Energy Retrofit of Historic Timber-Frame Buildings- Hygrothermal Monitoring of Building Fabric

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1 INTRODUCTION

Energy retrofits have been identified as a key action to decarbonize the UK's building stock and improve hygrothermal comfort [1]. When undertaken with sufficient knowledge and consideration, the energy retrofit of historic buildings can be successfully achieved [2]. However, both aesthetic and technical issues must be fully understood in order to avoid unintended consequences [2]. Research in the UK has focused on the predominant solid masonry construction [3-5], with little research covering the 68,000 historic timber-framed buildings that form an integral part of the UK and specifically England's cultural identity [6]. This paper explores this previously under-researched area.

A key concern with the energy retrofit of historic timber-framed buildings is the risk of elevated moisture content, increasing the potential for insect attack and fungal decay [7]. This paper presents the use of in situ monitoring, digital simulation and laboratory testing to begin to assess this risk.

2 DESCRIPTION OF THE RESEARCH

2.1 *In Situ Monitoring*

In situ hygrothermal monitoring was undertaken at five historic timber-framed buildings in the UK, three in Herefordshire and two in East Anglia. Monitoring included U-value measurements following BS ISO 9869-1:2014 [8], thermography following best practice guidance [9, 10], pressure testing according to BS EN ISO 9972:2015 [11], measurements of internal hygrothermal comfort using TinyTag Ultra 2 TGU-4500 sensors and simplified occupant questionnaires [12]. Timber moisture content was also monitored at two of the case studies using electrical resistance measurements.

2.1.1 *Results*

The use of modern insulation materials should improve the thermal performance of the infill panels, however the measured U-values were often lower than those calculated. This discrepancy can be attributed to the thermal bridging of the exposed timber-frame and poor detailing especially at the junction between frame and infill.

At one case study the replacement infill detail achieved only 53% of the calculated U-value. Thermographic surveys (Figure 1) highlight the lack of hermeticity between infill and timber-frame, leading to a high air change rate and associated increased heat loss. This was confirmed through pressure testing, with an air permeability index of 19 $m^3/h/m^2$.

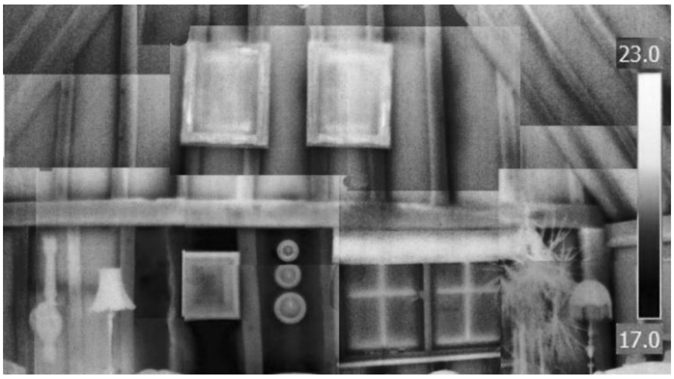

Figure 1. Thermographic image of interior of case study 5, showing poor connection between infill and timber-frame.

Measurements of timber moisture content and temperature at the same case study showed that the use of non-vapour permeable materials, in conjunction with the poor detailing, had led to the creation of hygrothermal conditions that would facilitate biological attack [13]. In another case study, measurements pre and post-retrofit showed an increase in timber moisture content due to the lack of controlled ventilation.

The monitoring of hygrothermal conditions at all five case studies showed poor comfort conditions despite improvements to their external envelopes. Influencing factors include poor airtightness, incoherent retrofit strategies and inadequate, inefficient heating. Despite this, the occupants' thermal perceptions at three case studies contradicted the measured results, with their comments suggesting that their desire to live in these historic properties led to an acceptance of a lower thermal comfort threshold.

2.2 *Digital hygrothermal simulations*

Digital hygrothermal simulations with WUFI® Pro 5.3 were undertaken for 13 replacement panel infill details proposed by current guidance [7, 14, 15], in six geographical locations (Suffolk, Cambridgeshire, Kent, Devon, Herefordshire and Cumbria), representing the principal climates where timber-framed buildings are to be found in England [6].

2.2.1 *Results*

The results suggest that orientation, climatic conditions and infill material all significantly influence the moisture content, however, no prolonged periods of hygrothermal conditions favourable to biological decay agents were identified [16]. Surprisingly the location with the highest risk was not that with the highest rainfall, Cumbria, but rather Suffolk, where higher rainfall occurs during summer months, coinciding with warmer temperatures. It must however be acknowledged that these simulations represent idealised constructions with homogenous layers, rather than the heterogeneous reality, and that material data are limited for historic materials.

2.3 *Physical Test Panels*

Given the limitations of digital simulations, the interstitial hygrothermal monitoring of physical test panels was also undertaken. Three test infill panels 1020mm x 1020mm x 100mm (L x W x D) were constructed within reclaimed oak frames. The chosen infill materials were wattle-and-daub, expanded cork, and a detail using wood fibre and wood wool as suggested by Historic England [15]. The panels were mounted as part of a dividing wall between two climate-controlled chambers at the University of Bath's Building Research Park. Temperature and moisture content were monitored in the centre of the panel and at the interface between infill and oak frame at depths of 10mm, 50mm and 90mm. Results were compared with digital simulations using WUFI® Pro 5.3 and WUFI 2D using measured climatic data.

2.3.1 *Results*

Under extreme steady state conditions, sustained for three weeks, interstitial condensation was measured in the woodfibre/woodwool panel [17]. However this did not reoccur during a following fortnight of cyclical dynamic conditions. Whilst the digital simulations did successfully predict this condensation, discrepancies were identified both between measured and simulated data and between simulation methods. Further long term monitoring is now being funded by Historic England.

3 CONCLUSIONS

- Modern insulation can improve the thermal performance of historic timber-framed buildings, although thermal bridging by the frame and poor detailing can significantly reduce their effectiveness.
- Non-vapour permeable materials and poor detailing can increase the risk of biological attack.
- Panel orientation, climatic conditions and infill material all significantly influence the moisture content, with warm damp climates being most at risk.
- Under extreme conditions interstitial condensation has been observed to occur, however discrepancies exist between simulated and measured data. Further research is therefore required.

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