**COMPARISON OF MOISTURE SURVEY AND U-VALUES FOR A UK 220mm SOLID BRICK WALL**

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**ABSTRACT**

Existing buildings form a major challenge for thermal upgrade because of individual idiosyncrasies. Estimations suggest some 20% of UK houses are of traditional 220mm solid brick construction and are therefore an important consideration for energy reduction. Although generic U-values are given in published data sets, the validity of these is being questioned because field tests suggest that actual construction gives a better performance, thus creating challenges for government initiatives where payback is dependent on energy savings. Conversely, U-values of existing walls may be increased, therefore worsened, due to moisture content. An eight-week period of moisture surveys and heat flux sensor testing of adjoining north-east and south-east facing 220mm solid brick walls of a small UK dwelling is presented. The aim is to add to the understanding of relationships between moisture readings and U-values, by comparing normal surveying moisture survey results and U-value measurements. The analyses show periods of saturation and patterns of initial drying. The measured U-values of the walls at different moisture readings are presented. Findings were that the U-values increased with above 20%wme moisture readings and with NE over SE orientation, but that they were generally lower than published.

**Keywords:** U-values, moisture, solid wall, brickwork

**INTRODUCTION**

New-build requirements are aiming for higher levels of insulation to reduce energy wastage through building fabric. Most countries have large existing building stocks and are beginning to examine investment in thermal upgrade work, to reduce energy use for space heating and cooling. Client investment often relies on good payback periods, while there are also global needs for accurate assessments of actual energy savings, particularly for underpinning government initiatives such as the UK’s Green Deal (UK Government, 2013). If the performance achieved does not meet expectations, significant problems arise for the business model. Generally, forecasts rely on theoretical calculations, such as SAP in the UK (BRE, 2012b). Energy performances, particularly when seeking to achieve low and zero carbon standards, are dependent on very low incidences of defects in insulation layers, air barriers and the installation/commissioning of services. Theoretical calculations generally do not predict such defects in new-build, and when considering existing premises the uncertainties increase. Not only are defects in retrofitted measures unaccounted for, but there is also considerable uncertainty in the performance of the existing fabric.

Recent legislative and practice standards have been based on modelling with less emphasis on testing results in the field. Quantifying the actual performances of buildings can only be effectively realised by in-situ testing, post-occupancy evaluation and dynamic data analysis. Wingfield, Miles-Shenton and others have performed detailed co-heating tests to measure whole-building heat loss coefficients on a variety of new build dwellings. Findings (Joseph Rowntree Housing Trust, 2012; [Wingfield et al, 2008](#_ENREF_28); [Bell et al, 2010](#_ENREF_2); Antretter, 2007) show that, in general, even where dwellings measured have been those for which an aspiration of high energy standards has existed and therefore where extra care might have been expected to be taken during the build process, thermal performance of the as-built fabric in recently constructed houses in the UK is much worse than that predicted by theoretical calculations. Discrepancies in measured versus predicted mean U-values range between around 10% to over 100% above theoretical values (Stafford, 2011; Antretter, 2007), in each case the actual measured heat loss being greater than that predicted. If similar discrepancies exist for refurbishment works, then returns and payback will be less than anticipated.

Existing properties built before radical tightening of energy performance regulations are expected to continue to dominate building stocks (DCLG, 2006). Estimations suggest some 20% of UK houses are of traditional 220mm solid brick construction and are therefore an important consideration for energy reduction. Existing buildings form a major challenge for thermal upgrading due to their individual idiosyncrasies. They are diverse in age, construction, material standard, condition and thermal performance. Some will be partially upgraded thermally, most will not (DCLG, 2012).

Although standard U-values for this construction are given in data sets such as RdSAP (BRE, 2012a) the validity of these is being questioned because field tests suggest that the actual construction may give a better performance than suggested. This can create significant problems for initiatives such as the UK’s Green Deal (UK Government, 2013), where payback is dependent on energy savings. Initial performance that is better than expected is also a problem because it results in an underestimation of the potential savings. On the other hand, U-values of existing walls may be increased, therefore worsened, because of moisture content, the level of deterioration, and the standard of construction. A growing body of research is considering the effects of insulation and its propensity to contribute to interstitial condensation and mould (Browne, 2012; Rye et al, 2012). Where damp walls are insulated, this tendency can increase because of a reduction in the walls’ capacity to regulate moisture, commonly referred to as its breathability (Santos, 2008; English Heritage, 2010).

