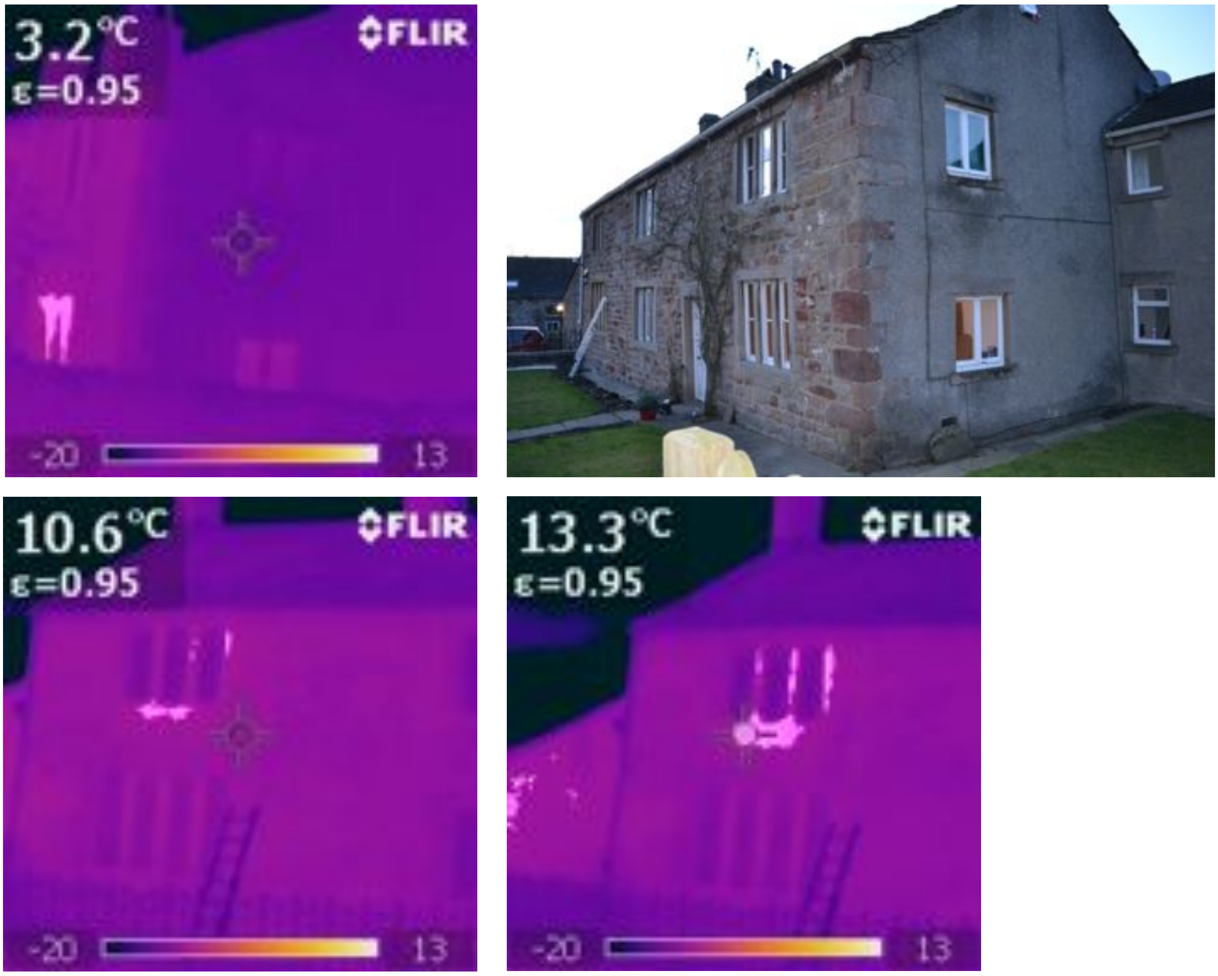



*Figure 19. White House Farm, Skipton – south and east walls.*

The front of White House Farm faces south and was subject to solar gain on the day of the survey. This is confirmed by a recorded difference in surface temperatures between the south, east and north walls shown in Figures 19 & 20. A spot temperature on the east wall (which is rendered) was recorded at 3.2$^{o}$C, compared to a south wall spot temperature of 10.6$^{o}$C, with an elevated temperature recorded at the sills and mullions of bedroom 1 (13.3$^{o}$C). Temperatures recorded for the north wall vary between 6.5 $^{o}$C and 8.9$^{o}$C, with detail of the variation in surface temperatures shown in Figure 20. The west gable end of the building showed elevated wall temperatures where the exhaust gases from the kitchen range flue had warmed the stone work (Fig. 21).

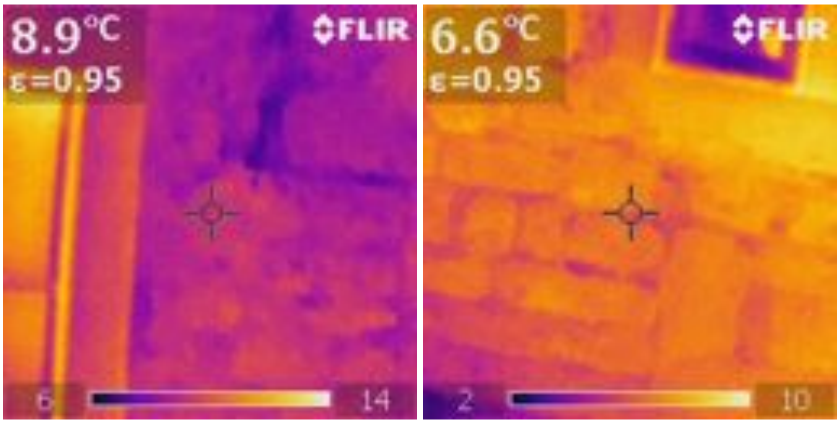



*Figure 20. White House Farm, Skipton – exterior of north wall (living room)*

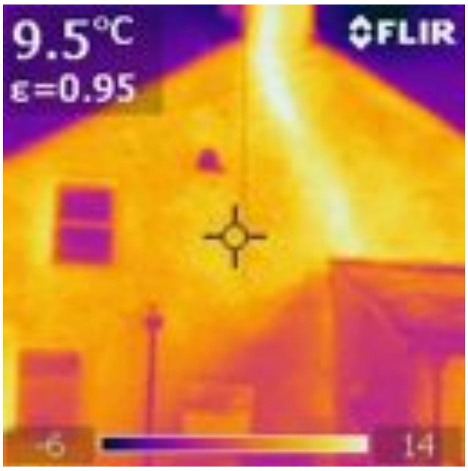



*Figure 21. White House Farm, Skipton – west end wall*

The internal thermal images were taken whilst the dwelling was depressurized, exaggerating infiltration results. Distortion of results by solar gain is an issue for some lower thermal mass elements of White House Farm, such as the south facing sloping ceilings in bedrooms and it is not possible to comment on leakage around windows on the south wall, due to the effect of solar gain on the mullions (Fig. 19).

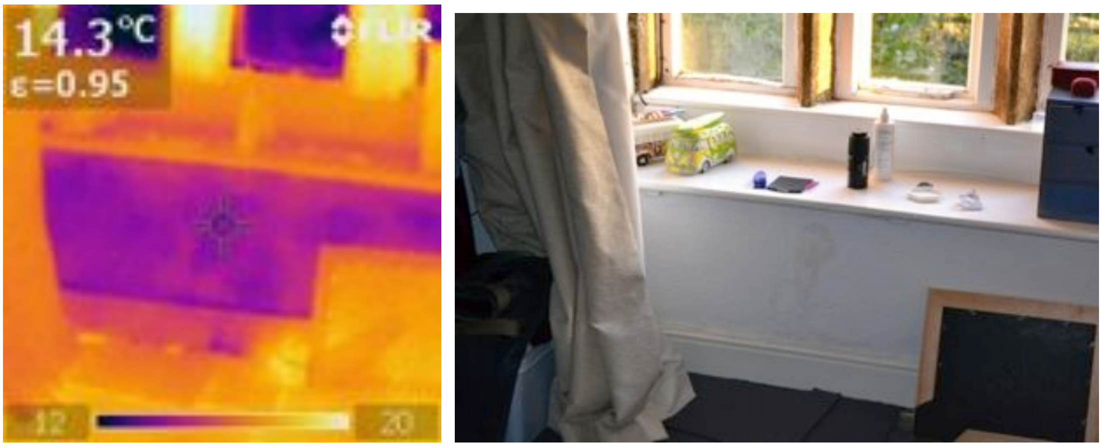



*Figure 22. White House Farm, Skipton - main bedroom, south facing window.*

The pattern of stonework beneath the plaster can be clearly seen throughout the property (Figs. 22 & 23). There is evidence of ingress at the junction of external walls to the floor in the first floor rooms (Fig. 24) apart from the bathroom where there appeared to be no significant points of infiltration. Ingress was also seen around exposed beams and at the wall–ceiling junction above the staircase (Fig. 25).


*Figure 23. White House Farm, Skipton – Main bedroom, south wall.*

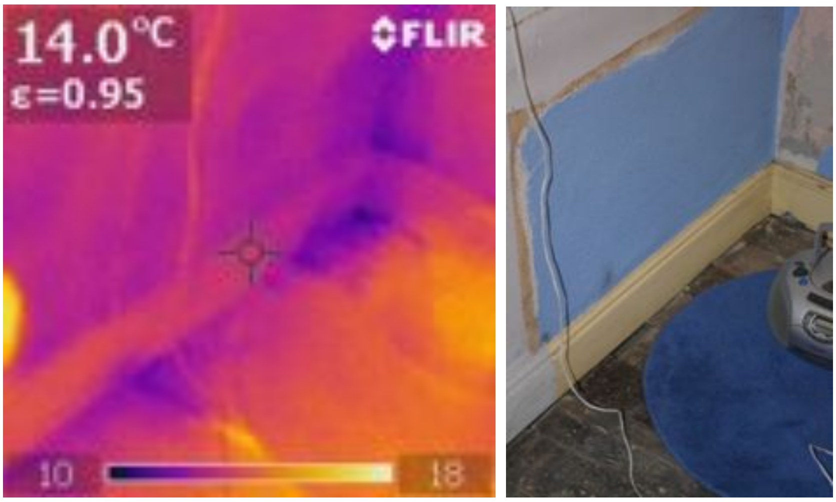



*Figure 24. White House Farm, Skipton - Bedroom 3*

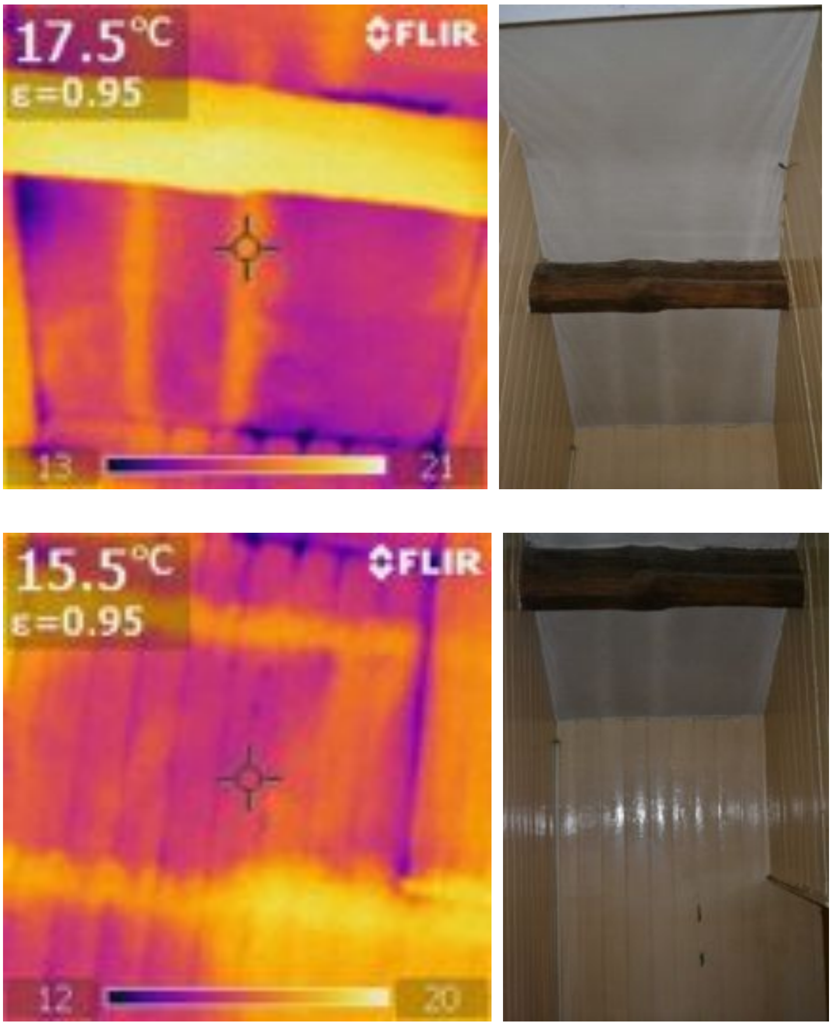



*Figure 25. White House Farm, Skipton – staircase (north facing roof)*

## MOISTURE

### Interstitial Moisture

*Figure 26. Interstitial monitoring set up at White House Farm, Skipton, 2011.*

Material moisture measurements were made on the south facing ground floor wall of the kitchen (Fig. 16). Interstitial temperature and relative humidity sensors were located at the heights and depths given in Table 14 and recorded temperature and relative humidity changes at four points within the wall between the period 10 - 24th February 2011.

| BUILD UP external - internal | SENSOR | HEIGHT from ffl | DEPTH from int sur finish | Wall sections |
|---|---|---|---|---|
| Sandstone - 549mm | Sensor 1 | 1730mm | 50mm | Cement skim/patch - sandstone |
| Lime Plaster - 3mm | Sensor 2 | 1580mm | 200mm | Lime/cement finishes - lime mortar joint |
| Gypsum/cement skim - 20mm | Sensor 3 | 1430mm | 300mm | Int finishes - Sandstone |
| OVERALL = 572mm | Sensor 4 | 1280mm | 500mm | Cement - void - flint - void - sandstone |

*Table 14. Interstitial gradient sensor record for White House Farm, Skipton, 2011.*

Figure 27 shows the average values of each sensor over the monitoring period graphed as separate temperature and dewpoint gradients. The values derived from the relative humidity sensors have been converted to dewpoints in order to indicate the likelihood of condensation forming within the wall.

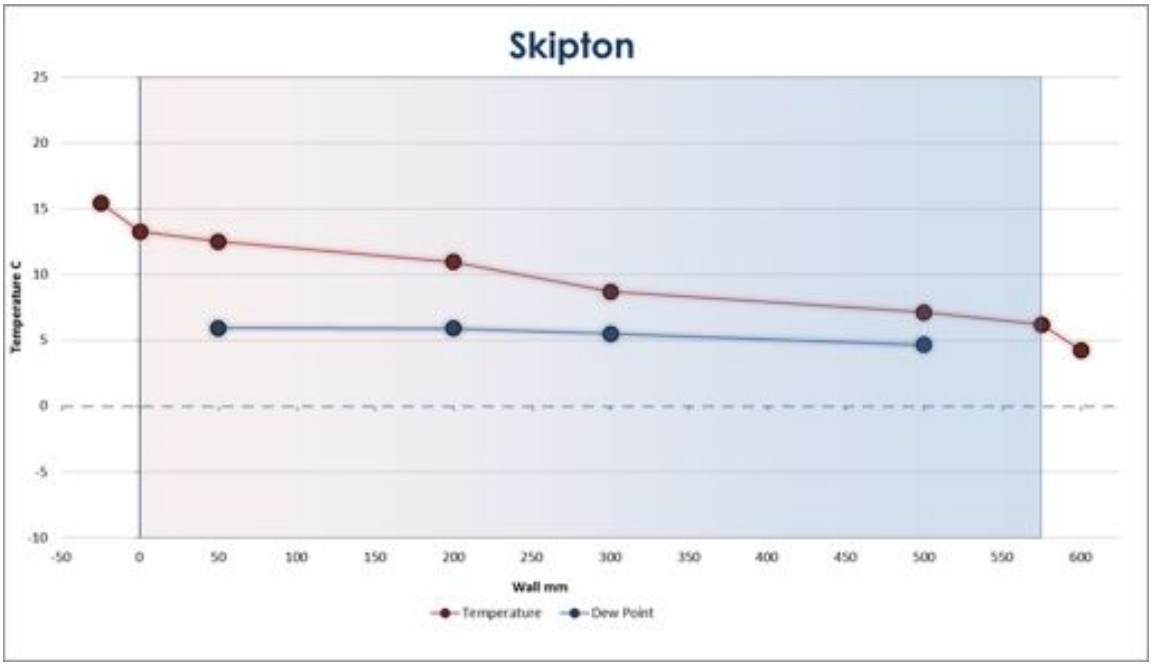



*Figure 27. Temperature and dewpoint gradient for White House Farm, Skipton, February 2011.*

The temperature gradient indicates the insulative effect of the wall where there is a 7.5˚C temperature difference on average between the interior and exterior surfaces. The different temperature gradients between each sensor point indicates a wall of less homogenous construction and this is particularly marked between points two and three which were positioned either side of the wall's rubble core. The steep temperature drop from between these two points show the beneficial effect of the core where it acts as a quasi cavity and buffers the internal conditions from the colder external temperatures. The dewpoint gradient is relatively steady through the wall and as expected begins to converge towards the exterior wall face as the temperature falls. At no point do the temperature and dewpoint gradients intersect, the temperature margin calculated for this wall over the monitoring period being 4.34˚C, therefore it would appear that there is no likelihood of interstitial condensation forming within the wall as it is currently configured.

Sensor values for the wall were logged at 5 minute intervals and this information has been animated in order that changes in temperature and dewpoint maybe analysed over time. (To view the interstitial gradients animation for White House Farm, Skipton visit www.archimetrics.co.uk). The effects of solar radiation gain to the south facing wall can be observed on a few occasions during the monitoring period, when peaks in external air and surface temperature transfer someway into the body of the wall. Similar peaks in indoor temperatures affecting the body of the wall can also be observed. However neither peaks in interior or exterior temperatures transfer across the wall in its entirety indicating neither excessive heat loss nor heat gain. This stabilising effect is likely to be a result of the heavy weight nature (thermal mass) of the mass masonry construction.

Surface Moisture

On 24th February 2011 two measurements were taken of moisture conditions of the interior wall surface, a resistive measurement of the surface itself and a capacitance reading to a depth of approximately 40mm. Figure 28 plots the two measurements in relation to one another to a height of 2000mm above finished floor level along a nominal moisture scale.

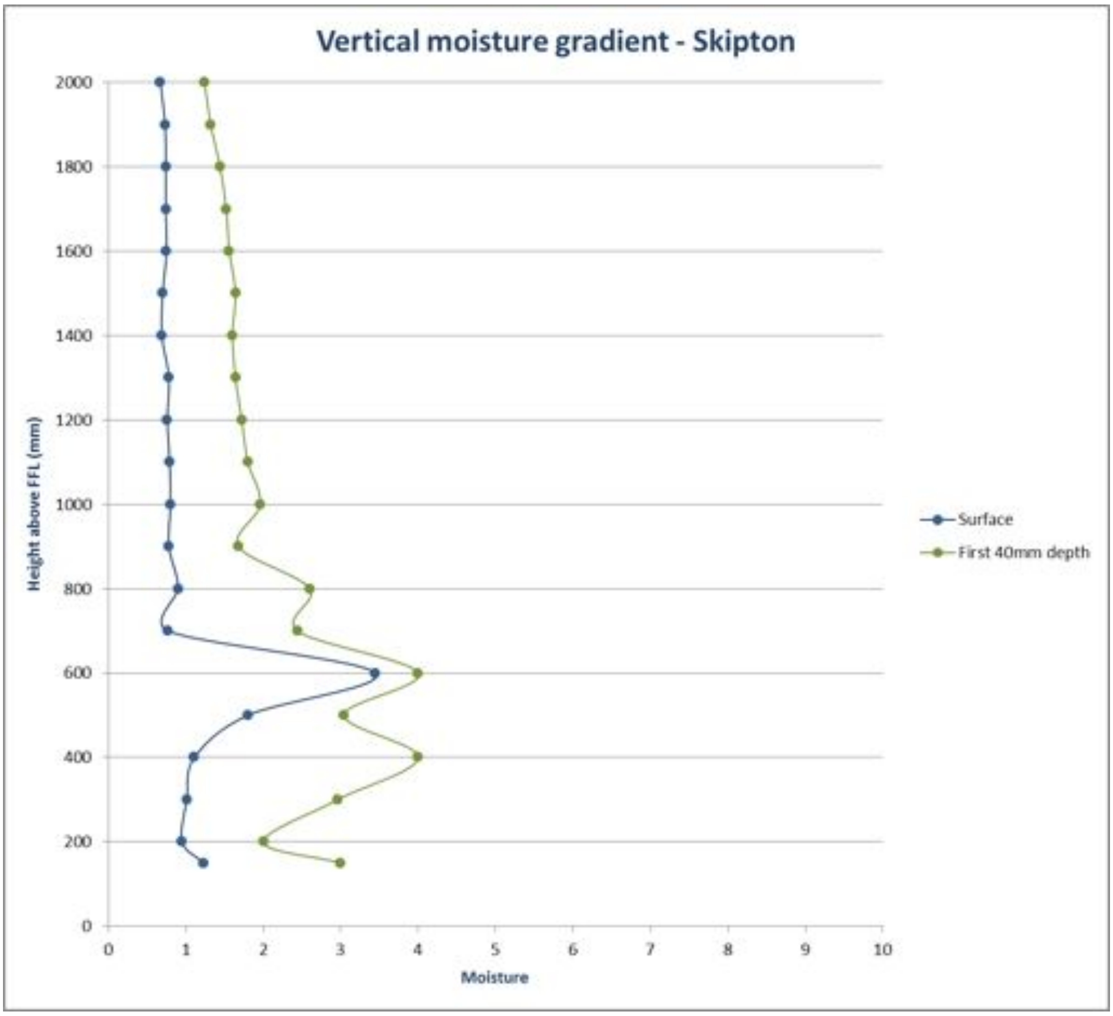



*Figure 28. Surface moisture measurements at White House Farm, Skipton, 24th February 2011.*

The profile of the two vertical moisture gradients roughly mirror one another and stabilise at 1000mm above finished floor level. Below this height moisture levels occasionally spike, with the increases recorded across both measured planes at 600mm. This height coincided with the presence of a stone window sill which may indicate the presence of water tracking along this component into the body of the wall. However it is interesting to note that the surface moisture readings above and below this height show the wall performing within its usual range. This could be as a result of the wall finishes which buffer or protect the surface of the wall from the higher underlying moisture content allowing for a more consistent performance for the wall surface.

