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Physical Monitoring of Replacement Infill Panels for Historic Timber-Framed Buildings in the UK:

Comparing hygrothermal simulations and dual climate chamber testing

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ABSTRACT: With the aim of reducing carbon emissions and increasing hygrothermal comfort, buildings across the UK are undergoing energy retrofits. With historic buildings, it is important that retrofit actions have a limited negative impact on the building's fabric and cultural significance. Work to date in the UK has focused on the retrofit of historic solid masonry construction, with little research into the retrofit of historic timber-framed buildings. Changes to these buildings must be managed through the use of established conservation principles. However, where infill panels are beyond repair or have previously been substituted with inappropriate materials, there exists the potential to retrofit a material with a higher thermal performance. Nonetheless, it must be ensured that this retrofit does not create interstitial hygrothermal conditions that could threaten the survival of surrounding historic fabric. In this paper the authors present the hygrothermal simulation and physical monitoring of three different potential replacement infill panels. Results from Glaser calculations, WUFI® Pro and WUFI® 2D are compared to measured results of physical test panels mounted between two climate-controlled chambers. Whilst all three prediction methods successfully identified interstitial condensation where it was measured to occur, major discrepancies existed both between simulated and measured results, and between different simulation methods.

KEYWORDS: Timber-Framed, Hygrothermal simulation, Hygrothermal monitoring, Interstitial condensation, Retrofit

1. INTRODUCTION

As we seek to improve the energy efficiency of our built heritage it is important that care is taken to minimise negative impacts and avoid damage to the building's significance, character and fabric [1]. A key consideration is the influence of thermal insulation on the hygrothermal performance of the external envelope, where increases in moisture content arising from interstitial condensation could adversely affect the pre-existing historic materials. Research in the UK has so far focused on the impact of insulation on solid masonry construction [2-4] with little investigation into the retrofit of the 68,000 historic timber-framed buildings which form an important part of Britain's cultural identity.

2. RETROFITTING HISTORIC TIMBER-FRAMED BUILDINGS IN THE UK

Historic timber-framed buildings in the UK consist of a structural timber frame with a solid infill. This is traditionally wattle-and-daub, a framework of thin timber members (wattlework) covered by an earthen render (daub). Other historic infills include lath and plaster and brick nogging [5]. Whist some of these buildings are over clad with tiles, weatherboarding or continuous plaster, in many cases the timber frame is exposed both internally and externally (Fig.1&2).

Figure 1: Externally exposed frame. (Whitman, 2015)

Figure 2: Internally exposed frame. Whitman, 2015)

When retrofitting these buildings, in order to retain the aesthetics and character of the building, the exposed framing often precludes the use of internal or external wall insulation. This leads to problems created by the thermal bridging of the frame, potentially focusing interstitial condensation at the junction between the infill panel and the timber-frame. In addition, achieving a seal at this junction is often problematic, leading to issues with moisture ingress and poor airtightness.

Work to any historic building in the UK should follow a set of ethical principles as set out by each of the four national governmental bodies related to heritage, Historic England [6], Cadw [7], Historic Environment Scotland [8] and the Northern Ireland Department for Communities, Historic Environment Division [9]. In general, it is expected that where possible, every effort will be made to retain existing historic fabric, and where replacement is required that this normally takes place on a “like-for-like” basis [ibid]. It is, however accepted that this is not always possible or the best option. For example, where historic infill is beyond repair, has been replaced with inappropriate modern materials, or its removal is required to facilitate the repair of adjacent timbers, there exists the opportunity to retrofit an infill material with a higher thermal resistance [10]. Due to the need to maintain the vapour permeability of the panel, potential alternative infill materials include wood fibre, expanded cork, sheep’s wool and hemp-lime. For this experiment the performance of traditional wattle-and-daub, expanded cork and a detail using wood fibre and wood wool as suggested by Historic England [11] were compared (Fig.3).