Existing properties bring complexities and unknown factors for any testing protocol. Challenges include a tendency to be unique in precise construction and design, dampness and age defects affecting performance, unknown air-leakage pathways), and a lack of agreed protocol for testing existing properties. These challenges are not limited to UK dwellings but are seen throughout the world albeit in different construction formats. Few existing properties (relative to new-build) have been tested to date, but some UK bodies (SPAB, 2012; Historic Scotland, 2012; Joseph Rowntree Foundation, 2012) have carried out thermal performance testing of existing dwellings. The dampness of the existing walls is not usually measured but it is a generally held belief that U-values probably increase with dampness. The Energy Savings Trust (2010) have developed typical base cases to inform refurbishment measures. English Heritage ([2010](#_ENREF_13)) in acknowledging energy conservation, mention testing activities of pressurisation and thermal imaging, but go no further.

The surveying professions usually carry in their stock of equipment simple moisture meters for testing the dampness of walls. Commonly used moisture meters do not give true indications of the amounts of moisture in masonry, or of percentage moisture content, but do give a “wood moisture equivalent” or “wme”, expressed as a percentage (General Electric, 2011). Different materials are considered to be damp at different percentage moisture contents and the wme can indicate damp conditions of equal significance for building pathology purposes in brick and plaster regardless of the real difference in moisture content.

As the surveying profession comprises practitioners most likely to ascertain an indication of a wall’s current performance when considering any thermal upgrade work, it was decided to use the equipment available to a surveyor when considering the level of dampness in a wall for the purposes of this research. The aim was to add to the understanding of relationships between moisture readings and U-values, by comparing normal surveying moisture survey results and U-value measurements of a 220mm solid brick wall in the UK.

**METHOD**

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Figure 1. (1) SW elevation, (2) SE elevation, (3) Ground Floor plan of test property indicating point of moisture ingress through NE & SE walls, and (4) Heat flux sensor positions and mositure meter grid positions: opening in wall indicates external door position in SE wall.

The research data was limited to a single UK traditional 220mm solid brick wall property. The two-storey domestic property suffered visually apparent, excessive ingress of moisture in July 2012, and the cause was rectified. The elevations and ground floor plan are shown in Figure 1. This example provided a property possessing very wet masonry on adjoining north-east and south-east facing walls, which would be expected to dry out over the remaining summer period. This test property provided a number of benefits in that it gave areas of varying levels of dampness, in the same and adjacent walls (and therefore most probably the same wall construction), including two adjoining walls of 90o different orientation, and it could provide reducing levels of dampness in the same walls as the walls dry. The wall was also naturally wetted. A disadvantage was the summer period, sometimes without a reasonable delta T.

The U-values of the walls were measured and corrected for environmental conditions, at different heights and different moisture readings. Ten heat flux sensors were attached to the north east and south east elevational walls, in the areas affected by the damp ingress. Their positions are shown and described in Figures 1 and 3.

Theoretical U-value calculations were carried out, based on those provided by BRE U-value Calculator version 2.03 for a masonry solid wall using the method given in BS EN ISO 6946 (BSi, 2007). Additional values were taken from the data in BS EN 12524:2000 (BSi, 2000). A theoretical U-value calculation was carried out for the base wall. This used generic values given in British Research Establishment and British Standards Institution data sets for a 220mm thick brick wall plastered internally with 13mm gypsum plaster, taking account of a 0.24 brick to mortar fraction.

At each sensor point, an individual theoretical U-value was calculated based on the known construction and finish. These incorporated 15 to 20mm of lime or gypsum plaster, skim, papered finishes, and calculated bridge fractions of 0.172 mortar and 0.077 air for the variation of English garden wall bond brickwork. With reference to BS EN ISO 6946:2007, (BSi, 2007) the air layers were taken as unventilated, but very recent unpublished test results suggest that this might not be the case.