INDOOR AIR QUALITY & COMFORT/FABRIC RISK

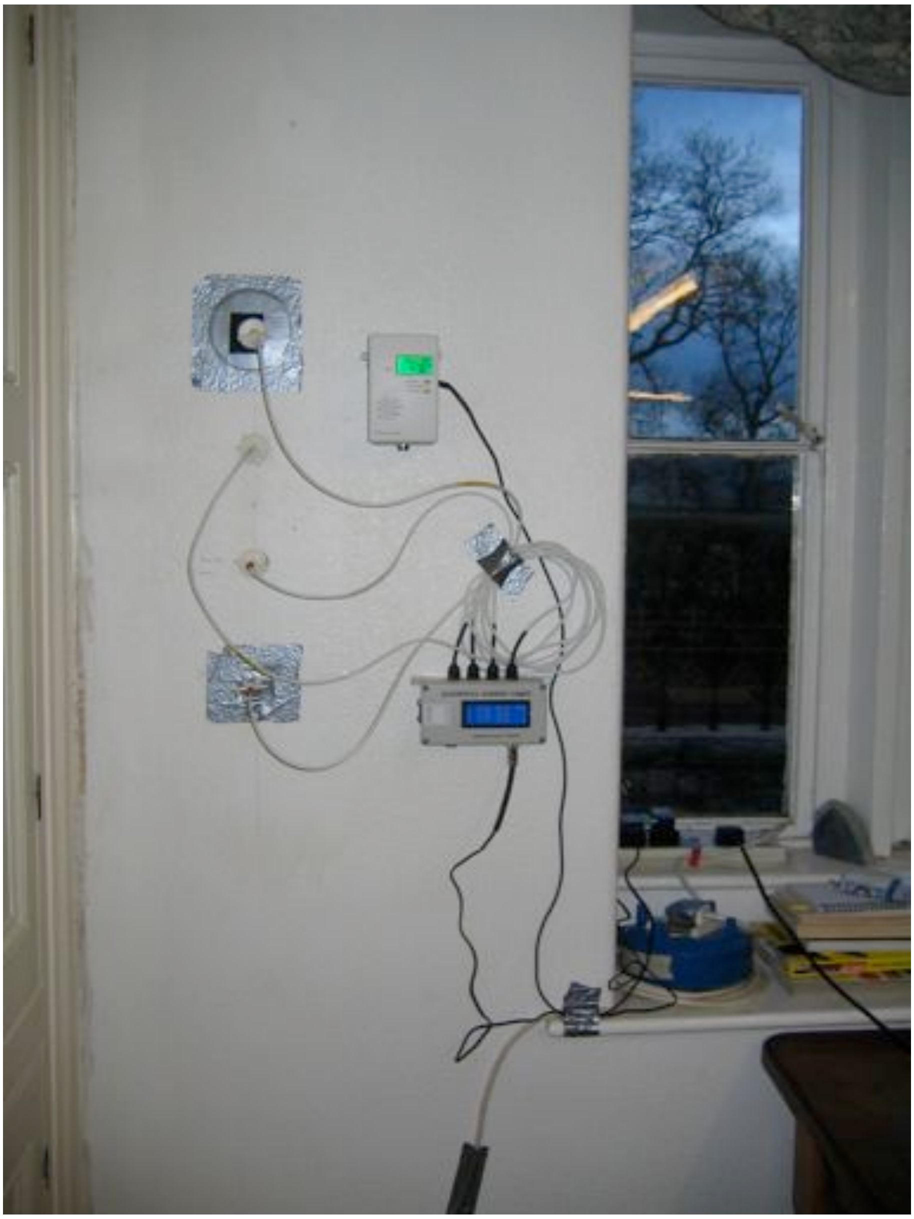


*Figure 29. Interstitial and Air Quality loggers at White House Farm, Skipton, 2011.*

| **PROPERTY** | **$CO_2$ (ppm)** | **Temp (˚C)** | **RH (%)** |
|---|---|---|---|
| Skipton | 554.5 | 16.2 | 63.3 |

*Table 15. Indoor Conditions at White House Farm, Skipton 2011.*

Table 15 provides a summary of the indoor conditions surveyed within the kitchen on the ground floor at White House Farm (Fig. 29). The figures represent average values recorded over the monitoring period 10 - 24th February 2011.

Parameters surveyed were $CO_2$, air temperature and relative humidity levels. The individual indoor temperature and relative humidity readings were also plotted against an index of human comfort and fabric risk. The results for White House Farm can be seen in Figure 30.

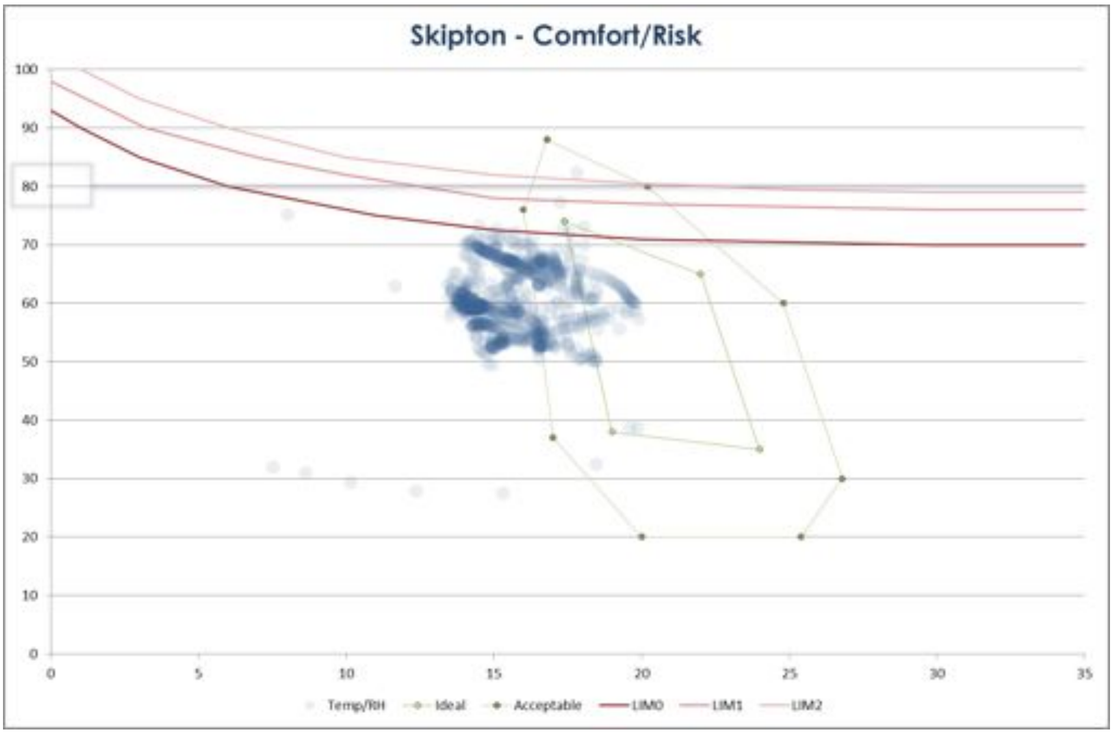
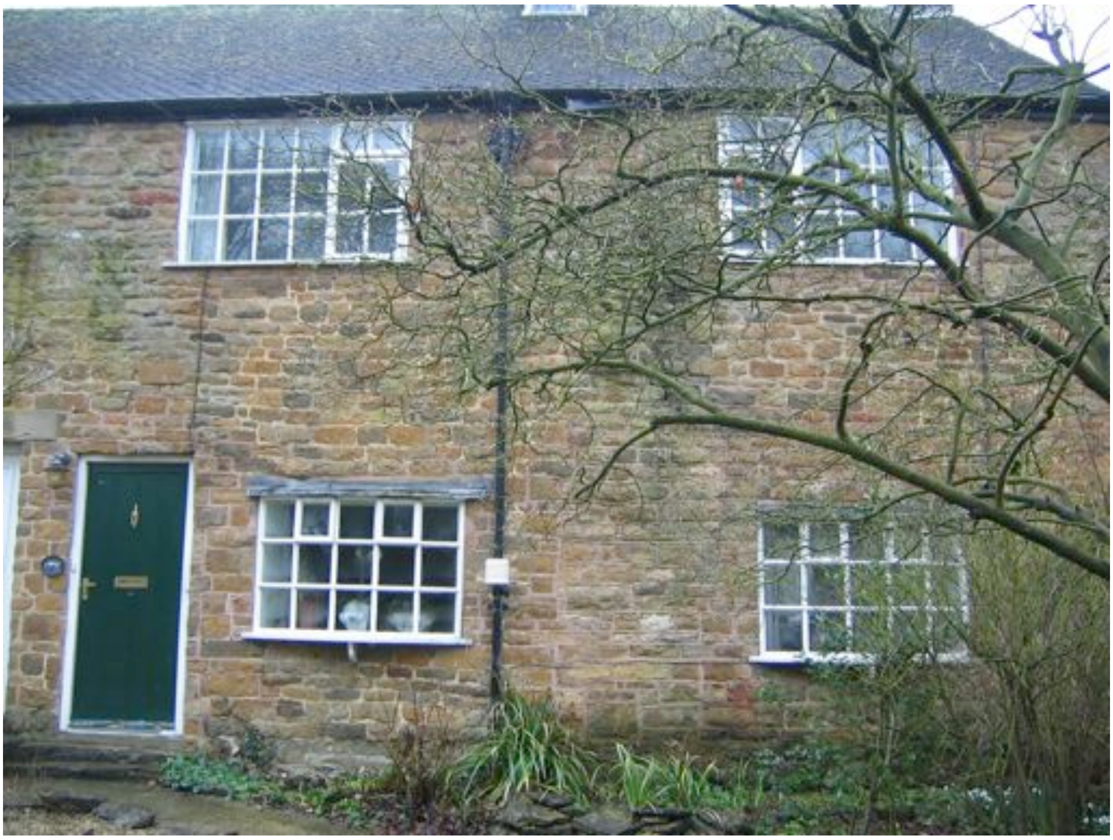



*Figure 30. Comfort/Risk Analysis for White House Farm, Skipton, 2011.*

As is shown in Figure 30 the majority of the temperature/relative humidity measurements fall slightly outside of the parameters deemed ideal or even acceptable for human comfort, with lower temperatures and slightly raised humidity being recorded at White House Farm. However these conditions do not seem to imperil the fabric of the building as the temperature/relative humidity cluster sits below the limiting isopeths for mould gradients which mark the tolerance thresholds for various material types (LIM 0 - ideal culture medium, LIM 1 - timber, LIM 2 Masonry).

# April Cottage, Lower Brailes, Warwickshire.
# 2011



Description: C19 two storey terraced cottage of Hornton stone with modern additions comprising of a brick kitchen extension to rear and attic room with dormer roof. The walls are of coursed stone blocks set in lime mortar with no discernable rubble core, Hornton stone being a ferruginous limestone of the middle lias found in the nearby village of Hornton.

Occupancy: 1 person

Floor Area: 113 $m^2$

*Figure 31. Plan of April Cottage, Lower Brailes, with ground floor on LHS.*

The red dot indicates the location of the monitoring equipment. The air permeability perimeter is shown in blue, with the secondary test zone shown in red.

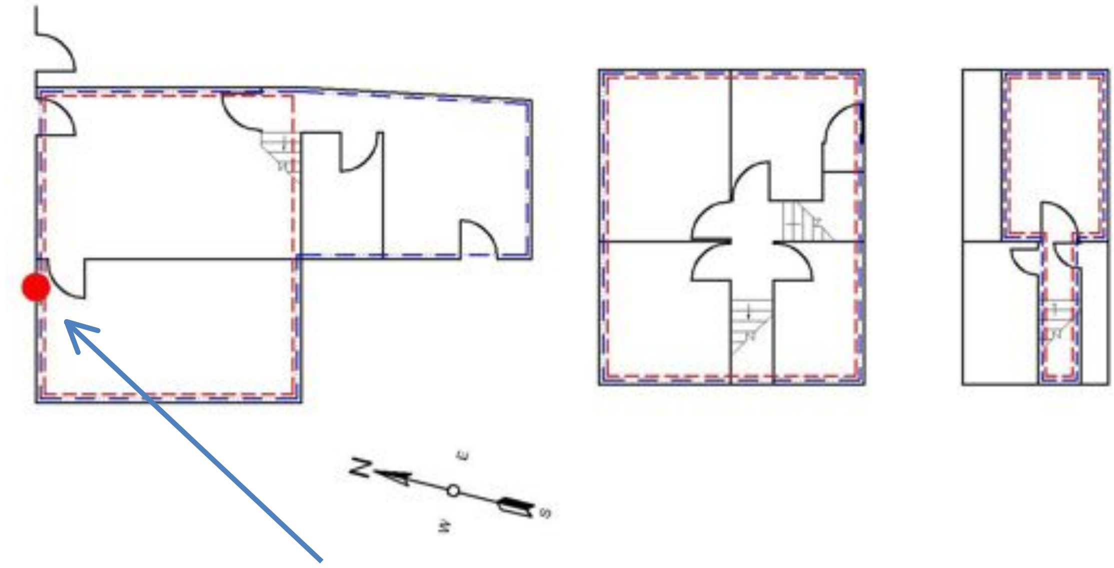


*Figure 32. Positions of in situ monitoring equipment at April Cottage, Lower Brailes, 2011.*

U-VALUES

Between 21st February - 28th March 2011 two *in situ* U-value measurements were taken on the north wall of the ground floor living/office room (Figs. 31 - 32). The results along with standard U-value calculations made following the BR 443 method are shown in Table 1.

| Location | Materials/ Build Up | mm | In-situ U-value | BR 443 U-value |
|---|---|---|---|---|
| North Wall Grd Floor Living Rm/Office - low 21/02/11-28/03/11 | Hornton Stone rubble<br>Lime Plaster<br>Gypsum skim | 499<br>20<br>3 | | |
| | Total | 522 | 1.39 | 2.03 |
| North Wall Grd Floor Living Rm/Office - high 21/02/11-28/03/11 | Hornton Stone rubble<br>Lime Plaster<br>Gypsum skim | 499<br>20<br>3 | | |
| | Total | 522 | 1.49 | 2.03 |

*Table 16. U-value results for April Cottage, Lower Brailes, 2011.*

The two *in situ* U-values measured for the wall at April Cottage are within the same range, 1.39 W/m$^2$K and 1.49 W/m$^2$K, the difference between them being within the ± 10% error margin attributed to the *in situ* U-value method. There is a difference of 0.10 W/m$^2$K between the upper and lower *in situ* U-values with the upper heat flux sensor recording a greater level of heat loss, 1.49 W/m$^2$K than the lower sensor, 1.39 W/m$^2$K. This pattern does not conform to the relationship found in other properties in the study where normally the lower section of walls measured greater rates of heat loss it is thought due to higher concentrations of moisture at the base of the walls from ground water take up. The reason for this inversion may be because, at sometime historically, the eaves at April Cottage have been raised to alter the cottage from one and half to two storeys (this can be deduced as the adjoining terraced house retains the original eaves height). Where the wall head has been raised to accommodate the full storey the wall has also been stepped back creating an exposed ledge three quarters of the way up the front elevation. The wall beneath this ledge is stained green suggesting damp conditions which support algae growth on the surface of the stone work and there is plant growth on the top of the ledge (Fig. 33).

*Figure 33. April Cottage, Lower Brailes front elevation showing green staining.*

Because of this construction it is possible that water collecting on the ledge is also penetrating into the body of the wall and moving down to ground floor level causing the interior of the wall to have a higher moisture content someway up the wall, hence the inversion in heat loss pattern for this section. There is further evidence from the thermographic survey of this property and in the reporting of interstitial moisture for April Cottage to support this theory.

There is a large discrepancy between the *in situ* U-values and the calculated U-values for this wall. This divergence corresponds with similar discrepancies found for stone walls in other studies. 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 i.e. inability to provide a full definition of all the materials and voids involved in the wall build up, the use of generalised thermal conductivity information and the oversimplification of the wall structure by the calculating software. Given the problems previously identified and following best practice guidance the *in situ* U-values can be taken to be the more accurate assessment of thermal transmittance for this wall at April Cottage.

## AIR PERMEABILITY

The complete living space at April Cottage was air permeability tested on 25th February 2011, with the test equipment mounted in the dining room entrance to the property. As an additional test, the original part of the dwelling was examined alone, though this is subject to the reservation that it was not possible to open the door and windows in the adjacent extension. Both test areas are identified in Figure 31. Interior and exterior conditions at the time of testing are noted in Table 17 and the results of the whole dwelling air permeability test are shown in Table 18.

| | |
|---|---|
| Date of Test: | 25 February 2011 9.30am onwards |
| Prevailing weather conditions at time of test: | Dry, light breeze. 13°C, 80% RH (approx. 11am) |
| Conditions inside dwelling: | Living room - 18°C 81% RH (approx. 11.30am) – building being heated by propane gas heater to elevate temperature for thermal imaging. |

*Table 17. Interior and exterior conditions for air permeability test at April Cottage, Lower Brailes.*

| | Units | Results | Comments |
|---|---|---|---|
| **Whole dwelling** | | | |
| Internal floor area | $m^2$ | 113 | |
| Habitable building volume | $m^3$ | 263 | |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 285 | |
| Measured air flow | $m^3h^{-1}$ | 2478 | The doors into the roof voids from the second floor landing were poorly fitting and these were taped over for the purpose of the testing and therefore excluded from the test results. |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 8.7 | $m^3$ of air per hour per $m^2$ of surface area of the living space at the test pressure. |
| Air changes per hour at 50Pa | ach@50 Pa | 9.4 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

*Table 18. Results for whole house air permeability test at April Cottage, Lower Brailes.*

The air flow measured for the whole dwelling was 2478 $m^3h^{-1}$ at 50 Pa pressure difference. Relating this figure to the total surface area of the property, table 3 shows this equates to an air permeability of 8.7 $m^3h^{-1}m^{-2}$ @50 Pa. This performance is favourable compared to the limiting air permeability applied under Approved Document L1A 2010 for new build dwellings (10 $m^3h^{-1}m^{-2}$ @50 Pa). Comparing the dwelling volume to the measured air flow, the air change rate at 50Pa is 9.4, representing the number of times per hour the total volume of air in the building will change at this pressure difference. From Sherman, this would represent an air change rate of just under 0.5 ach broadly complying with orthodoxy (BRE 1985, Warm & Oxley 2002).

In an attempt to isolate the older part of the building from the modern addition, a stage test was also carried out, considering the older part of the dwelling only, see Figure 32 for the extent of measured area.