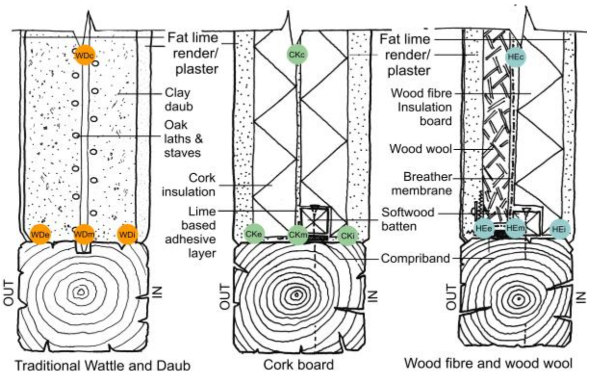

Figure 3. Detailed sections of three panel infill build-ups showing monitoring positions

3. METHODOLOGY

In order to physically measure the hygrothermal performance of these three details, three test infill panels 820mm x 820mm x 100mm (L x W x D) were constructed within oak frames constructed from reclaimed oak. The dimensions of the panels were dictated by the test facility, however a review of a representative sample of 100 surviving UK timber-framed buildings was undertaken to establish the average infill panel size for comparison (Fig.4).

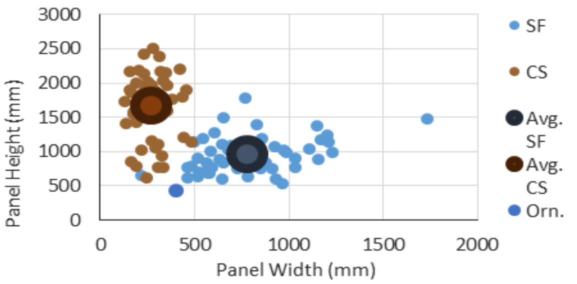

Figure 4. Dimensions of 100 representative sample infill panels. Square Framed (SF), Close Studded (CS), Ornamental (Orn).

This indicates that 53% were “square framed”, 46% “close studded” (tall rectangular panels) and 1% “ornamental”. The average dimensions of the square framed panels were 785mm x 950mm with a standard deviation of ±260mm. As such, the test panels can be said to be typical in size.

The use of reclaimed oak was chosen for the frames following dynamic vapour sorption (DVS) testing of three oak samples felled during the 17th, 19th and 21st centuries. The results, measuring the vapour sorption profiles for each sample, showed that the older the timber the less moisture it absorbs (Fig.5).

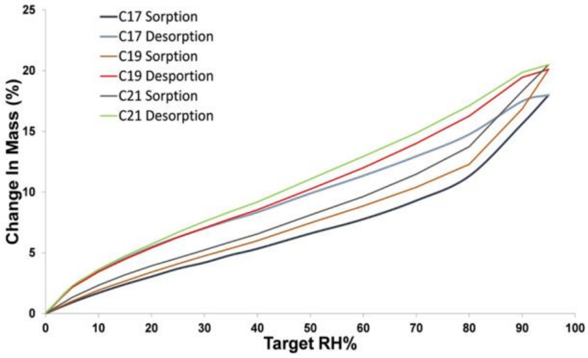

Figure 5. Sorption profiles for 3 samples of oak felled in different centuries.

Experimental testing took place at the University of Bath’s Building Research Park using their Large Environmental Chambers. The three panels were mounted as part of a dividing wall between the two climate-controlled chambers (Figs.6&7).

Figure 6. Panels in climate chamber. View from “internal” chamber.

Figure 7. Dual climate chamber

Temperature (°C) and moisture content (%) were monitored in four positions within each panel, one in the centre of the panel at a depth of 50mm and three in the centre of the lower timber frame at a depth of 10mm, 50mm and 90mm (Fig.3). The temperature was measured using type-T thermocouples (range -75°C to +250°C, accuracy ±0.5°C) connected to a Campbell Scientific CR1000 data logger. The moisture content was measured using electrical resistance. For each monitoring position, copper wires were attached to two stainless steel screws, inserted in the oak frame, placed 20mm apart, parallel to the wood grain. The copper wires were connected back to a Campbell Scientific CR1000 data logger measuring resistance, wired and programmed according to advice provided by Historic England [12], originally developed by Dr Paul Baker of Glasgow Caledonian University. This method was selected due to the potential for continuous measurements and the small size of the wire/screw arrangement, thereby limiting the influence of the sensor on the wall's performance. The wiring for both electrical resistance and temperature measurements was also routed to minimise the creation of any direct paths for hygrothermal movement.