Heat flux can be converted to thermal transmittance if the temperature difference is known. Data was collected from the ten Hukseflux heat flux sensors at 10-minute intervals. Five Tinytag Ultra2 data collectors were used to measure the difference in temperature between the internal and external environments. Additional data was taken from two local weather stations: a WXT520 Vaisala weather transmitter, positioned at York University Department of Electronics (Department of Electronics, 2012), and the Davis Vantage Pro weather station at Naburn Hill Farm, York, both approximately 6km away from the test house (Hobson Farming Ltd, 2012).

A moisture meter survey was undertaken using a Protimeter Mini 111, at weekly intervals on a grid pattern on the internal walls as illustrated in Figures 1 and 2. Measurements were taken into plaster only. The method of taking moisture meter readings used was deliberately that commonly used by surveyors and other building professionals when undertaking measurements to determine the dampness of a wall by using percentage moisture wme readings. Additional to tabulated presentations, the recordings were illustrated in colour bands on an excel sketch, and the areas then softened using extra measurements as required, as illustrated in Figure 2.

Data was collected for an initial eight-week period. Daily (24-hour) averages of the heat flux measurements were calculated along with daily standard deviations. Daily averaged internal and external temperatures gave the daily temperature differences delta T, and the heat flux density in W/m2 divided by the delta T gave the averaged daily U-value in W/m2K at each sensor point.

Analyses compared graphs and tables of the data including the theoretical U-value, averaged percentage wme, standard deviations of the averaged percentage wme, the highest %wme, the closing %wme, the U-value (daily average) at the highest value, and the U-value (daily average) at the accepted typical lowest value. Theoretical calculated and measured U-values are given to two decimal places.

**RESULTS AND DISCUSSION**

RdSAP suggests a U-value for a solid brick wall pre-1950 as 2.1W/m2K in Appendix s, Table 6. (BRE, 2012a). The theoretical U-value calculation for the tested base wall gave a theoretical base U-value for the walls of 2.11W/m2K. The individual theoretical sensor point U- value calculations, based on the known construction and different wall finishes on the base wall, gave differing theoretical U-values between 1.58 and 2.09W/m2K, with an average of 1.70W/m2K, all slightly lower than the standard base case of 2.11W/m2K. For the measured points, graphs of the U-values over time, taken from the measured heat flux data at each point and deltaT and show the daily variances for each sensor. Averaged U-values over the period at each sensor point varied between 0.73 and 2.54W/m2K. The averaged daily U-values for all the sensors were graphed and the trend-line suggested an average of around 1.30W/m2K for the 220mm solid brick wall.

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Figure 2: (1) A moisture meter reading data set (shading in the table indicates heat flux sensor positions). (2) Moisture readings illustrated in colour bands. (3) Moisture readings smoothed out with additional readings, to visually indicate the extent of ‘dampness’.

The moisture readings taken of the wall did not indicate the wall internal surface layers drying out as quickly as expected. The 2012 July to September weather conditions were mainly influenced by low pressure, high rainfall totals, cool temperatures with the mean 0.4°C below average, and cloudy with 82% of normal sunshine. (Met Office, 2012).

The analyses showed periods of initial saturation and patterns of drying. The pattern of moisture at each heat flux sensor position was graphed. At the sensor points, the moisture meter reading variations could then be mapped against U-value variations and averaged data compared. Because the aim of the research was to compare normal surveying moisture survey results and U-value calculations to ascertain whether U-values increase with measured moisture readings, the relative dampness readings of the wall positions were grouped into ‘dry’, ‘medium’ and ‘wet’ and tabled against the theoretical and measured U-values. A reading below 20%wme was regarded as ‘dry’, readings between 20 and 70%wme as ‘medium’ and above 70%wme as ‘wet’. The medium and wet split was arbitrarily chosen; dry below 20%wme was chosen because a moisture meter reading of above 20% in any material is regarded as a damp condition for building pathology (General Electric Company, 2011; Melville and Gordon, 1973). The summary table is shown at Figure 3.