This test does not truly reflect the air permeability figure because the outer door and windows were closed rather than open to the outdoors (which has the effect of making the older part of the building look tighter than it is), but they do help to put the different parts of building into context. These figures must only therefore be treated as indicative as it does not comply with the standard test procedure. The results of this test are detailed in Table 19 and indicate the older part of the building has a higher air permeability (9.4 $m^3h^{-1}m^{-2}$ @50 Pa) than the dwelling as a whole (8.7 $m^3h^{-1}m^{-2}$ @50 Pa).

| | **Units** | **Results** |
|---|---|---|
| **Older part of dwelling** | | |
| Internal floor area | $m^2$ | 96 |
| Habitable building volume (of above areas) | $m^3$ | 224 |
| Dwelling envelope area i.e. surface area of living space (of above areas) | $m^2$ | 230 |
| Measured air flow | $m^3h^{-1}$ | 2152 |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 9.4 |
| Air changes per hour at 50Pa | ach@50 Pa | 9.6 |

*Table 19. Air permeability results for older part of April Cottage, Lower Brailes.*

Flues

Under the standard test procedure, chimneys and flues in the dwelling are excluded from the results. However, measurement of the air flow was made whilst the building was depressurised. Both flues in April Cottage have ventilation plates fitted. There was no evidence of any flow from the flue in the Dining Room, but an additional flow of $61m^3h^{-1}$ was recorded from the intake in the Living Room.

## THERMOGRAPHIC SURVEY

Thermal imaging was carried out inside April Cottage whilst the air permeability testing was carried out on 25th February 2011. There was only a 5$^{o}$C difference in temperature between inside the dwelling and ambient temperature, limiting the results obtained. However, the use of thermal imaging whilst the air permeability testing took place exaggerated the ingress occurring. Infiltration through the floor / ceiling voids was particularly noticeable during the testing process, to the extent that carpets in the rear first floor room and on the second floor lifted (Fig. 34).


*Figure 34.  April Cottage, Lower Brailes – second floor landing*

Thermal weak points in the building fabric were noticeable. Figure 36 shows the lack of insulation between the ceiling and the roof in the front first floor bedroom. Ingress around doors and window casements and opening lights was in evidence, together with infiltration around services - Figure 37 shows ingress into the service void in the bathroom and infiltration around the pipe work associated with the washbasin on the second floor.


*Figure 35. April Cottage, Lower Brailes – first floor bedroom*


*Figure 36.  April Cottage, Lower Brailes – bathroom*

## MOISTURE

### Interstitial Moisture

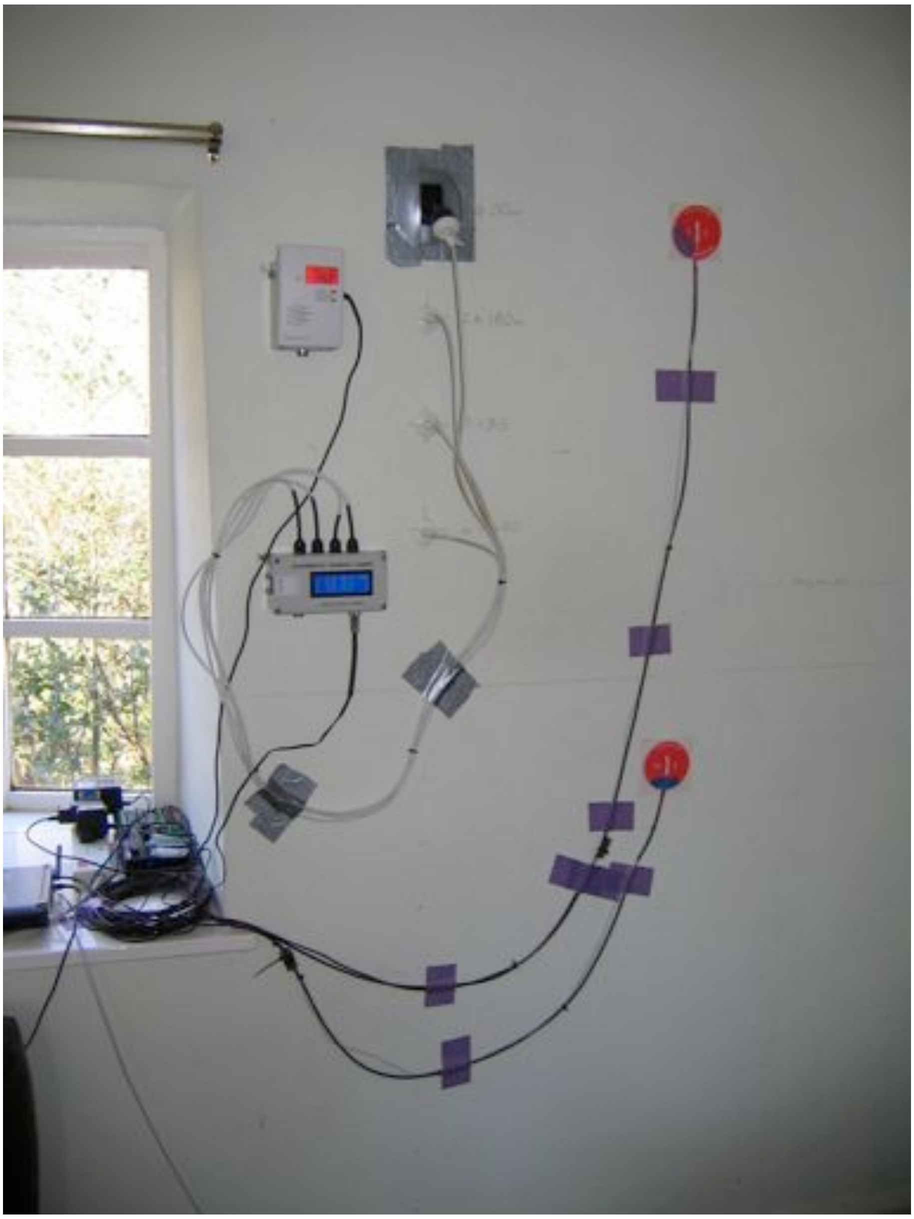


*Fig. 37. Interstitial, U-value and IAQ monitoring set up at April Cottage, Lower Brailes, 2011.*

Material moisture measurements were made on the north facing ground floor wall of the living/office (Fig. 37). Interstitial temperature and relative humidity sensors were located at the heights and depths given in Table 20 and recorded temperature and relative humidity changes at four points within the wall between the period 14th March - 28th March 2011.

| BUILD UP external - internal | SENSOR | HEIGHT from ffl | DEPTH from int sur finish |
|---|---|---|---|
| Stone - 500mm | Sensor 1 | 1875mm | 50mm |
| Lime Plaster - 20mm | Sensor 2 | 1725mm | 180mm |
| Gypsum skim - 3mm | Sensor 3 | 1575mm | 315mm |
| OVERALL = 522mm | Sensor 4 | 1425mm | 450mm |

*Table 20. Interstitial gradient sensor record for April Cottage, Lower Brailes, 2011.*

Figure 38 shows the average values of each sensor over the monitoring period graphed as separate temperature and dewpoint gradients. The values derived from the relative humidity sensors have been converted to dewpoints in order to indicate the likelihood of condensation forming within the wall.

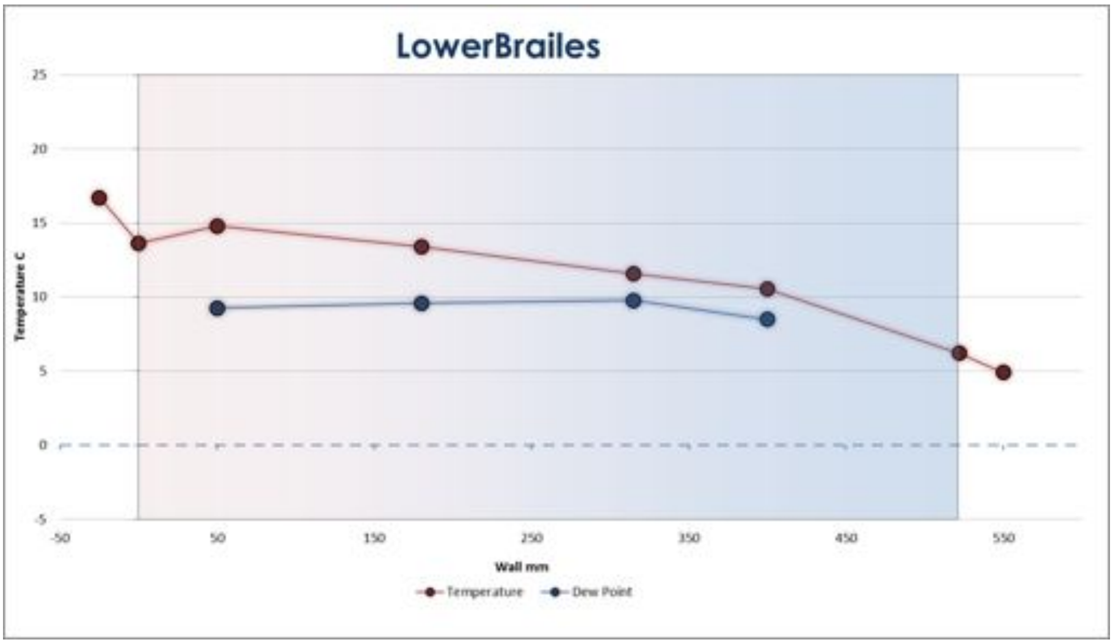



*Fig. 38. Temperature and dewpoint gradient for April Cottage, Lower Brailes, March 2011.*

The temperature gradient indicates the insulative effect of the wall where there is an 8˚C temperature difference on average between the interior and exterior surfaces. The consistency of gradient between each temperature sensor (points within the body of the wall) shows a wall of homogenous construction and indeed little loose rubble was encountered during the installation of the sensors. The dewpoint margin calculated over the monitoring period for this wall was 3.30˚C. The dewpoint gradient for this wall is a little unusual as it shows the closest convergence between dewpoint and temperature occurring at some depth within the body of the wall, at sensor position 3 (315mm back from the internal wall surface). The normal pattern, seen at other properties, sees the temperature and dewpoint lines converging near the exterior face of the wall as the temperature drops to meet cold exterior conditions. The close relationship between temperature and dewpoint at node 3 in this wall could be a reflection of higher moisture (relative humidity) conditions at this point as a result of water penetration into the body of the wall from the exposed ledge above (see discussion in U-value section).

Sensor values for the wall were logged at 5 minute intervals and this information has been animated in order that changes in temperature and dewpoint maybe analysed over time. (To view the interstitial gradients animation for April Cottage, Lower Brailes, visit www.archimetrics.co.uk). As interior and exterior air temperatures fluctuate it is possible to see the degree of influence this exerts through the wall structure. As would be expected sensors positioned in proximity to the internal and external surfaces respond, after a slight delay, in sympathy with the surrounding conditions i.e. heat input into the room causes a rise in temperature at sensor position 1 (50mm back from internal surface). What is also noticeable, however, is the relative lack of volatility in the responses of the temperature sensors placed deeper within the core of the wall (2 and 3, 180mm and 315mm back from internal surface). For significant periods during the fourteen day monitoring period sensor 2 is effectively static, only occasionally fluctuating a few degrees above and below 13˚C despite peaks in external and internal temperatures of - 3.5˚C and 21˚C respectively. The equable temperature response of the middle two sensors is a reflection of the high degree of thermal mass involved in the wall construction. It may also be possible to discern the cooling effect of convection at the interior surface of the wall at Lower Brailes where the gradient between the interior air temperature and first internal wall sensor remains consistent but the temperature at the wall surface dips (Fig. 38).

On 14th March 2011 two measurements were taken of moisture conditions of the interior wall surface, a resistive measurement of the surface itself and a capacitance reading to a depth of approximately 40mm. Figure 39 plots the two measurements in relation to one another to a height of 2000mm above finished floor level along a nominal moisture scale.

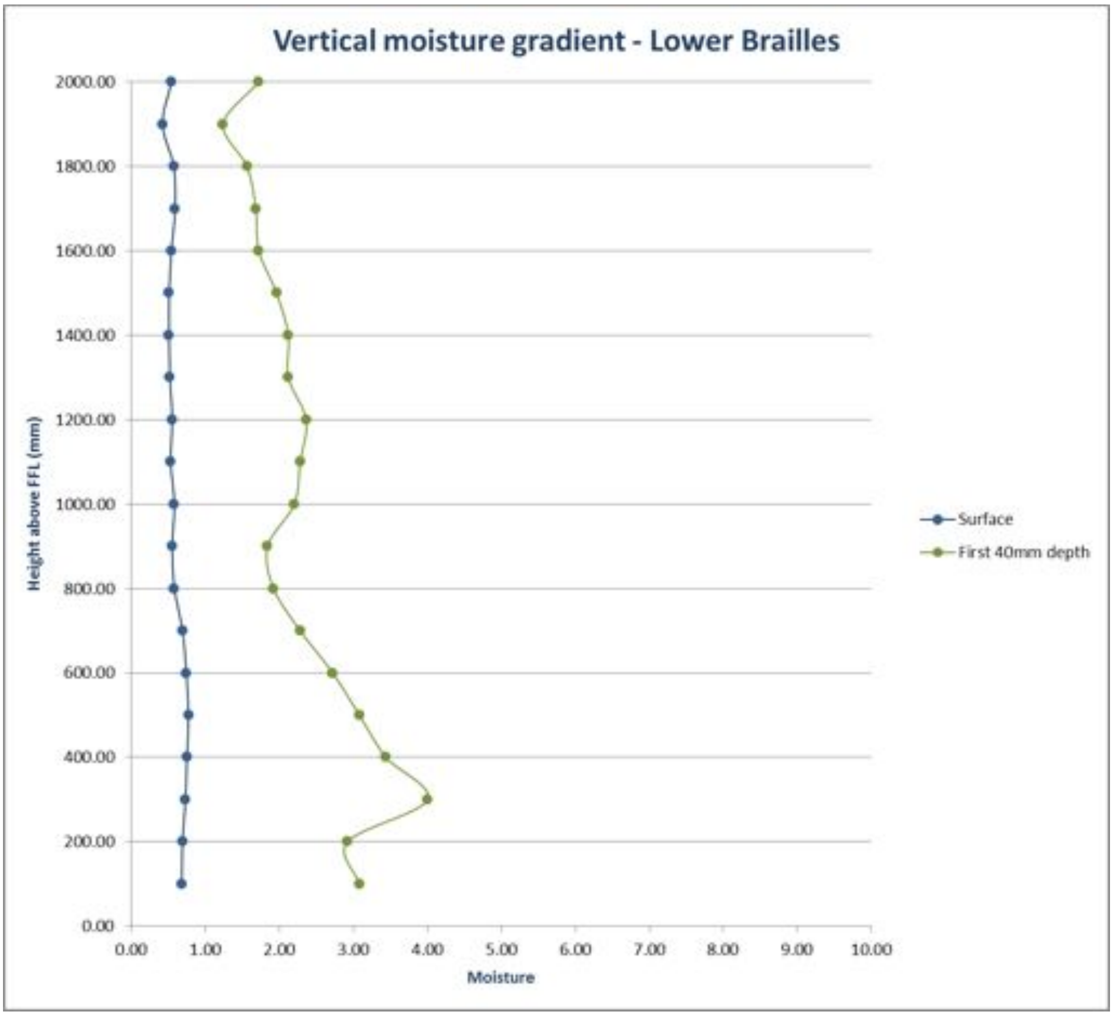



*Figure 39. Surface moisture measurements at April Cottage, Lower Brailes, 14th March 2011.*

The profile of the surface moisture gradient shows little deflection from the vertical indicating the moisture conditions at the wall's surface are stable and consistent within the range of the height measured (2000mm). The surface of the wall has relatively lower amounts of moisture present than that shown by the measurements taken 40mm back from the wall surface, here moisture content is greater and peaks at 300mm up from finished floor level. It was observed that external ground levels were raised due to the presence of a flower bed against this part of the wall and this could account for the peak in moisture level at this point. Moisture content at 40mm deep decreases in relation to height above finished floor level, but unlike measurements taken at other properties the relationship between surface and 40mm measurements does not seem to stabilise and run parallel to one another above the 1000/1200mm 'rising damp' level. Perhaps this is also an indication of higher than normal moisture content within the body of the wall as a result of the exposed ledge higher up the wall elevation (see above).

INDOOR AIR QUALITY & COMFORT/FABRIC RISK

Table 20 provides a summary of the indoor conditions surveyed within the kitchen on the ground floor at April Cottage (see plan). The figures represent average values recorded over the monitoring period 14th March - 28th March 2011.

| **PROPERTY** | **$CO_2$ (ppm)** | **Temp (˚C)** | **RH (%)** |
|---|---|---|---|
| Lower Brailes | 1191.5 | 17.7 | 57.0 |

*Table 20. Indoor Conditions at April Cottage, Lower Brailes 14th March - 28th March 2011.*

Parameters surveyed were $CO_2$, air temperature, and relative humidity levels. The individual indoor temperature and relative humidity readings were also plotted against an index of human comfort and fabric risk. The results for April Cottage can be seen in Figure 40 below.

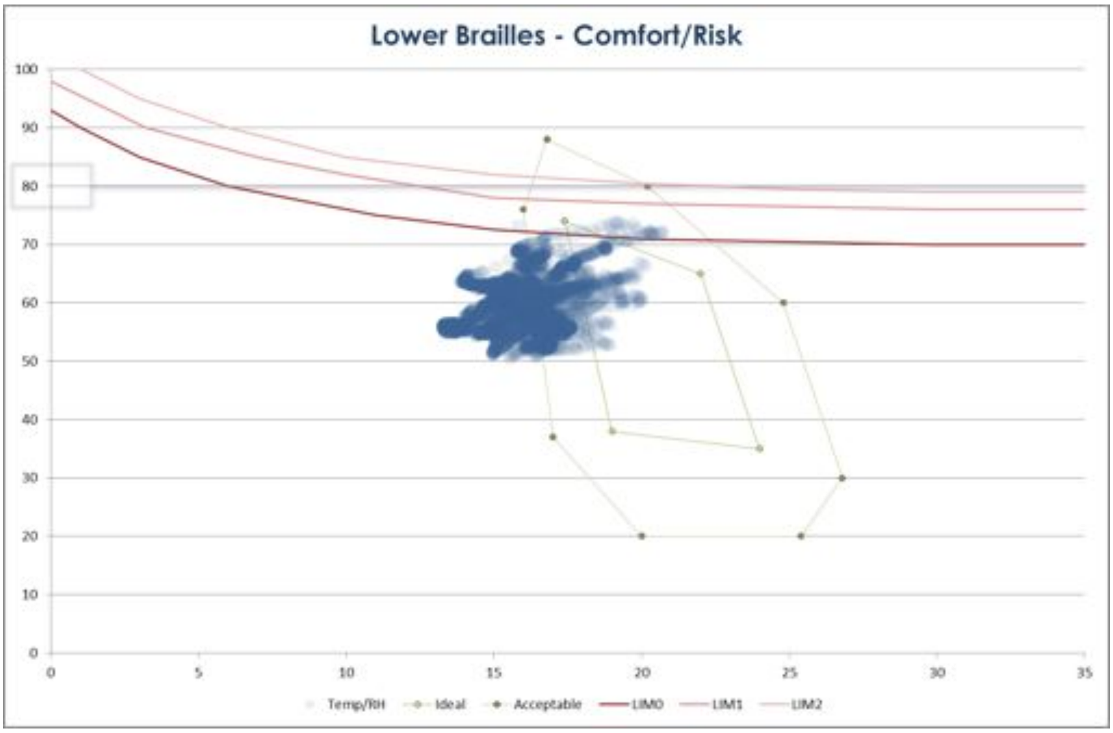



*Figure 40. Comfort/Risk Analysis for April Cottage, Lower Brailes 2011.*

As is shown in Figure 40 the majority of the temperature/relative humidity measurements fall slightly outside of the parameters deemed ideal or even acceptable for human comfort, with lower temperatures and slightly raised humidity being recorded at April Cottage. However these conditions do not seem to imperil the fabric of the building as the majority of the temperature/relative humidity cluster sits below the limiting isopeths for mould gradients which mark the tolerance thresholds for various material types (LIM 0 - ideal culture medium, LIM 1 - timber, LIM 2 Masonry).

## The Firs, Riddlecombe, Devon.
## 2011

Description: Two storey, semi-detached, nineteenth century cob cottage with early twentieth century single storey addition in cob to right side and more recent extensions to rear. Mainly new timber double glazed units.

Occupancy: Family of 5.

Floor Area: 86m$^2$

*Figure 40. Plan of The Firs, Riddlecombe (ground floor on RHS).*

Location of monitoring equipment shown by red dot. Air permeability test perimeter shown in blue, with secondary test zone indicated with red dotted line.