In addition, the dry-bulb air temperature (°C) and relative humidity (%) of each climate chamber were monitored with Campbell Scientific CS215 RHT probes (range- 0 to 100% RH, -40°C to +70°C, accuracy ±2% RH, ±0.4°C). Concurrently, in situ U-value measurements were undertaken in accordance with BS ISO 9869-1 [13]. These measurements were taken in two monitoring positions per panel, one close to the centre (offset from the interstitial monitoring position to avoid interference) and 100mm from a corner to assess the edge effect from the timber frame. Measurements were made using Hukseflux HFP01 heat flux plates and type-T thermocouples connected to a Campbell Scientific CR1000 data logger with readings taken at 5-minute intervals.

To determine the set temperature and relative humidity of the test chamber, Glaser calculations were undertaken in accordance with BS EN ISO 13788:2012 [14]. These calculations plot the vapour pressure against the saturation vapour pressure, across the thickness of the panel build-up under steady-state conditions and constant heat transfer. Where the vapour pressure touches or crosses the saturation vapour pressure, interstitial condensation is deemed to occur. The results of these calculations showed that with internal conditions of 21°C/70% RH and external of 5°C/80% RH, interstitial condensation would occur within the wood fibre panel, and the wattle-and-daub would see an increase in moisture towards its inner face. Conditions would have to be increased to 90% RH, internally and externally, to produce any increase in moisture content within the cork panel. Although subsequently modified, at the time of testing prolonged operation of the climate chamber at 90% RH was not possible due to technical constraints. Therefore, the set points of 21°C/70% RH for the internal chamber and 5°C/80% RH for the external chamber were used for the experiment.

Following 3 weeks of monitoring, the datasets were downloaded and analysed. The measured hygrothermal conditions within the two climate chambers were then used to simulate the interstitial hygrothermal performance of the panels using WUFI® Pro 5.3 (one dimensional hygrothermal movement) and WUFI® 2D (two dimensional). All material data used in the simulations was taken from the Fraunhofer materials database provided with the software. There is therefore a degree of error with the use of this material data, as it is data measured on German materials which may differ from the UK materials used in the construction of the test panels. This constraint is however unavoidable due to the lack of adequate data for UK building materials, especially those in historic buildings.

3. RESULTS

3.1 Thermal Performance

Table 1: Measured and calculated U-values

Panel type	Centre (W/m²K)	Corner (W/m²K)	Calculated (W/m²K)
Wattle-and-daub	2.72	2.10	2.85
Cork	0.49	0.47	0.45
Wood fibre	0.59	0.60	0.63

The results of the in situ U-value monitoring are presented in Table 1 along with the values calculated according to BS EN ISO 6946:2007 [15]. A positive edge effect is seen for the wattle-and-daub due to the thermal conductivity of the oak frame being lower than the panel. A negative edge effect is seen for the wood fibre as the infill has a lower thermal conductivity than the frame. The positive edge effect for the cork was not expected, however thermography showed this was due to a horizontal central joint in the cork panel reducing the thermal performance at the central measuring location. Overall the cork had the best thermal performance.

3.2 Interstitial Moisture Content

The results of the Glaser calculation, the WUFI® Pro 5.3 and WUFI® 2D simulations and the interstitial moisture content measured in the test panels were compared and are presented in Table 2.

Table 2: Moisture content as measured and simulated. Increase (↑), slight increase (↗), decrease (↓), slight decrease (↘) and steady (→). Key findings highlighted in red.