The full data sets were grouped and regrouped to find relationships. Comparisons were also made with daily environmental conditions. It was found that there is a correlation between walls which would be regarded as damp for building pathology purposes and the U-value. Points on the walls which could be regarded as damp showed an average U-value around 1.63W/m2K compared to an acceptably dry wall showing an average of 0.79W/m2K. This suggests that a wall that is damp is likely to have a higher U-value than when it is dry. However, there is less evidence of a simple relationship between U-values and moisture readings when considering the level of dampness. The evidence did not support the notion that the wetter a wall was, the greater the U-value.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sensor Ref | Height above FL mm | Wall facing direct-ion | Position in relation to door | Wall plaster type and finish | Theoretical U-value | Av moisture level: 'Dry'<20%; 'Med'>20<70 'Wet'>70% | Av daily measured U-value | Av daily measured U-value less effect of wall finish  |
| F1 | 250 | SE | LHS  | Gypsum, Skim, EPS | 1.46 | Wet | 0.98 | 1.03 |
| F2 | 800 | SE | LHS  | Gypsum, Skim | 1.53 | Wet | 1.11 | 1.11 |
| F3 | 1200 | NE | LHS  | Gypsum, Skim | 1.53 | Wet | 2.39 | 2.39 |
| F4 | 2000 | NE | LHS  | Gypsum, Skim | 1.95 | Med | 2.40 | 2.54 |
| F5 | 2000 | SE | LHS  | Gypsum, Skim, EPS, paper 1  | 1.45 | Wet | 1.14 | 1.21 |
| G1 | 250 | SE | RHS  | Gypsum, Skim, EPS, paper 1 | 1.45 | Wet | 0.89 | 0.96 |
| G2 | 1200 | SE | RHS  | Gypsum, Skim, EPS, paper 1 | 1.45 | Dry | 0.66 | 0.73 |
| G3 | 2500 | SE | LHS  | Lime, Skim, EPS, paper 2  | 1.45 | Med | 1.36 | 1.50 |
| G4 | 2500 | NE | LHS  | Lime, Skim, EPS, paper 2 | 1.95 | Med | 1.60 | 1.74 |
| G5 | 2500 | SE | RHS  | Lime, Skim, EPS, paper 2 | 1.95 | Dry | 0.72 | 0.86 |
| Theoretical generic U-value calculation for base wall  | 13mm gypsum, Skim | 2.11 |   |   |   |
| Published figure for pre-1900 solid brick wall (BRE, 2012a) | 2.1 |  |  |  |

Figure 3: Summary comparison table of position descriptions, averaged moisture levels, theoretical and measured U-values.

When comparing areas of wall that could be regarded as damp, which are at similar heights and similar dampness, it can be seen that there was a large difference in U-value between those sensors on the north-east wall and those on the south-east. By comparing F4:G3, F3:F2, G4:G3 and F4:F5, all the first sensors in the pairs were positioned on the north-east wall with the second sensor in each pair on the south-east wall. All the pairs, apart from G4:G3, show an approximate 1W/m2K factor difference between the two averaged U-values. The G4:G3 pair may be an anomaly because over the test period the wall behind them became much drier when tested with the moisture meter so that they almost spanned into the “dry” wall category toward the end of the test and this may have skewed the averages taken.

Above 20%wme, the walls displayed instability in the U-value. Some patterns of environmental conditions seemed to emerge where high peaks of U-value are measured. The environmental conditions suggested which may relate to higher U-values were high wind speeds and gusts with a SE to SW direction, coupled with rain, low pressure, little or no sun and low solar energy. No patterns of environmental condition were ascertained for low points of U-value measurement.

**CONCLUSIONS**

The aim of this paper was to add to the understanding of relationships between moisture readings and U-values, by comparing common surveying moisture survey results and U-value measurements of a nominal 220mm solid brick wall in the UK. Theoretical U-value calculations and measured U-values taken over an eight week period were compared with percentage wood moisture equivalent readings on adjoining north-east and south-east walls.

To summarise the findings, a “dry” wall, measuring below 20%wme when tested with a moisture meter internally, tended to correlate with lower U-values. Above 20%wme, the orientation of the wall had the greatest effect, regardless of the moisture meter reading. A wall having a %wme above 20 increased the U-value by about 1W/m2K or a factor of 50% or above. An orientation of north-east rather than south-east increased U-value by a factor of 60-100%.

In addition, while the U-values increased with moisture reading, they were generally lower than published values. As the measured performance was better than calculated, this could be a problem if it results in an underestimation of any potential savings in refurbishment. It can therefore be extrapolated that national savings in energy use and the reductions in carbon emissions may be considerably lower than anticipated.

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