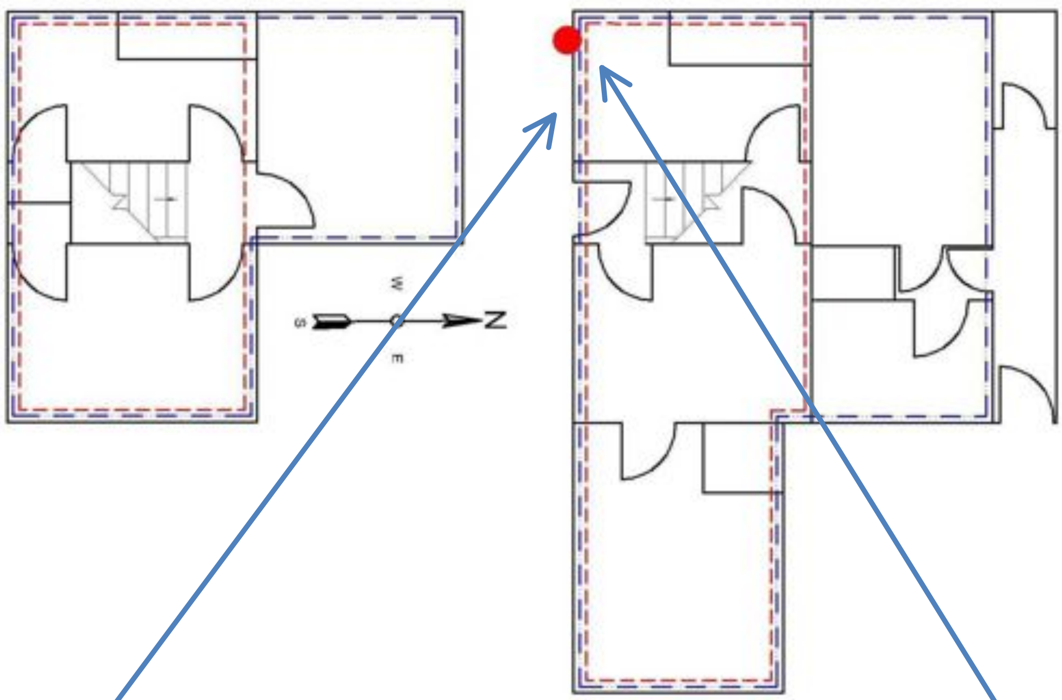



*Figure 41. Positions of in situ monitoring equipment at The Firs Riddlecombe 2011.*

U-VALUES

Between 25th February - 11th March 2011 two *in situ* U-value measurements were taken on the south wall of the ground floor office room (Figs. 40 & 41). The results along with standard U-value calculations made following the BR 443 method are shown in the Table 21 below.

| **Location** | **Materials/ Build Up** | **mm** | **In-situ U-value** | **BR 443 U-value** |
|---|---|---|---|---|
| South Wall Grd Floor Office - low<br>630mm above ffl | Cement render<br>Cob<br>Clay & Lime Plaster<br>Gypsum skim | 40<br>617<br>20<br>3 | | |
| 25/02/11-11/03/11 | Total | 680 | 1.05 | 0.93 |
| South Wall Grd Floor Office - high<br>1790mm above ffl | Cement render<br>Cob<br>Lime Plaster<br>Gypsum skim | 40<br>617<br>20<br>3 | | |
| 25/02/11-11/03/11 | Total | 680 | 0.76 | 0.93 |

*Table 21. In situ and calculated U-value results for The Firs, Riddlecombe March 2011.*

The two *in situ* U-values measured for this wall are significantly different, the difference between them being outside of the ± 10% error margin attributed to the *in situ* U-value method. The U-value measured at the lower part of the wall (at 630mm above finished floor level) shows greater thermal transmissivity, 1.05 $W/m^2K$ than that measured higher up, 0.76 $W/m^2K$ (at 1790mm from ffl). The reason for this is likely to be due to the high concentrations of moisture found towards the base of this cob wall which increases the conductivity of the wall as a whole (see later section on moisture).

The U-value that was calculated for this wall using the BR 443 standard sits between the two *in situ* U-values that were found. A calculated U-value relies on knowledge of the individual thermal conductivity values (sometimes called K values or lambda values) for the materials that make up a wall, in this instance cob. Cob is not detailed on the standard material databases found within the calculating software therefore it is necessary to search elsewhere for this information. The thermal conductivity value used in this calculation, 0.73 W/mK, is from a paper written on behalf of the Devon Earth Building Association by Tony Ley and Mervyn Widgery[5] and is the value given for cob at the lower end of its density range 1700 kg/m3. The fact that one of the *in situ* U-values recorded on the drier section of cob wall, 0.76 W/m$^2$K is of lower number value than the calculated U-value 0.93 W/m$^2$K suggests that the cob in this wall is at even lower density (and thus is less thermally conductive) than the range given in this research. The improved *in situ* figure is also likely to be a reflection of the ability of an *in situ* U-value measurement, unlike a standard calculation, to take into account the beneficial effect of thermal mass, as well as other external factors such as solar radiation (it was a south facing wall) within the overall description of the wall's thermal transmissivity.

## AIR PERMEABILITY

Air permeability testing was carried out on the complete habitable volume at The Firs on 16th March. As an additional test, the original part of the building was examined alone (Fig. 40.) though this has the reservation that it was not possible to open the door and windows in the extensions excluded from this space. Interior and exterior conditions at the time of testing are noted in Table 22 and the results of the whole dwelling air permeability test are shown in Table 23.

| | |
|---|---|
| Date of Test: | 16 March 2011 10am onwards |
| Prevailing weather conditions at time of test: | Sunny, no cloud cover, still, no precipitation. External shade conditions 12°C 78% RH (11.30am approx) |
| Conditions inside dwelling: | Living room 22°C 60% RH (approx.11am); Kitchen 21°C 68% RH (approx.12 noon) |

*Table 22. Interior and exterior conditions for air permeability test at The Firs, Riddlecombe.*

[5] Tony Ley, Mervyn Widgery, (1997) "Devon Earth Building Association: cob and the Building Regulations", Structural Survey, Vol. 15 Iss: 1, pp.42 - 49

| | Units | Results | Comments |
|---|---|---|---|
| **Whole dwelling** | | | |
| Internal floor area (ground and first floors) | $m^2$ | 86 | |
| Habitable building volume | $m^3$ | 189 | |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 245 | |
| Measured air flow | $m^3h^{-1}$ | 1355 | External door from conservatory open. |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 5.5 | $m^3$ of air per hour per $m^2$ of surface area of the living space. |
| Air changes per hour at 50Pa | ach@50 Pa | 7.2 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

*Table 23. Results for whole house air permeability test at The Firs, Riddlecombe.*

Under the test conditions, the air flow measured for the property as a whole was 1355 $m^3h^{-1}$. Related to the total surface area of the property, Table 23 shows this equates to an air permeability of 5.5 $m^3h^{-1}m^{-2}$ @50 Pa. This performance is well within the limiting air permeability applied to new buildings under Approved Document L1A 2010.

Relating the dwelling volume to the measured air flow, the air change rate at 50Pa is 7.2 ach, representing the number of times per hour the total volume of air in the building will change at this pressure difference. From Sherman, this would represent an air change rate just under 0.4, which is lower than orthodoxy. It was noted the householder reported condensation problems in bedrooms overnight and this is likely to be related to the low infiltration rates measured.

| | Units | Results |
|---|---|---|
| **Older part of building (including sitting room)** | | |
| Internal floor area (ground and first floors) | $m^2$ | 54 |
| Habitable building volume | $m^3$ | 124 |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 184 |
| Measured air flow | $m^3h^{-1}$ | 927 |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 5.0 |
| Air changes per hour at 50Pa | ach@50 Pa | 7.5 |

*Table 24. Air permeability results for cob components of The Firs, Riddlecombe.*

In order to consider the cob dwelling (both 19$^{th}$ and 20$^{th}$ Century parts) separately from the extensions to the rear of the building, a stage test was also carried out (Fig. 40). This test does not truly reflect the air permeability figure because the outer doors were closed rather than open to the outdoors (which has the effect of making the older part of the building look tighter than it is) but they do help to put the different parts of building into context. The results of this test are detailed in Table 24 and indicate the cob part of the dwelling has a lower test result (5.0 $m^3h^{-1}m^{-2}$ @50 Pa) than the result for the building as a whole (5.5 $m^3h^{-1}m^{-2}$ @50 Pa).

Flue Test

Under the standard test procedure, chimneys and flues in the dwelling are excluded from the results. However, the air flows under depressurisation for the two flues at The Firs were measured. Though they will not directly relate to the air flows through chimneys when in use / not in use, the air flows (Table 25) from both these flues is low compared to other dwellings tested within the study.

| | **Additional m3h-1 @50Pa** |
|---|---|
| Sitting room (20C extension) – wood burning stove fitted | 32 |
| Living room stove– wood burning stove fitted | 22 |

*Table 25. The Firs, Riddlecombe – additional air flows relating to flues under air permeability test conditions.*

## THERMOGRAPHIC SURVEY

Thermal imaging was carried out inside The Firs whist the air permeability test was carried out on 16th March. There was no evidence of leakage from the recently replaced windows, however, there was evidence of ingress through the rear external door (Fig. 42) and around loft hatches (Fig. 43). A particularly cold area in the NE corner of the sitting room was noted (20$^{th}$ century cob) and is shown in Figure 44. With respect to the first floor, a variation in insulation on sloping ceiling of the rear bedroom extension was noted and is pictured in Figure 45 where solar gain was elevating the roof temperature. In the older part of the building, ingress around beams was also noted.

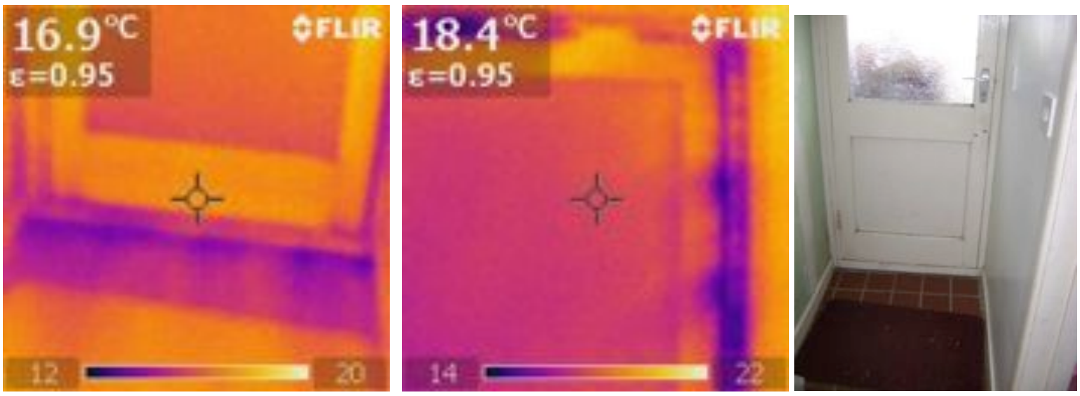



*Figure 42. The Firs, Riddlecombe – rear ground floor extension – external door.*


*Figure 43. The Firs, Riddlecombe – rear ground floor extension - loft hatch in rear lobby*


*Figure 44. The Firs, Riddlecombe – Sitting room (20th century cob) - north east corner*

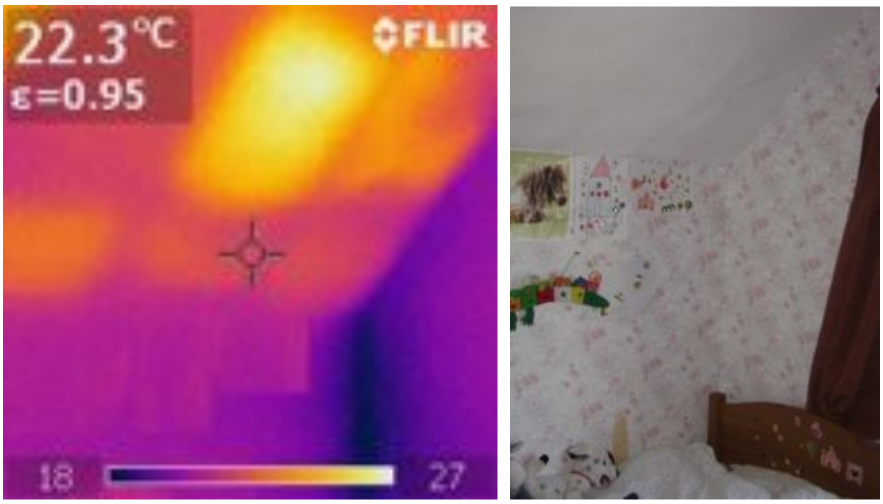



*Figure 45. The Firs, Riddlecombe – first floor extension: bedroom 2*

Whilst the air permeability test was being carried out, ingress of smoke in Bedroom 3 from the chimney of the adjoining property was witnessed. This can be seen in Figure 46, which shows the floor area warmed by the flue gases from the adjoining house's chimney being pulled into the room.

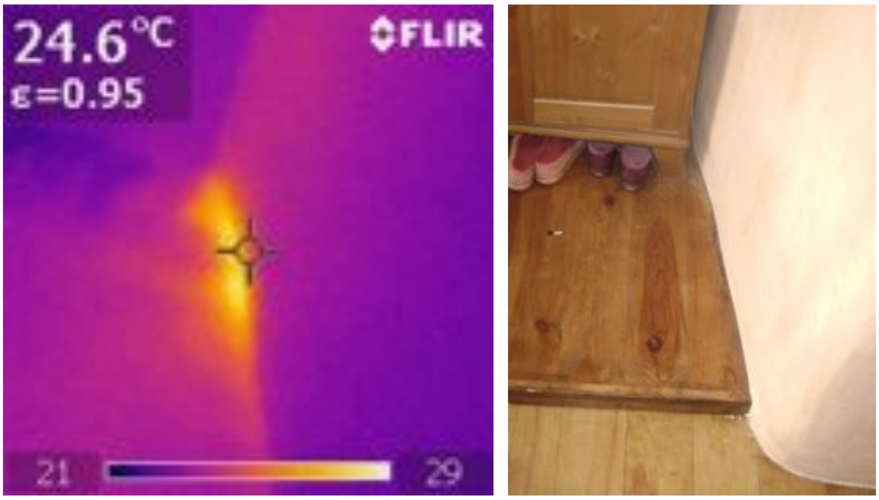



*Figure 46. The Firs, Riddlecombe – bedroom 3 - chimney flue gases.*

## MOISTURE

### Interstitial Moisture

*Figure 47. Interstitial, U-value and IAQ monitoring set up at The Firs, Riddlecombe, 2011.*

Material moisture measurements were made on the south facing ground floor wall of the office (Fig. 40). Interstitial temperature and relative humidity sensors were located at the heights and depths given in Table 26 and recorded temperature and relative humidity changes at four points within the wall between the period 25th February - 11th March 2011.

| BUILD UP external - internal | SENSOR | HEIGHT from ffl | DEPTH from int sur finish |
|---|---|---|---|
| Cement Render - 40mm | Sensor 1 | 1800mm | 50mm |
| Cob - 617mm | Sensor 2 | 1600mm | 225mm |
| Lime Plaster - 20mm | Sensor 3 | 1400mm | 400mm |
| Gypsum skim - 3mm | Sensor 4 | 1200mm | 580mm |
| OVERALL = 680mm | | | |

*Table 26. Interstitial gradient sensor record for The Firs, Riddlecombe, 2011.*

Figure 48 shows the average values of each sensor over the monitoring period graphed as separate temperature and dewpoint gradients. The values derived from the relative humidity sensors have been converted to dewpoints in order to indicate the likelihood of condensation forming within the wall.

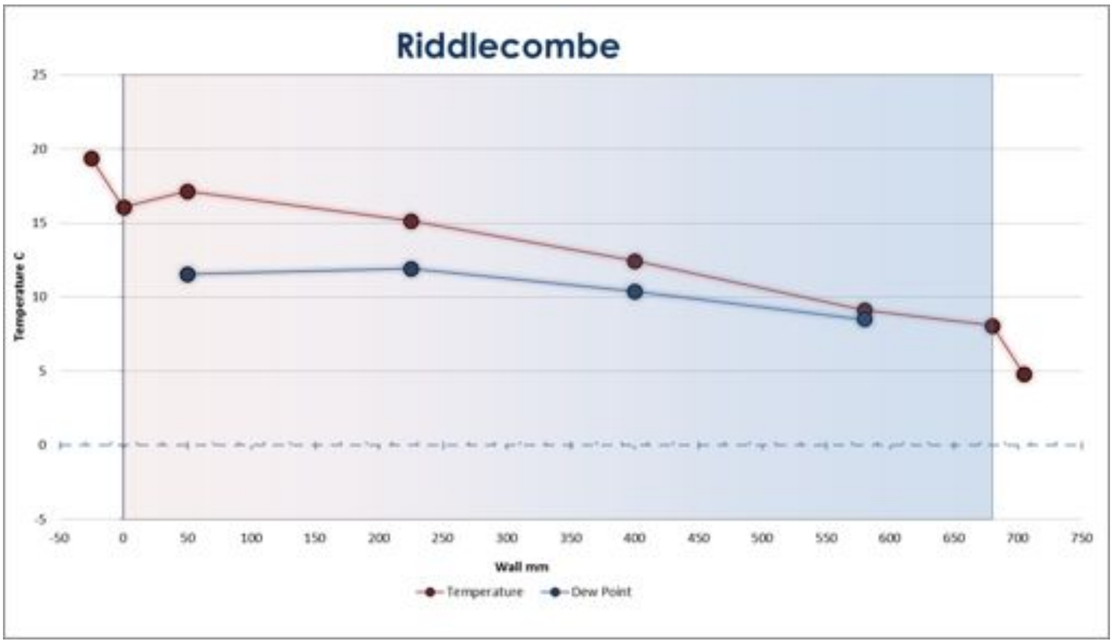



*Figure 48. Temperature and dewpoint gradient for The Firs, Riddlecombe, 2011.*

The temperature gradient indicates the insulative effect of the wall where there is an 8˚C average temperature difference between the interior and exterior surfaces. The consistency of gradient between the four intramural sensors indicates a wall of homogenous, uniform construction as could be expected in a mass walling material such as cob and indeed the consistency of material can be confirmed from the cores taken during the installation process, when only very occasionally was the cob interspersed with lumps of aggregate, 4-5mm in diameter.

An examination of the dewpoint gradient for this wall shows a position of near convergence with the temperature gradient at a depth of 580mm within the wall (sensor 4). Indeed the margin between temperature and dewpoint at this point is only 2.86˚C suggesting that indeed condensation maybe forming beyond this point towards the extremities of the colder external wall. The narrow dewpoint margin found at Riddlecombe maybe explained by the likelihood of high moisture content within the body of the wall structure, particularly towards the outer leaf of the wall. This is due to the cob being covered externally in a cement render which is cracked and likely to be admitting water into the wall but is prevented from evaporating by the presence of the render (Fig. 49.)

*Figure 49. Cracked render at The Firs, Riddlecombe, 2011.*

Sensor values for the wall were logged at 5 minute intervals and this information has been animated in order that changes in temperature and dewpoint maybe analysed over time. (To view the interstitial gradients animation for The Firs, Riddlecombe, visit www.archimetrics.co.uk). Overall fluctuations from the intramural sensors remain fairly static, particularly those temperatures recorded at sensors 1-3 located within the centre and inner leaf of the wall. The effects of solar radiation gain to the south facing wall can be observed on some occasions during the monitoring period, when peaks in external air and surface temperature transfer someway into the body of the wall and cause greater fluctuations to temperatures recorded at sensor position 4 (580mm back from internal surface). Interestingly these peaks do not obviously result in any significant rise in temperature transferring through the entire wall structure and temperatures from the other sensors remain relatively static in relation to the internal air/surface temperatures. This probably illustrates a productive relationship between thermal mass and thermal resistivity within this wall construction, in that the majority of the mass of the wall is protected from the extremes of external temperature change and thus, given sufficient heat input, is able to retain a consistently comfortable internal temperature.

Surface Moisture

On 25th February 2011 two measurements were take of moisture conditions of the interior wall surface, a resistive measurement of the surface itself and a capacitance reading to a depth of approximately 40mm. Figure 50 plots the two measurements in relation to one another to a height of 2000mm above finished floor level along a nominal moisture scale.