Infill	Loc.	Glaser	WUFI® Pro5.3	WUFI® 2D 3.3	Measured	Agreement
Wattle and Daub	Ext.	→	↓	↓	↑	✗
	Cen.	→	↗	↗	→	✓
	Int.	↑	↑	↑	↗	✓
Cork	Ext.	→	↗	↓	↑	✗
	Cen.	→	→	→	→	✓
	Int.	→	↘	↑	→	✗
Wood fibre	Ext.	→	↗	↓	↑	✗
	Cen.	↑	↑	↑	↑	✓
	Int.	→	↓	↑	↓	✗

Table 2 indicates if the moisture content increased, decreased or remained steady throughout the duration of the test/simulation period for each of the prediction methods, compared to the measured results. The final column of the table indicates if there was found to be agreement between the simulated and measured results for each monitoring location. The results demonstrate that there was agreement between simulations and measurements for four of the nine monitoring positions (44%). Most importantly, the measured rise in moisture content in the centre of the wood fibre panel, arising from interstitial condensation, was successfully identified by all three prediction techniques. However these failed to foresee the measured rise in moisture content in each of three external lime renders. Equally there can be seen to be contradictions between results generated by the two versions of WUFI®. Further research is required to investigate the reason for these discrepancies.

None of the simulation techniques nor the measured data showed any suggestion of interstitial condensation within the cork infill panel. Coupled with the superior thermal performance of this detail, these results would suggest that this potentially could be a good retrofit solution.

4. CONCLUSION

The results show that for steady state conditions the simulations successfully anticipated interstitial condensation where it occurred, however increases in moisture content towards the external face of all three panels were not predicted.

Overall the cork infill detail performed the best, with the greatest thermal performance and no interstitial condensation being identified. It should however be noted that these results are all for forced steady-state conditions that are unlikely to exist in real life. Dynamic cyclic testing on the same panels has since been undertaken and funding for a longer term monitoring programme with real climatic conditions is currently being sought.

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REFERENCES

1. Historic England. (2012). *Energy Efficiency and Historic Buildings: Application of Part L to historic and traditionally constructed buildings* (Revised 2012). p.4.
2. Gandhi, K. Jiang, S. & Tweed, C (2012). *Field Testing of Existing Stone Wall in North Wales Climate. SusRef: Sustainable Refurbishment of Building Facades and External Walls*. Cardiff University.
3. Rye, C., Scott, C. & Hubbard, D. (2012). *The SPAB Research Report 1. U-Value Report*. Revision 2 ed.: Society for the Protection of Ancient Buildings.
4. Baker, P. (2015). *Hygrothermal Modelling of Ditherington Flax Mill*. Research Report Series. Historic England.
5. Harris, R. (2010). *Discovering Timber-Framed Buildings*, Oxford, UK, Shire Publications. p.20
6. Historic England (2008). *Conservation Principles: Policies and Guidance for the Sustainable Management of the Historic Environment.* Historic England. p.52
7. Cadw (2011). *Conservation Principles for the Sustainable Management of the Historic Environment in Wales*. Cadw. p.24
8. Historic Environment Scotland (2016). *Historic Environment Scotland Policy Statement.* Historic Environment Scotland. p.9
9. Historic Environment Division (2017). *Historic Environment Fund Repair Stream*. Northern Ireland Department for Communities. p.15
10. Ogley, P. (2010). *Insulating timber-framed walls*, London, English Heritage.
11. McCaig, I. & Ridout, B. (2012). *English Heritage practical building conservation- Timber*, London; Farnham, Surrey; Burlington, VT, English Heritage; Ashgate.
12. McCaig, I. (2016). *RE: CR1000 Data logger programme*. Personal email to Whitman, C.
13. British Standards Institution (2014). *BS ISO 9869-1:2014 Thermal insulation- Building elements- in situ measurement of thermal resistance and thermal transmittance Part 1: Heat flow meter method.* London: BSI.
14. British Standards Institution (2012). *BS EN ISO 13788:2012 Hygrothermal performance of building components and building elements - Internal surface temperature to avoid critical surface humidity and interstitial condensation - Calculation methods*. London: BSI.
15. British Standards Institution (2007). *BS EN ISO 6946:2007 Building components and building elements — Thermal resistance and thermal transmittance — Calculation method.* London: BSI.