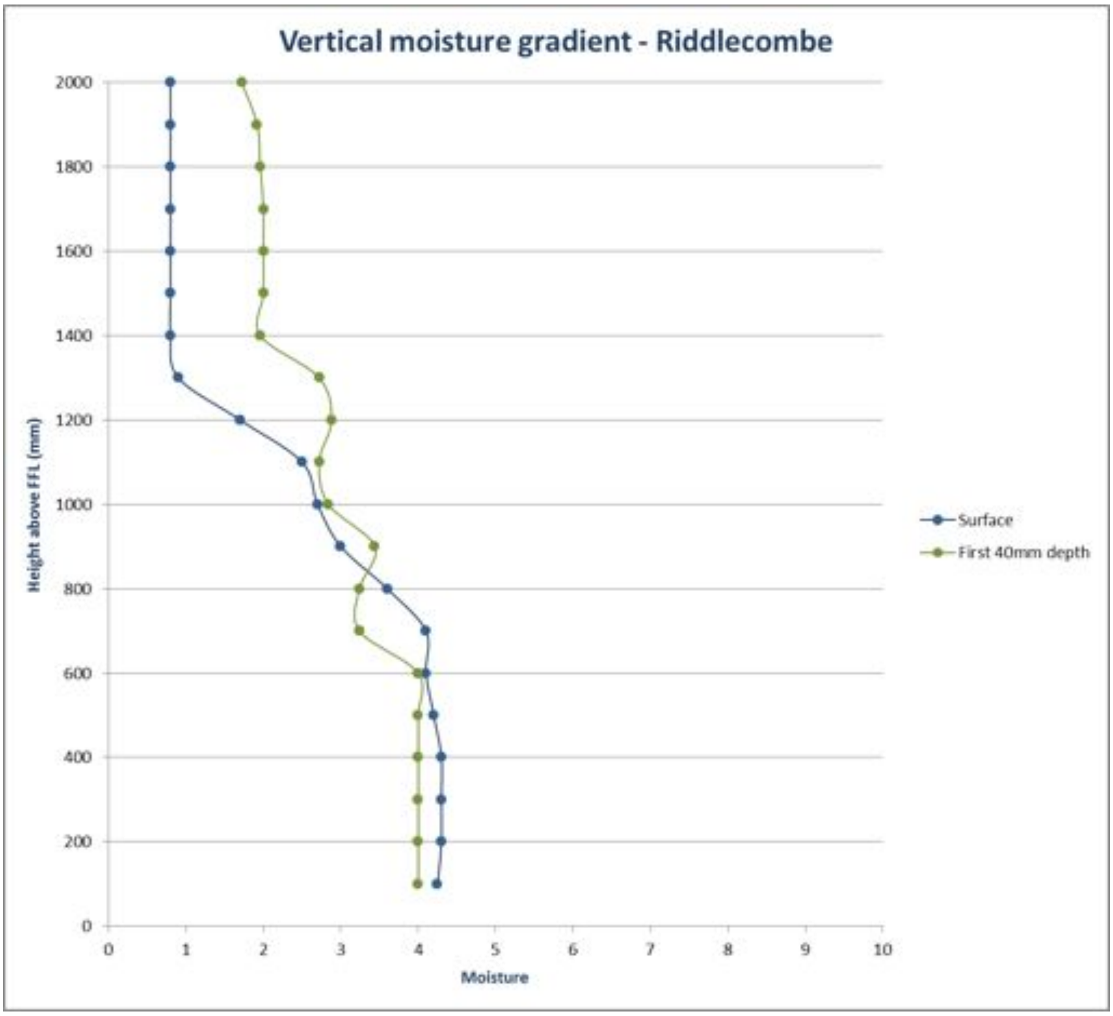



*Figure 50. Surface moisture measurements at The Firs, Riddlecombe, 25th February 2011.*

Unlike the measurements made at all the other properties, the measurements of surface moisture taken up to 800mm above finished floor level at Riddlecombe show the surface to have a relatively higher moisture content than measurements taken deeper into the wall (40mm deep). Above 800mm the relationship reverts to the more normal one and, of the two gradients, the wall surface then shows relatively lower moisture content. It has already been noted from remarks made concerning the dewpoint margin for this wall that the condition of the external render is probably causing moisture to be retained interstitially and the poorer U-value for the lower part of the wall coupled with these surface moisture measurements suggests that moisture may be concentrating at the foot of the wall. This maybe a result of water driven in through the render or from a high incidence of ground water in proximity to the foot of the wall as the ground in front of the front elevation is paved with concrete, or both. It is also interesting to note that both moisture content measurements diminish above the 1200mm rising damp level suggesting that capillary action and thus ground water is a major factor in the moisture content of the wall below this level.

INDOOR AIR QUALITY & COMFORT/FABRIC RISK

Table 27 provides a summary of the indoor conditions surveyed within the office on the ground floor at The Firs, Riddlecombe (see fig.40). The figures represent average values recorded over the monitoring period 25th February - 11th March 2011.

| PROPERTY | $CO_2$ (ppm) | Temp (˚C) | RH (%) |
|---|---|---|---|
| Riddlecombe | 1097.5 | 19.5 | 60.4 |

*Table 27. Indoor Conditions at The Firs, Riddlecombe 25th February - 11th March 2011.*

Parameters surveyed were $CO_2$, air temperature, and relative humidity levels. The individual indoor temperature and relative humidity readings were also plotted against an index of human comfort and fabric risk. The results for The Firs can be seen in Figure 51.

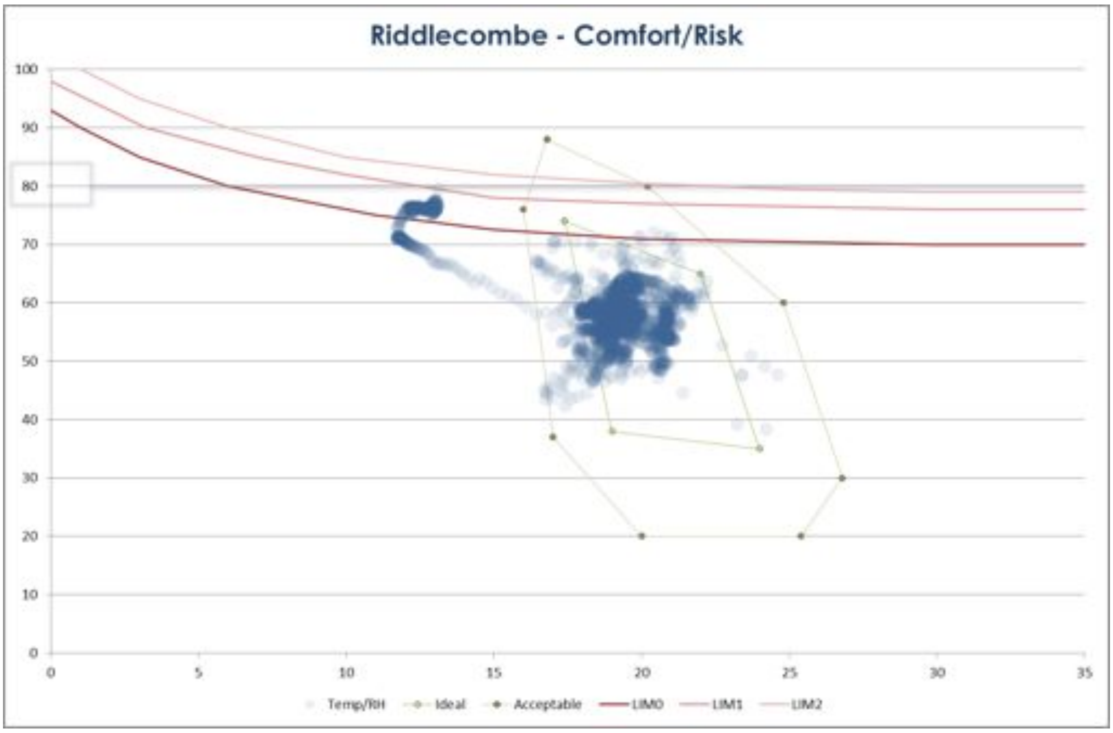



*Figure 51. Comfort/Risk Analysis for The Firs, Riddlecombe, 2011.*

As is shown in Figure 51, the majority of the temperature/relative humidity measurements for the office room at The Firs fall within the parameters deemed ideal for human comfort. It is thought that the trail of measurements isolated from the main cluster represents the period of time when the family were absent from the property for a few days. Over this time, the temperature fell and relative humidity was raised and peaked above the boundary set for the limits of mould growth for an ideal culture medium (LIM 0).

## The Old Armoury, Ashburton, Devon.
## 2011

Description: Grade II listed,an early nineteenth century three storey terraced house of at least three phases of building. Front elevation in stone with lined render, west gable wall of Ashburton Limestone rubble including large stone rubble chimney. Ground floor walls constructed of Ashburton Limestone with timber-frame upper storeys. Hipped slated roof.

Occupancy: Family of 5.

Floor Area: Approx. 332m$^2$.

*Figure 52. Plan of The Old Armoury, Ashburton, with ground floor on LHS.*
Red dots indicate the locations of the monitoring equipment. The air permeability test area is shown in blue, with the secondary test zone indicated in red.

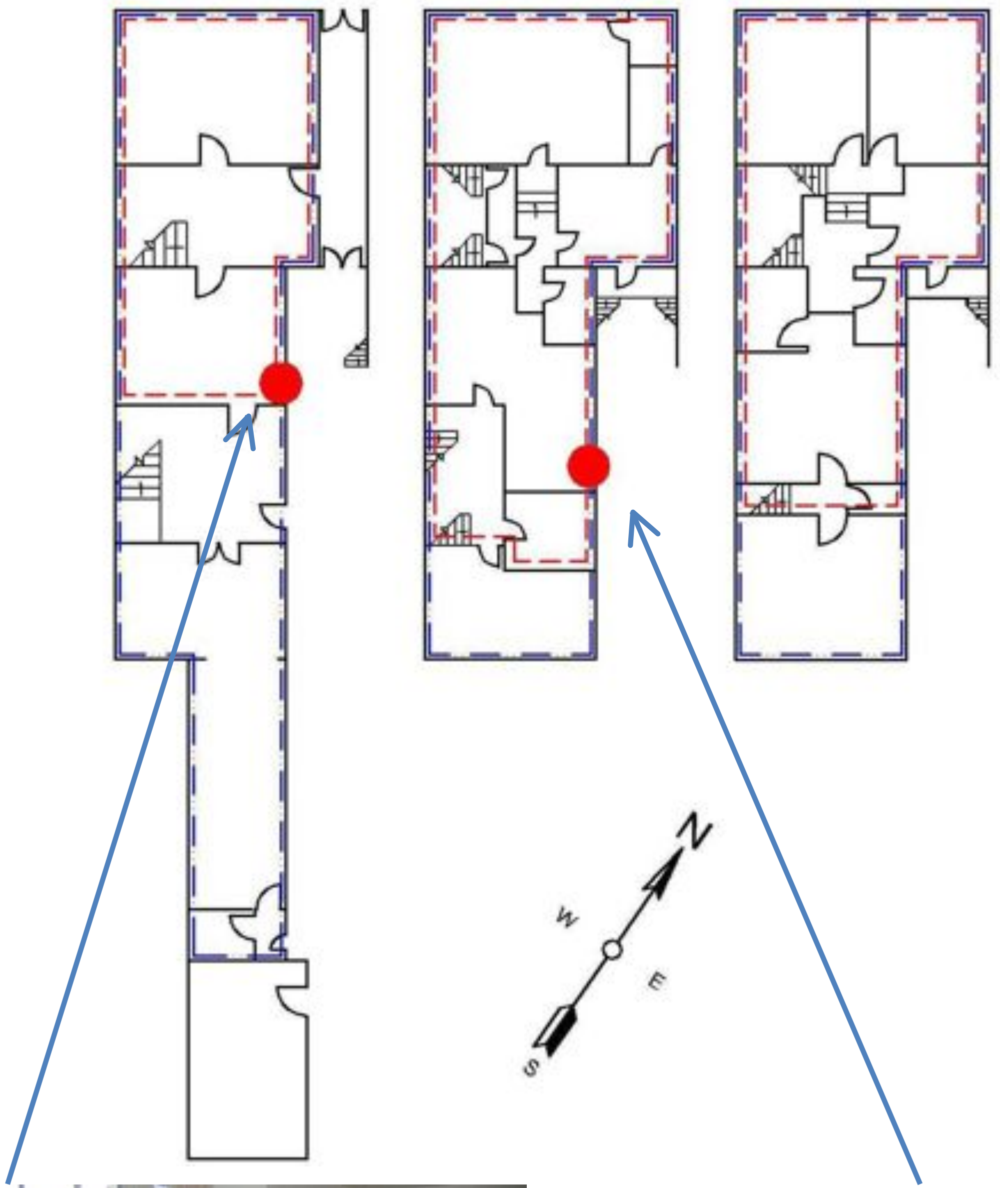



*Figure 53. Showing positions of in situ monitoring equipment at The Old Armoury, Ashburton, 2011.*

## U-VALUES

Between 18th February - 3rd March 2011 four *in situ* U-value measurements were taken on the east walls of the house, two in the living room of the ground floor and two on the timber-frame wall of a bedroom on the first floor (Figs 52 & 53). The results along with standard U-value calculations made following the BR 443 method are shown in Table 28.

| **Location** | **Materials/ Build Up** | **mm** | **In-situ U-value** | **BR 443 U-value** |
|---|---|---|---|---|
| East Wall Grd Floor Sitting Rm - low 18/02/11- 03/03/11 | Lime Render<br>Limestone Rubble<br>Lime Plaster | 40<br>534<br>20 | | |
| | Total | 594 | 1.33 | 1.79 |
| East Wall Grd Floor Sitting Rm - high 18/02/11- 03/03/11 | Lime Render<br>Limestone Rubble<br>Lime Plaster | 40<br>534<br>20 | | |
| | Total | 594 | 1.04 | 1.79 |
| East Wall 1st Floor Bedroom - low 18/02/11- 03/03/11 | Asbestos Sheet<br>Rockwool -<br>Plasterboard<br>Gypsum skim | 6<br>85<br>9.5<br>4.5 | | |
| | Total | 105 | 0.46 | 0.43 |
| East Wall 1st Floor Bedroom - high 18/02/11- 03/03/11 | Asbestos Sheet<br>Rockwool -<br>Plasterboard<br>Gypsum skim | 6<br>85<br>9.5<br>4.5 | | |
| | Total | 105 | 0.35 | 0.43 |

*Table 28. In situ and calculated U-value results for The Old Armoury, Ashburton, March 2011.*

The two *in situ* U-values measured for the ground floor wall, 1.33 W/m$^2$K and 1.04 W/m$^2$K, are significantly different from the U-value produced by calculation, 1.79 W/m$^2$K, and show that the wall has less heat loss than that predicted by the standard methodology. This divergence corresponds with similar discrepancies found for stone walls in other studies. 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 i.e. inability to provide a full definition of all the materials and voids involved in the wall build up, the use of generalised thermal conductivity information and the oversimplification of the wall structure by the calculating software. Given the problems previously identified and following best practice guidance the *in situ* U-values can be taken to be the more accurate assessment of thermal transmittance for this wall at The Old Armoury. The effect of higher moisture content at the base of traditionally built walls can also be seen in the difference between the two *in situ* U-values for this ground floor wall. The measurement of 1.33 $W/m^2K$ taken lower down the wall shows greater heat loss than the higher measurement of 1.04 $W/m^2K$ probably due to the effect of increased conductivity due to a higher concentration of moisture lower down the wall, below the 1200mm 'rising damp' level.

The *in situ* U-values for the east timber-frame wall of the bedroom, 0.46 and 0.36 $W/m^2K$, show good correspondence with that calculated for this same wall build up, 0.43 $W/m^2K$. The *in situ* measurements and comparative calculations were made for a material build up between studs and therefore relate principally to the performance of the mineral fibre infill used in this part of the frame. The reasons for the smaller discrepancies between the *in situ* and calculated U-values in this instance relates to the method of construction and materials deployed and conforms to similar trends identified in previous research, see, once more, *SPAB Research Report 1 - U-value Report*. Timber-frame walls are more suited to the calculation method as they are inherently easier to define being constructed of discrete and often easily identifiable layers. The BR 443 method is essentially a sum of the resistances of the individual layers which make up a wall so this pattern of construction conforms more closely to the rationale which underpins the calculation methodology. Coupled with this the materials used within the wall build up at The Old Armoury - plasterboard - mineral fibre - asbestos sheet - are all of modern origin and therefore have better defined thermal conductivity (lambda or K) values providing a more targeted, or possibly more accurate calculated

U-value. The variation between the two *in situ* U-values of 0.36 and 0.46 $W/m^2K$, which sit either side of the calculated U-value of 0.43 $W/m^2K$ may be explained by small differences in the packing density of the mineral wool fibre infill or perhaps slight differences in air movement within the wall structure having a cooling effect.

AIR PERMEABILITY

The air permeability testing was carried out on the 23rd March 2011. Interior and exterior conditions at the time of testing are noted in Table 29.

| | |
|---|---|
| Date of Test: | 23 March 2011 9.30am onwards |
| Prevailing weather conditions at time of test: | Sunny with some cloud. Dry. Little breeze. External conditions 15°C 61% RH (12.30pm approx) |
| Conditions inside dwelling: | Reception room 1 16°C 56% RH (approx.11.30am) |

*Table 29. Interior and exterior conditions for air permeability test at The Old Armoury, Ashburton.*

The dwelling has a complex layout. The test equipment was mounted in the doorway from the passageway into the hall, with the passageway being treated as external space and both front and rear passageway doors being propped open. For the purpose of the air permeability testing, The Old Armoury was divided into two parts, with older part of the building separated from the dining area and kitchen extension, together with the first floor and second floor bedrooms immediately above. The results of the test for the older part of the building are shown in Table 30.

| | Units | Results | Comments |
|---|---|---|---|
| Internal floor area (ground, first and second floors) | $m^2$ | 240 | |
| Habitable building volume | $m^3$ | 643 | |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 514 | |
| Air flow | $m^3h^{-1}$ | 11494 | Building could not be depressurised to 50Pa differential. Extrapolated result from 30Pa. |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 22.4 | $m^3$ of air per hour per $m^2$ of surface area of the living space. |
| Air changes per hour at 50Pa | ach@50 Pa | 17.9 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

*Table 30. Air permeability results for older part of dwelling – The Old Armoury, Ashburton.*

Due to the size of the building and the high level of air leakage, it was not possible to maintain a pressure differential of 50 Pa. The result of 11494 $m^3h^{-1}$ is therefore an extrapolated one. It needs to be borne in mind the test for the older part of the building is likely to be understating the air permeability, as doors and windows in the extension were not opened.

Relating the measured air flow to the surface area of the older part of the dwelling, Table 30 shows the extrapolated air permeability result of 22.4 $m^3h^{-1}m^{-2}$ @50 Pa, significantly exceeding the limit for new build dwellings under the Approved Document L1A 2010 (10 $m^3h^{-1}m^{-2}$ @50 Pa). The results for the older part of the building have been quoted, as the test for the building as a whole contains an error – a flue opening was not covered over in the dining area, and so the result for the building as a whole may be overstated – these results are shown in Table 31.

| | Units | Results | Comments |
|---|---|---|---|
| **Whole dwelling** | | | |
| Internal floor area (ground, first and second floors) | $m^2$ | 332 | |
| Habitable building volume | $m^3$ | 817 | |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 690 | |
| Air flow | $m^3h^{-1}$ | 15615 | Building could not be depressurised to 50Pa. Extrapolated result from 16Pa. |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 22.6 | $m^3$ of air per hour per $m^2$ of surface area of the living space. |
| Air changes per hour at 50Pa | ach@50 Pa | 19.1 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

*Table 31. Air permeability results for whole dwelling – The Old Armoury, Ashburton.*

Subject to the reservation regarding room dimensions, the extrapolated air permeability result for the building as a whole is 22.6 $m^3h^{-1}m^{-2}$ @50 Pa.
It should be noted that, although refurbishment of the dwelling had started, work in progress was limited to the two second floor front bedrooms. All walls were plastered in these two rooms, but no skirting boards had been fitted.

Relating the measured air flow to the volume of the dwelling, the air change rate extrapolated to 50Pa is 19.1 ach, representing the number of times per hour the total volume of air in the building will change at this pressure. From Sherman, at normal conditions this figure would represent an air change rate just under 1 ach, which orthodoxy would consider excessive.

Flues

Under the standard test procedure, chimneys and flues in the dwelling are excluded from the results. However for The Old Armoury, air flows under depressurisation for each the identified flues within the older part of the dwelling were measured following the main tests and are shown in Table 32 (condition as found, extrapolated from depressurisation achieved).

| | **Additional $m^3h^{-1}$ @ 50Pa (extrapolated)** |
|---|---|
| Ground floor - TV room fireplace uncovered | 211 |
| Ground floor - Sitting room fireplace uncovered | 1627 |
| First floor - Front bedroom fireplace | 272 |
| First floor – Middle bedroom – vent into chimney | 0 |
| Second floor- Ex-fireplace in store | 70 |
| 2nd floor - Front bedroom fireplace | 1017 |

*Table 32. The Old Armoury, Ashburton- additional air flows relating to flues under air permeability test conditions.*

The results given in Table 32 show a wide variety of air flows and, though they will not directly relate to the air flows through chimneys when in use / not in use, the air flow figure for the older part of the building increased by 28% with all the chimneys uncovered.

THERMOGRAPHIC SURVEY

Thermal imaging was carried out inside The Old Armoury in conjunction with air permeability test on 23rd March 2011. There was only a small difference in temperature between inside the building and ambient temperature, limiting the results obtained. However, the use of thermal imaging whilst air permeability testing took place exaggerated the infiltration occurring. Infiltration from the passageway to the adjoining rooms was noted and this is illustrated in Figure 54, which shows ingress at floor level in the first floor study. Ingress through ceiling and floor voids is evident in The Old Armoury (Figs. 55 & 56). Figure 57 shows ingress around the window reveal at ground floor level and Figure 58 pictures the second floor, front north west bedroom, which was under refurbishment, with ingress along the external wall at floor board level.

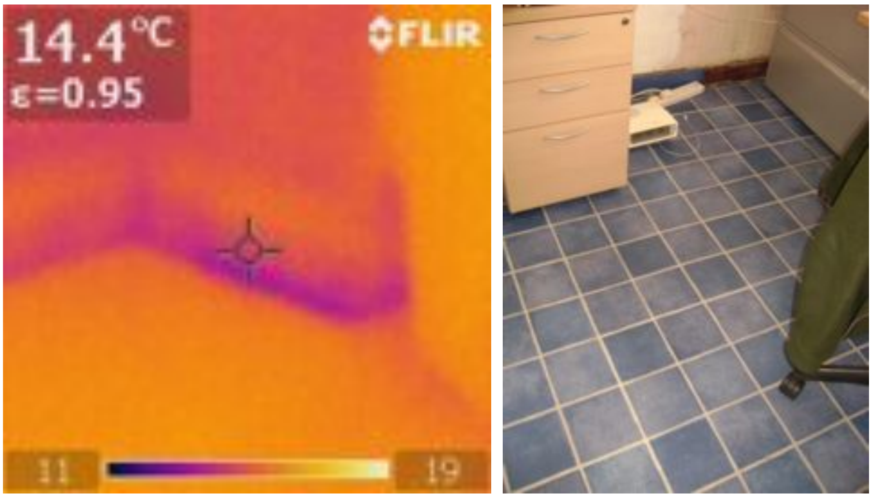



*Figure 54. The Old Armoury, Ashburton – first floor: study*


*Figure 55. The Old Armoury, Ashburton – ground floor: sitting room*

Ingress was evident around windows throughout the property, the worst example was in the TV room on the ground floor. Within the timber frame component of the building, thermal bridging / ingress was detected on the second floor, which shows thermal bridging / ingress around window (Fig. 57). Despite the small temperature differential between inside and external conditions, the thermal imaging did reveal some aspects of the building structure, Figure 58 shows the structure within the south west wall of the second floor, south east bedroom.


*Figure 56. The Old Armoury, Ashburton – second floor: front NW bedroom*


*Figure 57. The Old Armoury, Ashburton – second floor: middle bedroom*


*Figure 58. The Old Armoury, Ashburton -second floor: Front SE bedroom – SW wall*

# MOISTURE

## Interstitial Moisture

Material moisture measurements were made on the east facing wall of a bedroom on the first floor (Fig. 59). Interstitial temperature and relative humidity sensors were located at the heights and depths given in Table 33 and recorded temperature and relative humidity changes at four points within the wall between the period 18th February - 3rd March 2011.

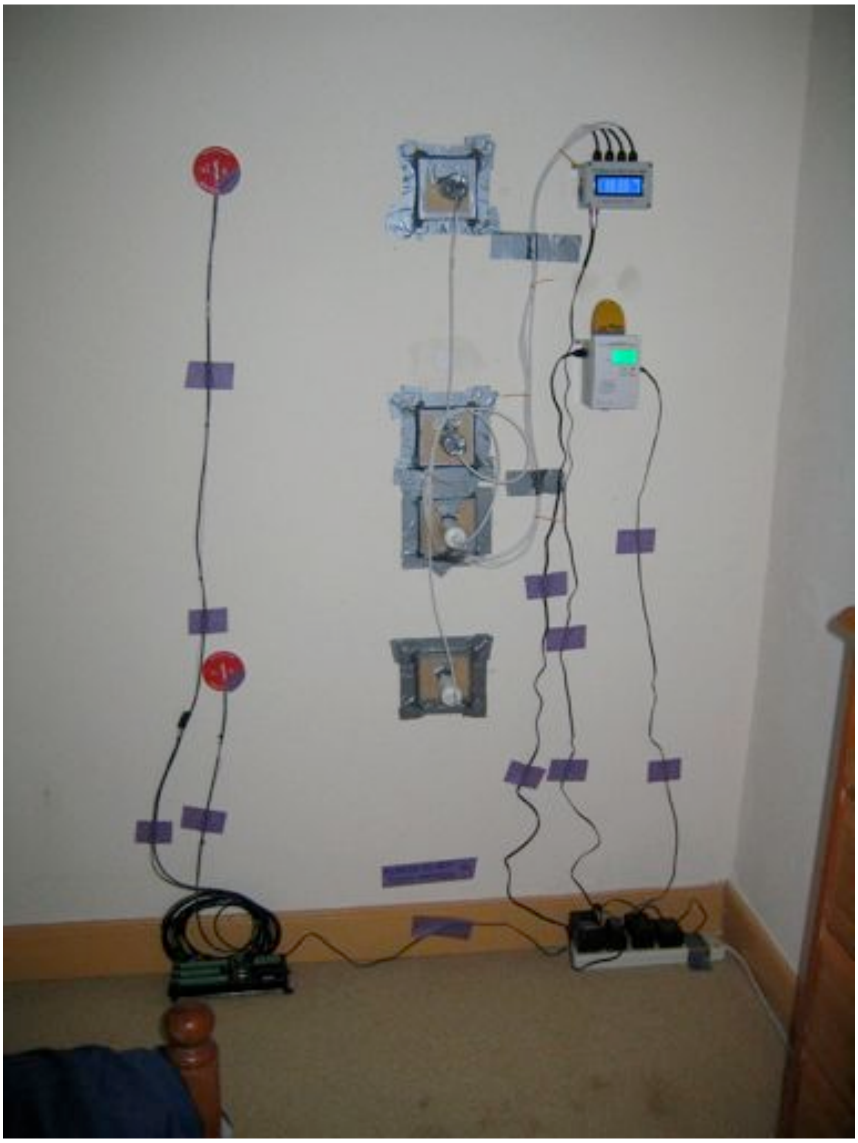


*Fig. 59. Interstitial, U-value and IAQ monitoring set up at The Old Armoury, Ashburton, March 2011*

| BUILD UP external - internal | SENSOR | HEIGHT from ffl. | DEPTH from int. sur. finish |
|---|---|---|---|
| Asbestos Sheet - 6mm | Sensor 1 | 1500mm | 15mm |
| Rockwool - 85mm | Sensor 2 | 1050mm | 40mm |
| Plasterboard & Skim - 14mm | Sensor 3 | 900mm | 65mm |
| OVERALL = 105 mm | Sensor 4 | 600mm | 100mm |

*Table 33. Interstitial gradient record for The Old Armoury, Ashburton,2011.*

Figure 60 shows the average values of each sensor over the monitoring period graphed as separate temperature and dewpoint gradients. The values derived from the relative humidity sensors have been converted to dewpoints in order to indicate the likelihood of condensation forming within the wall.

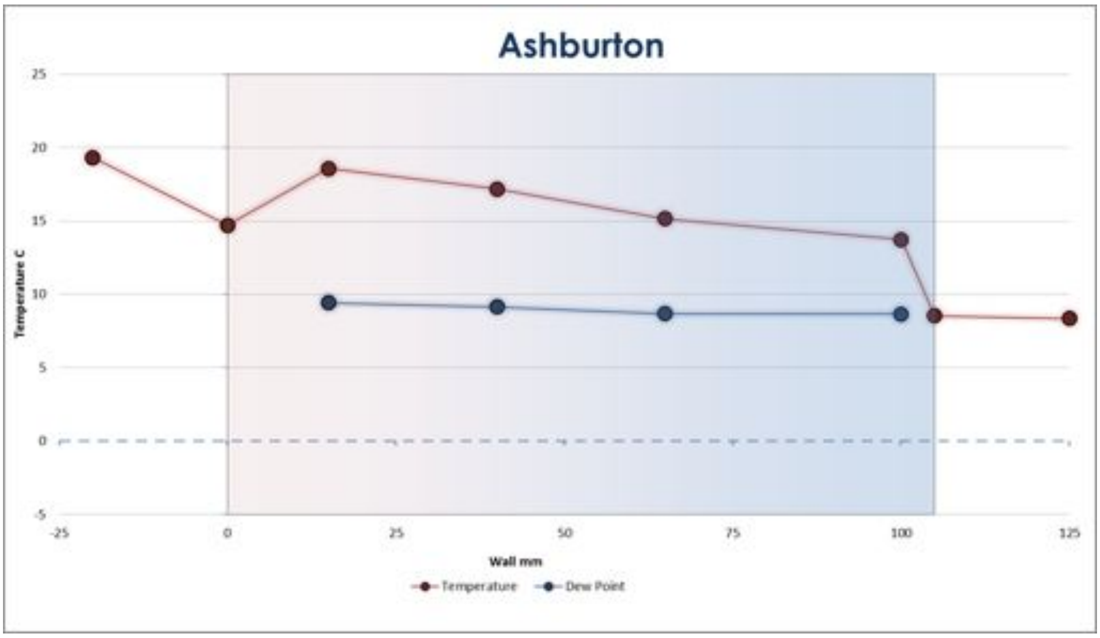



*Figure 60. Temperature and dewpoint gradients for The Old Armoury, Ashburton, 2011*

The temperature gradient indicates the insulative effect of the wall where there is a 6˚C average temperature difference between the interior and exterior surfaces. At Ashburton, although all the sensors were located at different depths within the same material (mineral wool fibre) the gradients between each sensor point vary slightly indicating that the wall cannot really be considered to be homogenous in the same way a mass material, such as cob can be. The dewpoint gradient plotted for The Old Armoury shows a wide margin between it and the temperature gradient, the margin being calculated as 7.18˚C, showing little chance of a condensation event for this wall even in proximity to the colder exterior side. The reasons for this wide margin maybe that the insulative effect of the mineral wool means that relatively high temperatures are maintained through out the wall section lessening the opportunity for humid air to be cooled to the dew point (the point where vapour will condense). In addition mineral wool exhibits very low vapour permeability which means that levels of relative humidity found within the wall are also likely to be quite low as vapour is able to make its way through this material with ease provided there is a sufficiently differentiated vapour pressure between the interior and exterior environment. Thirdly, it maybe that the wall is experiencing a high degree of air movement within the wall structure itself and this ingress of external air is also reducing the humidity found within the wall, although given the fibrous nature of the infill material this seems unlikely.

Sensor values for the wall were logged at 5 minute intervals and this information has been animated in order that changes in temperature and dewpoint maybe analysed over time. (To view the interstitial gradients animation for The Old Armoury, Ashburton, visit www.archimetrics.co.uk). The light weight nature of the wall construction is immediately noticeable from this animation where all four temperature sensor nodes show great fluctuations in relation to changes in both interior and exterior temperatures. The volatility of the response across the entire wall section is in marked contrast to other walls in the study, heavy-weight mass walls, where the more central temperature nodes remain mostly static for the duration of the monitoring period.

## INDOOR AIR QUALITY & COMFORT/FABRIC RISK

Table 34 provides a summary of the indoor conditions surveyed within the bedroom on the first floor at The Old Armoury (Fig. 52). The figures represent average values recorded over the monitoring period 18th February - 3rd March 2011. Due to equipment malfunction there is no $CO_2$ for this location.

| PROPERTY | $CO_2$ (ppm) | Temp (˚C) | RH (%) |
|---|---|---|---|
| Ashburton | | 19.1 | 49.8 |

*Table 34. Indoor Conditions at The Old Armoury, Ashburton, 2011.*

The individual indoor temperature and relative humidity readings were plotted against an index of human comfort and fabric risk. The results for can be seen in Figure 61.

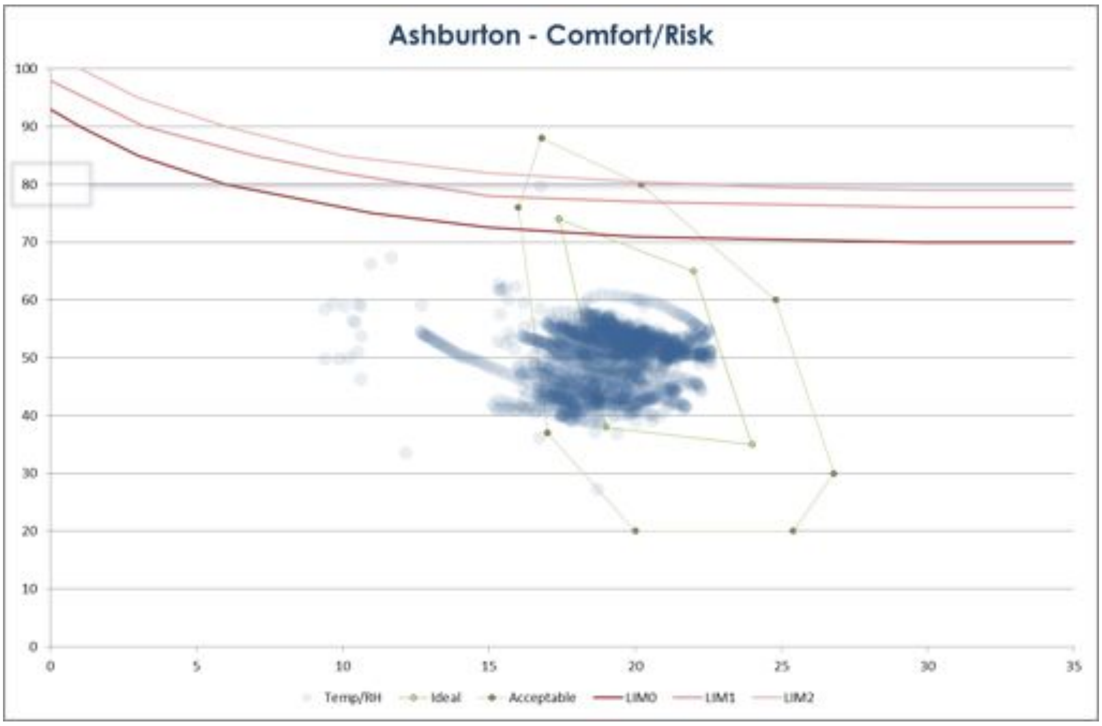



*Figure 61. Comfort/Risk Analysis for The Old Armoury, Ashburton, 2011.*

As is shown in Figure 61, the majority of the temperature/relative humidity measurements for the bedroom at Ashburton fall within the parameters deemed ideal for human comfort. It is thought that the trail of measurements isolated from the main cluster represents the period of time when the property was unoccupied for a few days. Over this time, the temperature fell and relative humidity was raised accordingly but was still well below any of the fabric risk gradients (LIM - limiting isopeth for mould).

# Mill House, Drewsteignton, Devon.
# 2011

Description: A barn built in granite dating from the nineteenth century or possibly earlier converted to a dwelling in 1970s with a modern extension added to the south east. UPVC double glazed windows throughout.

Occupancy: 2 persons.

Floor Area: 325m$^2$

*Figure 62. Plan of Mill House, Drewsteignton, with ground floor on LHS.*
The red dot indicates the location of the monitoring equipment. The air permeability perimeter is shown in blue, with the secondary test zone shown in red.

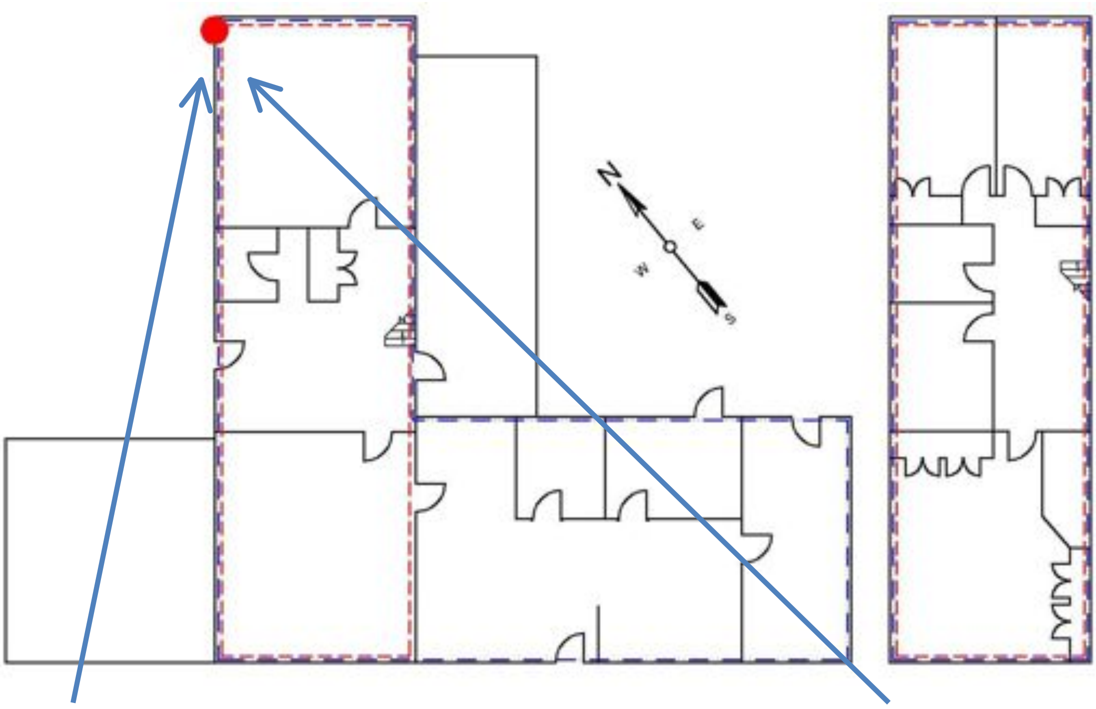


*Figure 63. Positions of in situ monitoring equipment at Mill House, Drewsteignton, 2011.*

U-VALUES

Between 4th - 18th March 2011 two *in situ* U-value measurements were taken on the north wall of the ground floor office room (Figs. 62 & 63). The results along with standard U-value calculations made following the BR 443 method are shown in Table 35 below.

| Location | Materials/ Build Up | mm | In-situ U-value | BR 443 U-value |
|---|---|---|---|---|
| North West Wall Grd Floor Study - high 1800mm above ffl | Granite<br>Lime Plaster<br>Tanking & gypsum | 580<br>20<br>3 | | |
| 04/03/11 - 18/03/11 | Total | 603 | 1.24 | 2.45 |
| North West Wall Grd Floor Study - low 800mm above ffl | Granite<br>Lime Plaster<br>Tanking & gypsum | 580<br>20<br>3 | | |
| 04/03/11 - 18/03/11 | Total | 603 | 1.5 | 2.45 |

*Table 35. In situ and calculated U-value results for Mill House, Drewsteignton March 2011.*

The two *in situ* U-values measured for the office wall, 1.24 W/m$^2$K and 1.5 W/m$^2$K, are significantly different from the U-value produced by calculation, 2.45 W/m$^2$K, and show that the wall has less heat loss than that predicted by the standard methodology. This divergence corresponds with similar discrepancies found for stone walls in other studies. 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 i.e. inability to provide a full definition of all the materials and voids involved in the wall build up, the use of generalised thermal conductivity information and the oversimplification of the wall structure by the calculating software. Given the problems previously identified and following best practice guidance the *in situ* U-values can be taken to be the more accurate assessment of thermal transmittance for this wall at Mill House.

The effect of higher moisture content at the lower sections of traditionally built walls can also be seen in the difference between the two *in situ* U-values for this ground floor wall. The measurement of 1.5 $W/m^2K$ taken at 800mm above finished floor level, lower down the wall, shows greater heat loss than the higher measurement of 1.24 $W/m^2K$ taken at 1800mm above finished floor level. The difference between these two U-values may be attributed to the effect of increased conductivity due to a higher concentration of moisture lower down the wall. Despite the fact that the external ground level drops away at this point along the front elevation, the lower sensor is still sited below the 1200mm 'rising damp' level and the capillary action of ground water rising through a wall with no damp-proof course could account for raised material moisture content below this height. This theory for the monitored wall at Mill House is in part supported by evidence from the surface moisture readings for the wall, see below.

## AIR PERMEABILITY

Air permeability testing was carried out on the complete habitable volume at Mill House on 18th March 2011, with test equipment mounted in the exterior door into the hall. As an additional test, the original part of the building was examined alone, though this test has the proviso that it was not possible to open the windows and doors in the modern extension excluded from this space. Both test areas are identified in Figure 62. Interior and exterior conditions at the time of testing are noted in Table 35 and the results of the whole dwelling air permeability test are shown in Table 36.

| | |
|---|---|
| Date of Test: | 18 March 2011 10am onwards |
| Prevailing weather conditions at time of test: | Dry, sunny. Very light breeze. 8°C, 82% RH (approx.1200). |
| Conditions inside dwelling: | Well heated. 19°C , 56%RH (approx.1300) |

*Table 35. Interior and exterior conditions for air permeability test at Mill House, Drewsteignton*

| | Units | Results | Comments |
|---|---|---|---|
| Whole dwelling | | | |
| Internal floor area (ground and first floors) | $m^2$ | 325 | |
| Habitable building volume | $m^3$ | 759 | |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 708 | |
| Measured air flow | $m^3h^{-1}$ | 6139 | It should be noted the outer doors and windows of the unheated conservatory to the rear of the barn conversion were left closed throughout the testing process. |
| Air permeability test result at 50Pa | $m^3h^{-1}m^{-2}$ @50 Pa | 8.7 | $m^3$ of air per hour per $m^2$ of surface area of the living space. |
| Air changes per hour at 50Pa | ach@50 Pa | 8.1 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

*Table 36. Results for whole house air permeability test at Mill House, Drewsteignton*

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The air flow measured for the property as a whole at 50Pa was 6139 $m^3h^{-1}$. Table 36 shows this equates to an air permeability of 8.7$m^3h^{-1}m^{-2}$ @50 Pa when related to the total surface area of the property. This performance is favourable compared to the limiting air permeability under Approved Document L1A 2010 for new build dwellings (10 $m^3h^{-1}m^{-2}$ @50 Pa).

Relating the dwelling volume to the measured air flow, the air change rate at 50Pa is 8.1ach, representing the number of times per hour the total volume of air in the building will change at this pressure difference. From Sherman, this would represent an air change rate of the order of 0.4 under normal conditions – slightly under the orthodox view of 0.5ach (BRE 1985, Warm & Oxley 2002).

In an attempt to isolate the older part of the building from the modern addition, a stage test was also carried out, considering the older part of the dwelling only (Fig. 63). This test does not truly reflect the air permeability figure because the windows and outer doors in the extension were closed rather than everything open to the outdoors (which has the effect of making the older part of the building look tighter than it is), but they do help to put the different parts of building into context. These figures must only therefore be treated as indicative. The results of this test are detailed in Table 37.

| Original building | | | |
|---|---|---|---|
| | **Units** | **Results** | **Comments** |
| Internal floor area (ground and first floors) | $m^2$ | 235 | |
| Habitable building volume | $m^3$ | 552 | |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 473 | |
| Measured air flow | $m^3h^{-1}$ | 2804 | |
| Air permeability test result at 50Pa | | 5.9 | $m^3$ of air per hour per $m^2$ of surface area of the living space. |
| Air changes per hour at 50Pa | ach@50 Pa | 5.1 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

*Table 37. Air permeability results for older part of Mill House, Drewsteignton*

Though only indicative, the result for original building (5.9 $m^3h^{-1}m^{-2}$ @50 Pa) being lower than the test result for the building as a whole (8.7$m^3h^{-1}m^{-2}$ @50 Pa), indicates the extension has a higher air permeability than the barn conversion.

Flues

Under the standard test procedure, chimneys and flues in the dwelling are excluded from the results. However, measurement of the air flow was made whilst the building was depressurised. Other than the oil fired range, there is a single flue from this property, which is fitted with a baffle and a stove is fitted in the fireplace. When the baffle and stove vents were open, the additional air flow recorded was 99$m^3h^{-1}$.

THERMOGRAPHIC SURVEY

Thermal imaging was carried out inside Mill House whilst the air permeability test on the complete building was being carried out on 18th March, exaggerating areas of infiltration through the building fabric. The most noticeable areas of ingress relate to the extension, with evidence of particular issues at the wall / ceiling junction and also ingress around the recessed light fitting (Fig. 64). Leakage between external timber doors and their frames was also apparent in this part of the dwelling (Fig. 65).


*Figure 64. Mill House, Drewsteignton Extension – kitchen (W corner).*

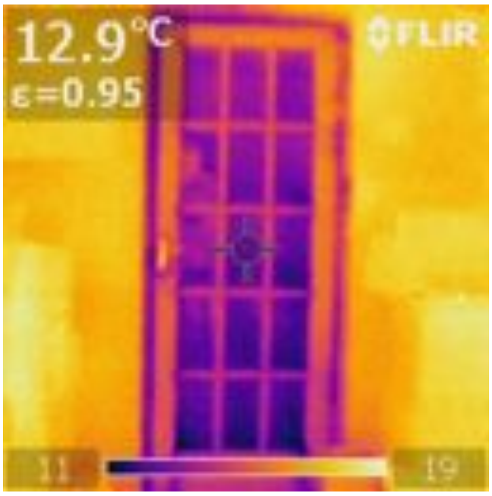


*Figure 65. Mill House, Drewsteignton extension – external door from kitchen*

With respect to the barn conversion, a temperature difference of just under 3$^{o}$C was recorded between the gable end wall in the study and the adjacent

NW wall, where the interstitial, U-value and IAQ monitoring equipment was sited (Fig. 66). Small amounts of ingress were noted around the UPVC door into the conservatory and around the loft hatch in the barn conversion. Throughout the dwelling there was a small, but consistent air leakage above the window casements, (Fig 67).

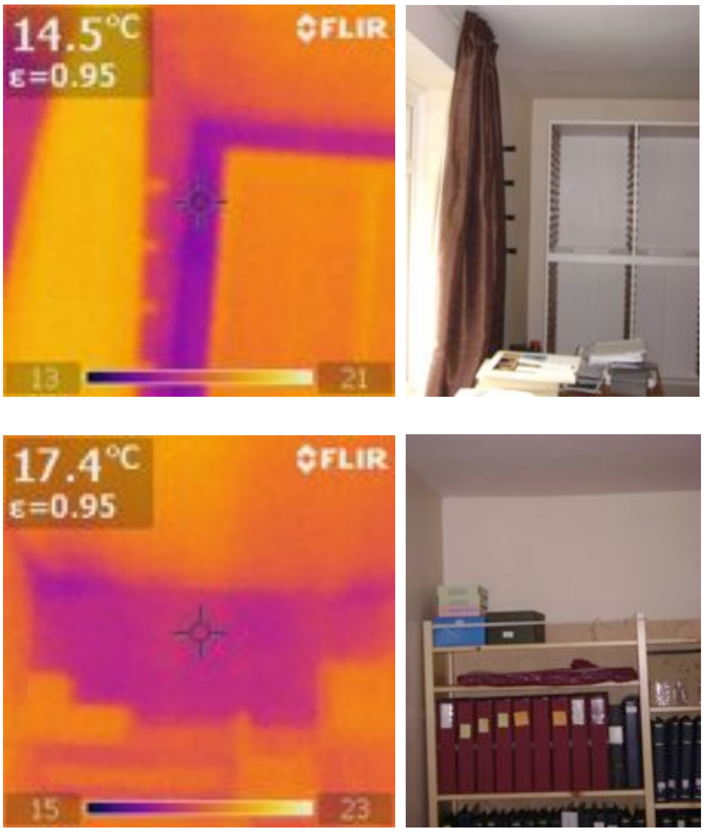


*Figure 66. Mill House, Drewsteignton – Study in barn conversion.*

*Top: Gable end wall (NE). Bottom: NW wall*

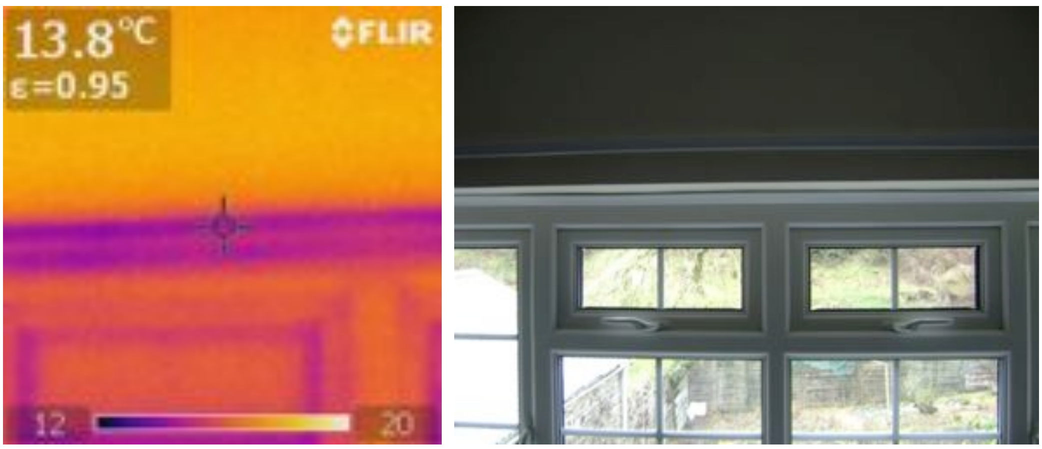


*Figure 67. Mill House, Drewsteignton – example of ingress adjacent to window casement.*

## MOISTURE

### Interstitial Moisture

Material moisture measurements were made on the north facing ground floor wall of the office room (Fig. 68). Interstitial temperature and relative humidity sensors were located at the heights and depths given in Table 38 and recorded temperature and relative humidity changes at four points within the wall between the period 4th - 18th March 2011.

*Figure 68. Interstitial, U-value and IAQ monitoring set up at Mill House, Drewsteignton, 2011.*

| BUILD UP external - internal | SENSOR | HEIGHT from ffl | DEPTH from int sur finish |
|---|---|---|---|
| Granite - 580mm | Sensor 1 | 1730mm | 50mm |
| Lime Plaster - 20mm | Sensor 2 | 1580mm | 200mm |
| Gypsum skim - 3mm | Sensor 3 | 1430mm | 350mm |
| OVERALL = 603mm | Sensor 4 | 1280mm | 470mm |

*Table 38. Interstitial gradient sensor record for Mill House, Drewsteignton, 2011.*

Figure 69 shows the average values of each sensor over the monitoring period graphed as separate temperature and dewpoint gradients. The values derived from the relative humidity sensors have been converted to dewpoints in order to indicate the likelihood of condensation forming within the wall.

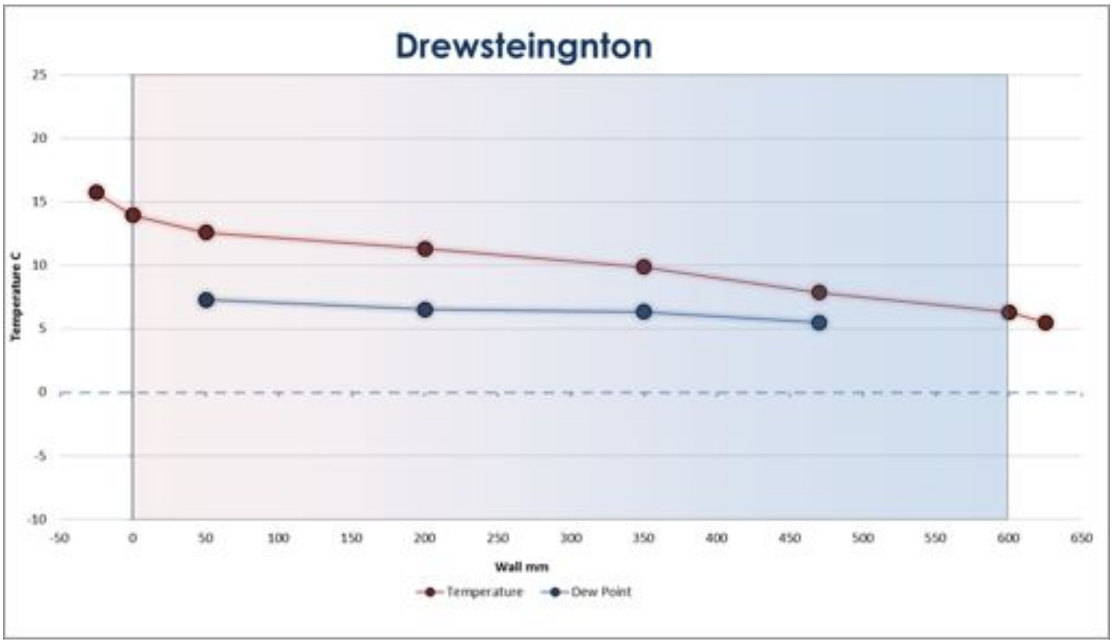


*Figure 69. Temperature and dewpoint gradient for Mill House, Drewsteignton, 2011.*

The temperature gradient indicates the insulative effect of the wall where there is an 8˚C average temperature difference between the interior and exterior surfaces. The consistency of gradient between sensors 1 - 3 and between 3 -4 shows a wall with a good degree of homogeneity and indeed little loose rubble was encountered during the core drilling required to install the sensors, neither was there any indication that the wall contained a rubble core. The dewpoint gradient is relatively steady through the wall; the average dewpoint margin calculated for the wall over the monitoring period is 4.01˚C. As expected the temperature and dewpoint gradients begin to converge towards the exterior leaf of the wall face as the temperature falls. However, at no point do the temperature and dewpoint gradients intersect and therefore it would appear that no interstitial condensation was formed during the monitoring period. The converging gradients also suggest an airtight wall construction not influenced by the lower relative humidity or drying effect of external air moving within the structure (unlike examples found at Shrewsbury and Devon Consols).

Sensor values for the wall were logged at 5 minute intervals and this information has been animated in order that changes in temperature and dewpoint maybe analysed over time. (To view the interstitial gradients animation for Mill House, Drewsteignton, visit www.archimetrics.co.uk). The behaviour of the sensors plotted over time demonstrates the heavy-weight nature of the granite construction materials, the intramural sensors, particularly 2 and 3 positioned towards the centre of the wall show only gentle fluctuations in relation to the more volatile changes in internal and external air/surface temperatures. Over the duration of the 14 day monitoring period both the external and internal temperatures gradually increased and the effect of this can be seen within the body of the wall where temperatures also steadily climb by a few degrees therefore demonstrating the ability of the stone wall to retain accumulated heat energy over a period of time.

Surface Moisture

On 4th March 2011 two measurements were take of moisture conditions of the interior wall surface, a resistive measurement of the surface itself and a capacitance reading to a depth of approximately 40mm. Figure 70 plots the two measurements in relation to one another to a height of 2000mm above finished floor level along a nominal moisture scale.

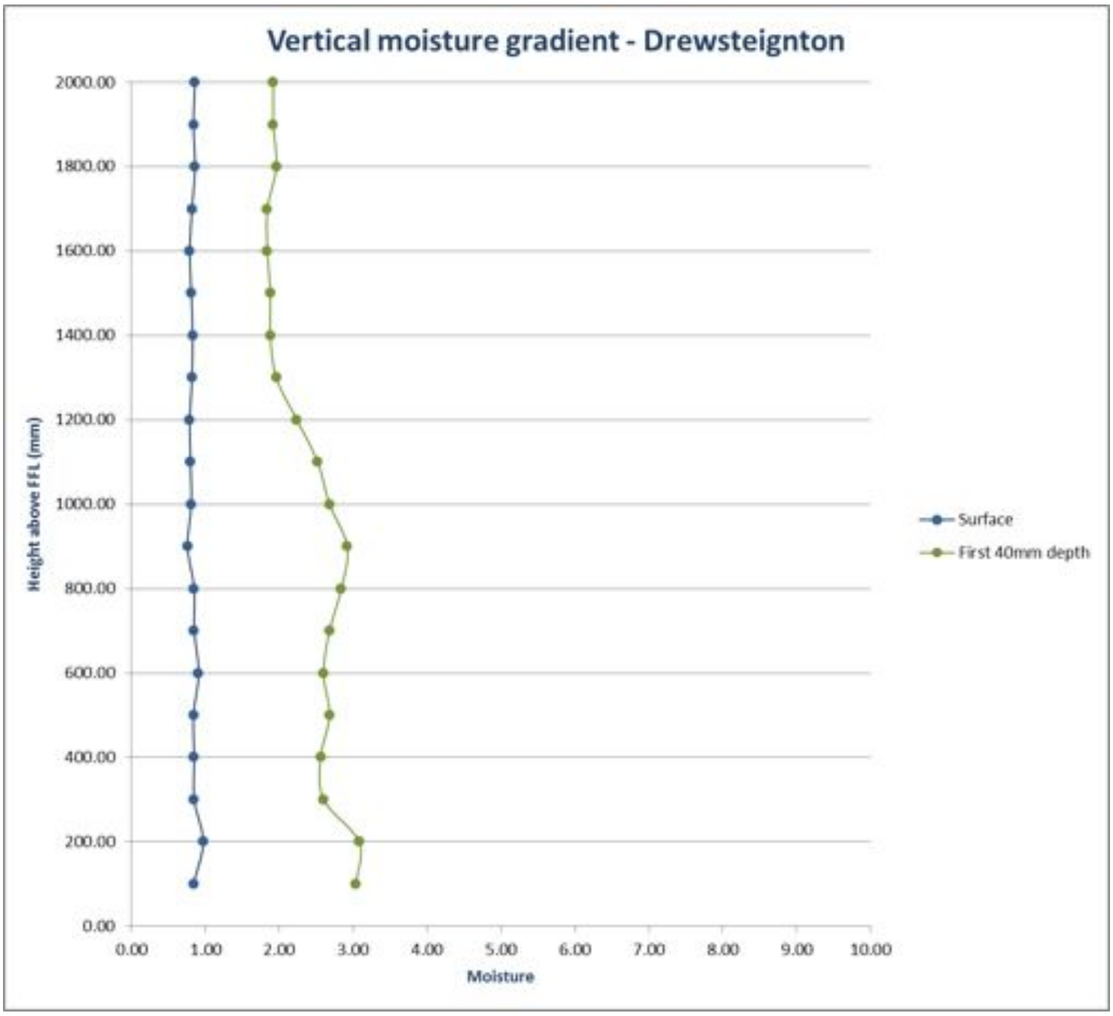


*Figure 70. Surface moisture measurements at Mill House, Drewsteignton. 2011.*

There was evidence at Mill House that a bitumous tanking type treatment had been applied to the wall beneath the gypsum plaster finish. The age and effectiveness of this treatment is difficult to determine but it may account for the consistent vertical gradient and relatively low moisture levels recorded for the surface of the wall. (Although similar gradients can be seen from other walls in this study that have not been subject to waterproofing treatments and maybe more related to evaporative drying at the wall's surface). The profile of the two moisture gradients begin to run in parallel above the 1200mm 'rising damp' level, indicating that below this the higher moisture levels recorded deeper into the body of the wall (40mm back from the internal surface) maybe as a result of ground water and capillary action. The presence of increased material moisture could also account for the higher U-value recorded for this lower section of the wall.

INDOOR AIR QUALITY & COMFORT/FABRIC RISK

Table 39 provides a summary of the indoor conditions surveyed within the office on the ground floor at Mill House. The figures represent average values recorded over the monitoring period 4th - 18th March 2011.

| **PROPERTY** | **$CO_2$ (ppm)** | **Temp (˚C)** | **RH (%)** |
|---|---|---|---|
| Drewsteignton | 581.0 | 16.8 | 55.13 |

*Table 39. Indoor Conditions at Mill House 4th - 18th March 2011.*

Parameters surveyed were $CO_2$, air temperature, and relative humidity levels. The individual indoor temperature and relative humidity readings were also plotted against an index of human comfort and fabric risk. The results for Mill House can be seen in Figure 71.

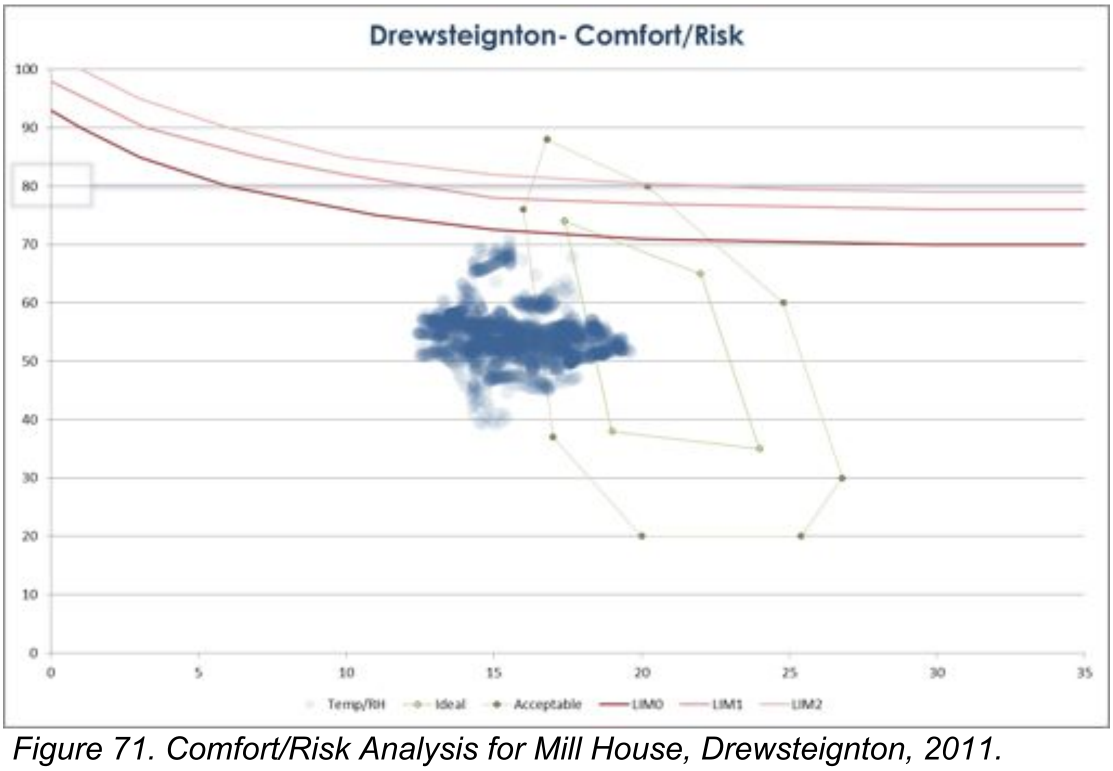


*Figure 71. Comfort/Risk Analysis for Mill House, Drewsteignton, 2011.*

As is shown in Figure 71, the majority of the temperature/relative humidity measurements fall slightly outside of the parameters deemed ideal or even acceptable for human comfort, with lower temperatures and slightly raised humidity being recorded for the office at Mill House. However these conditions do not seem to imperil the fabric of the building as the temperature/relative humidity cluster sits below the limiting isopeths for mould gradients which mark the tolerance thresholds for various material types (LIM 0 - ideal culture medium, LIM 1 - timber, LIM 2 Masonry).

## Rock View, Devon Consols, Devon.
## 2011

Description: Grade II listed mid-terrace mine captains cottage likely to have been built between 1857 - 1867 with a later (1867 - 1880) addition at the north east corner. The original doors and windows have been replaced with modern timber joinery. The following description of the property is taken from an Archaeological Appraisal document by Robert Waterhouse, 2009;

> "All of the solid walls of the house are constructed of killas (clay-slate) rubble of the Devonian Series, bonded with soft creamy-white lime mortar, often with coal ash as a pozzolan or setting agent. The rear (north-west) elevations are smooth-rendered, while the more exposed south-east elevation, in common with the adjoining cottages, is hung with a mixture of large slates. The originals here and on the roof are a greyish slate, possibly from Mill Hill near

> Tavistock, but several repairs have taken place over the years in Welsh and probably Spanish slate."

Occupancy: 1 person.

Floor Area: 161m$^2$

*Figure 72. Plan of Rock View, Devon Consols, with ground floor on the LHS.* The red dot indicates the location of the monitoring equipment. The air permeability perimeter is shown in blue.

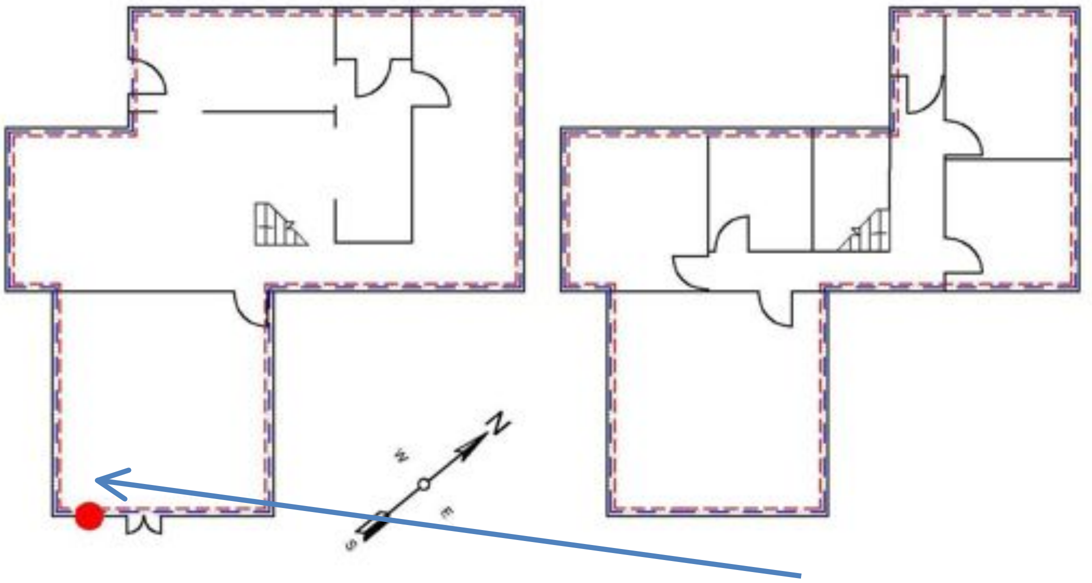


*Figure 73. Positions of in situ monitoring equipment at Rock View, Devon Consuls 2011.*

## U-VALUES

Four *in situ* U-value measurements were made in the office/living room at Rock Cottage over the period 5th March -12th May 2011 (Figs. 72 & 73). First a pair of measurements were taken for the interior drylining finish on the existing walls (5th March - 21st March) following this a pair of measurements were made behind the drylining on the original slate stone wall (21st March - 12th May). Unfortunately, during both monitoring periods external temperatures (which were unseasonably warm) were such that it was not possible to establish the required temperature differential between the interior and exterior environments. For this reason, at this interim stage, there is no usable *in situ* U-value data for the site. It is hoped that this maybe remedied early on in the next monitoring season in October 2011. Standard U-values have however been calculated for this location and are shown in Table 39.

| Location | Materials/ Build Up | mm | In-situ U-value | BR 443 U-value |
|---|---|---|---|---|
| Living Rm/Office - high | Hanging Slate | 20.0 | | |
| 1800mm above ffl | Slate stone rubble | 598.0 | | |
| | Air gap | 35.0 | | |
| | Plasterboard & skim | 12.5 | | |
| 5/3/11 - 21/3/11 | Overall | 665.5 | | 1.19 |
| Living Rm/Office - low | Hanging Slate | 20.0 | | |
| 400mm above ffl | Slate stone rubble | 598.0 | | |
| | Air gap | 50.0 | | |
| | Softwood wainscot | 20.0 | | |
| 5/3/11 - 21/3/11 | Overall | 688.0 | | 1.27 |
| Living Rm/Office | Hanging Slate | 20.0 | | |
| 21/3/11 - 12/5/11 | Slate stone rubble | 598.0 | | |
| | Overall | 618.0 | | 2.2 |
| Living Rm/Office | Hanging Slate | 20.0 | | |
| 21/3/11 - 12/5/11 | Slate stone rubble | 598.0 | | |
| | Overall | 618.0 | | 2.2 |

*Table 39. U-value results for Rock View, Devon Consols, 2011.*

## AIR PERMEABILITY

The complete living space at Rock View was air permeability tested, as shown in Figure 72 on 17th March 2011, with test equipment mounted in the kitchen entrance to the property. Separation of the two stages of building was not possible. The interior and exterior conditions at the time of testing are noted in Table 40 and the results of the whole dwelling air permeability test are shown in Table 41.

| | |
|---|---|
| Date of Test: | 17 March 2011 9.30am onwards |
| Prevailing weather conditions at time of test: | Sunny with some light cloud. Wind force 1-2. Dry. External conditions 11°C 69% RH (11.45am approx) |
| Conditions inside dwelling: | Living room 16°C 61% RH (approx.11am); Study 17°C 57% RH (approx.2pm) |

*Table 40. Interior and exterior conditions for air permeability test at Rock View.*

| | Units | Results | Comments |
|---|---|---|---|
| **Whole dwelling** | | | |
| Internal floor area (ground and first floors) | $m^2$ | 161 | |
| Habitable building volume | $m^3$ | 379 | |
| Dwelling envelope area i.e. surface area of living space | $m^2$ | 380 | |
| Measured air flow | $m^3h^{-1}$ | 7615 | Calculated from two separate readings |
| Air permeability test result at 50Pa | | 20.0 | $m^3$ of air per hour per $m^2$ of surface area of the living space. |
| Air changes per hour at 50Pa | ach@50 Pa | 20.1 | The number of times the complete volume of air in the property is changed per hour at the test pressure. |

*Table 41. Results for whole house air permeability test at Rock View.*

The air flow measured under the test conditions was 7615 $m^3h^{-1}$. Relating this result to the total surface area of the property, Table 41 shows that Rock View has achieved an air permeability test result of 20.0 $m^3h^{-1}m^{-2}$ @50 Pa.

Comparing this performance to the requirements for new build dwellings under Approved Document L1A, it is greater than the 2010 limit (10 $m^3h^{-1}m^{-2}$ @50 Pa).

Considering the measured air flow to the volume of the building, the air change rate at 50Pa pressure difference is 20.1ach; representing the number of times per hour the total volume of air in the building will change at this pressure. From Sherman, at normal conditions this figure would represent an air change rate of the order of 1ach, which orthodoxy would consider excessive.

Most key infiltrations routes were identified during the thermal imaging process (below). However there was a crack adjacent to Bedroom 4 on the first floor landing where there was movement of air from the neighbouring property, which could not be seen thermally, due to the lack of a temperature difference.

Flue Test

Under the standard test procedure, chimneys and flues in the dwelling are excluded from the results. However, for Rock View the air flows under depressurisation for each the four flues within the dwelling was measured (condition as found) and are shown in Table 42.

| | **Additional $m^3h^{-1}$ @50Pa** |
|---|---|
| Library fireplace uncovered | 685 |
| Study – multifuel stove intake opened | 100 |
| Living room flue uncovered | 440 |
| Bedroom 1 fireplace uncovered | 224 |

*Table 42. Rock View, Devon Consols – additional air flows relating to flues under air permeability test conditions.*

Though they will not directly relate to the air flows through chimneys when in use / not in use, the air flow figure for the building increased by 20% with all the chimneys uncovered.

THERMOGRAPHIC SURVEY

Thermal imaging was carried out inside Rock View whilst the air permeability test was carried out on 17th March 2011. There was only a relatively small difference between the temperature inside the building and ambient temperature, limiting the results obtained. However, the use of thermal imaging whilst the air permeability testing took place exaggerated the infiltration occurring.

The most notable ingress at Rock View under the test conditions was through the slate hung, south east wall of the property, evident in both the study and Bedroom 1, Figure 74 shows infiltration through wall and around base of French window in the study. Ingress on that side of the dwelling was also evident via the ceiling / floor void as shown in Figure 75 which reveals the structure above the existing ceiling in the study as a result.


*Figure 74. Rock View, Devon Consols  - study: external wall*


*Figure 75. Rock View, Devon Consols - Study ceiling*

Ingress was also noted through the stone wall in the kitchen where a washing copper had been located (Fig. 76) and through the external timber end wall of this room. Leakage around windows and their casements was evident throughout the dwelling and ingress through all of the loft hatches was recorded.


*Figure 76. Rock View, Devon Consols – Kitchen*

# MOISTURE

## Interstitial Moisture

Material moisture measurements were made on the south facing slate stone ground floor wall of the office/living room (Fig. 77). Interstitial temperature and relative humidity sensors were located at the heights and depths given in Table 43 and recorded temperature and relative humidity changes at four points within the wall between the period 21st March -12th May.

*Figure 77. Interstitial, U-value and IAQ monitoring set up at Rock View, Devon Consuls, 2011.*

| BUILD UP external - internal | SENSOR | HEIGHT from ffl | DEPTH from int sur finish |
|---|---|---|---|
| Hanging Slate - 20mm | Sensor 1 | 1730mm | 50mm |
| Slate stone - 598 mm | Sensor 2 | 1580mm | 200mm |
| | Sensor 3 | 1430mm | 350mm |
| OVERALL = 618 mm | Sensor 4 | 1280mm | 500mm |

*Table 43. Interstitial gradient sensor record for Rock View, Devon Consols, 2011.*

Figure 78 shows the average values of each sensor over the monitoring period graphed as separate temperature and dewpoint gradients. The values derived from the relative humidity sensors have been converted to dewpoints in order to indicate the likelihood of condensation forming within the wall.

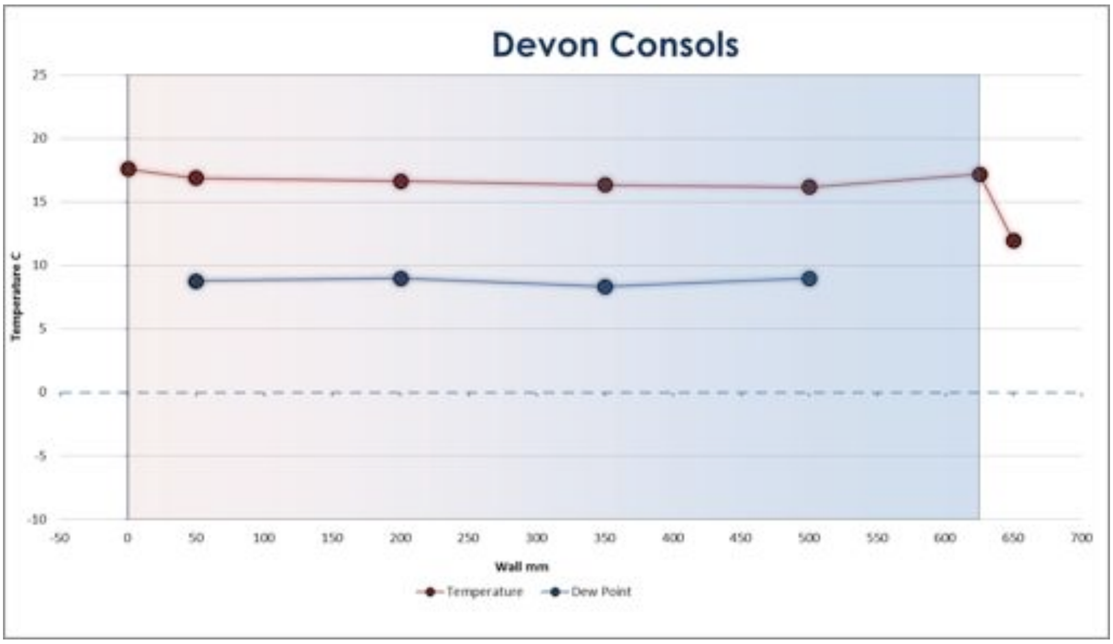


*Figure 78. Temperature and dewpoint gradient for Rock View, Devon Consols, 2011.*

The virtually horizontal temperature gradient shown in Figure 78 indicates the lack of any insulative effect of the wall during the monitoring period where there is no temperature difference between the interior and exterior surfaces. This is due to a combination of circumstances, the wall is south facing and covered with dark coloured slates which absorb heat as solar radiation, because these slates are hung from the mortar courses there is good contact between the slates and the stone of the wall behind ensuring good heat transfer into the wall structure. Rock View has no central heating system and so one might expect that as there is little heat input into the interior space during the day (other than solar gain through the glazed doors and windows which cover a large proportion of the ground floor wall) that the temperature gradient might reverse the normal pattern and dip towards the interior surface of the wall. However it remains steady through the full section of the wall. Although there is no central heating the living room/office at Rock View is heated in the evening with a wood burning stove. It maybe that this evening heat input, coupled with the gains made to interior air temperatures via glazing apertures during the day, is roughly equivalent to the heat input received as solar radiation externally. The gradient plotted in Figure 78 is the result of an averaging process and this, and also perhaps due to the thermal mass of the stone structure itself which will have a slow response to heat inputs and losses shows the thermal transmissivity of the wall as effectively static over the monitoring period. However, it should be noted that this pattern of the wall's thermal behaviour is not necessarily representative of the walls' performance as a whole. The monitoring period coincided with an unusually sunny late winter and the thermal gains made by the wall in this instance could not expect to be replicated during the majority of the winter heating season.

The dewpoint gradient for the wall at Rock View is also unusual as it does not conform to the standard pattern where dewpoint and temperature gradient tend to converge towards the exterior face of the wall structure. Here there is great separation between the two, the margin between being the largest of all the walls in the study, 7.76˚C. This is similar to the pattern found for the wall at Ashburton but most likely for different reasons. It was noted during the core drilling exercise at Rock View and also during the air permeability testing that the slate stone walls themselves were draughty and a source of air ingress. This was probably as a result of the poor condition of the historic limewash which was the internal finish for the walls before they were drylined which was now cracked, parts of the external hanging slate finish are also loose. The effect of the presence of external air within the body of the slate stone wall maybe to lower the relative humidity within the structure in two ways; by drying the air through air movement and/or by introducing external air of lower humidity and allowing internal air to be rapidly exhausted through the structure. A reduction in the relative humidity of the air found within the wall will in turn reduce the risk of interstitial condensation and may thus explain the wide dewpoint margin. It will also however have the effect of cooling the wall.

Sensor values for the wall were logged at 5 minute intervals and this information has been animated in order that changes in temperature and dewpoint maybe analysed over time. (To view the interstitial gradients animation for Rock View, Devon Consols, visit www.archimetrics.co.uk). From the animation it is possible to see the dramatic effect of solar gain on the external surface temperature of the south facing wall and the way that this heat transfers into the body of the construction. Likewise it is also possible to see, during the evening when a fire is lit and temperatures outside dip, the way heat transfers from interior of the room into the wall. This diurnal/nocturnal see-sawing between interior and exterior heat inputs supports the speculation made in the preceding paragraphs about these inputs effectively equalling one another and thus the absence of significant heat loss moving in one direction for the wall at Rock View. This stasis also explains the inability to provide *in situ* U-values for the property as these rely on heat flowing in one direction (normally from interior to exterior) for the majority of a monitoring cycle.

Surface Moisture

Because of the drylining finish to the wall that was monitored at Rock View it was not possible to collect relevant data for the surface moisture conditions of the stone wall behind this covering.

INDOOR AIR QUALITY & COMFORT/FABRIC RISK

Table 44 provides a summary of the indoor conditions surveyed within the living room/office on the ground floor at Rock View (see plan). The figures represent average values recorded over the monitoring period 21st March - 12th May.

| PROPERTY | $CO_2$ (ppm) | Temp (˚C) | RH (%) |
|---|---|---|---|
| Devon Consols | 493.1 | 18.4 | 59.2 |

*Table 44. Indoor Conditions at Rock View, 21st March -12th May.*

Parameters surveyed were $CO_2$, air temperature, and relative humidity levels. The individual indoor temperature and relative humidity readings were also plotted against an index of human comfort and fabric risk. The results for Rock View can be seen in Figure 79.

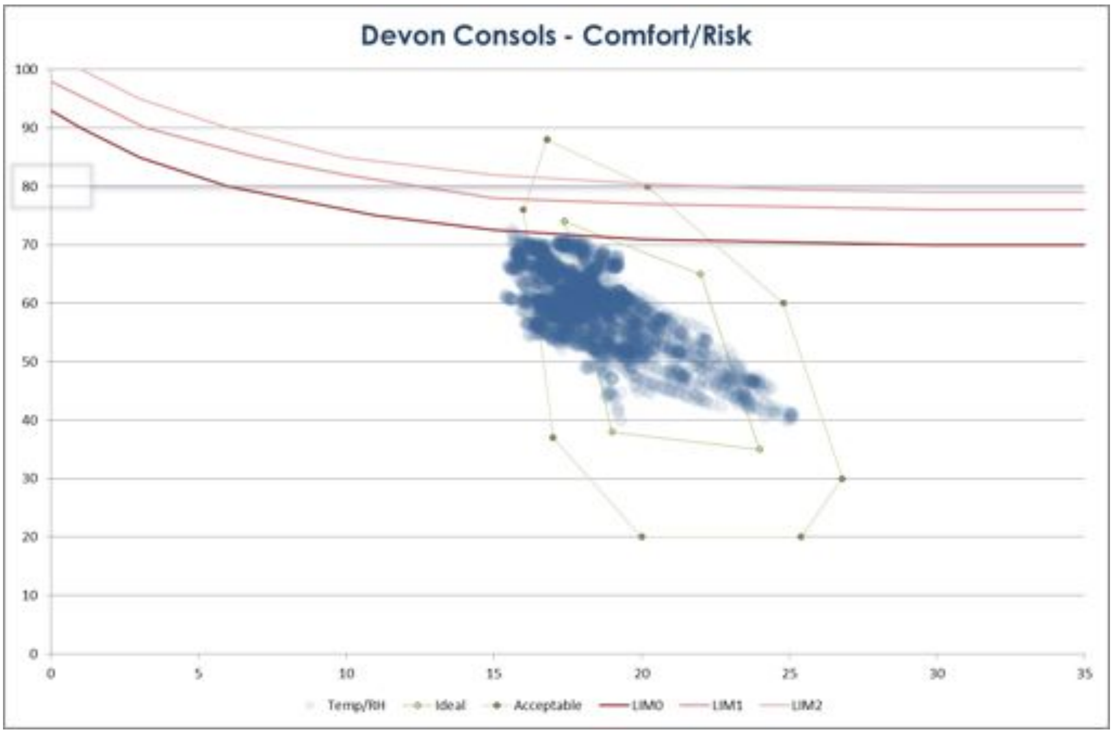


*Figure 79. Comfort/Risk Analysis for Rock View, Devon Consols, 2011.*

As is shown in Figure 79, the majority of the temperature/relative humidity measurements fall slightly outside of the parameters deemed ideal for human comfort but within the polygon that describes the acceptable limits. Neither do these conditions seem to imperil the fabric of the building as the temperature/RH cluster sits below the limiting isopeths for mould gradients which mark the tolerance thresholds for various material types (LIM 0 - ideal culture medium, LIM 1 - timber, LIM 2 Masonry).

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