Improving the Energy Performance of Historic Timber-Framed Buildings in the UK.

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Abstract: As we aim to improve the performance of our existing building stock, both to reduce carbon emissions and to improve occupant comfort, even timber-framed buildings that have stood for hundreds of years are now the focus of energy retrofits. This paper presents a review of the energy retrofit of three historic, half-timbered buildings in Herefordshire, UK. Using u-value and airtightness data measured in situ, dynamic energy simulations using DesignBuilder have been undertaken to assess the effectiveness of each of the applied retrofit strategies. These strategies include the installation of secondary glazing, plastering of thatched roofing, increased loft insulation and complete replacement of infill panels. Initial results suggest that strategies that result in improved airtightness have the highest impact on energy demand, whilst intrusive interventions within the timber-frame itself have limited positive impact.

Keywords: Energy Retrofit, Historic buildings, Timber-frame, Energy Simulation

Introduction

Although in the UK historic and traditional buildings are exempt from full compliance with the energy efficiency requirements of the building regulations (HM Government, 2016, Scottish Government, 2016), they must still aim to “improve energy efficiency as far as is reasonably practicable” (HM Government, 2016). Historic England states that “an informed approach can achieve significant energy efficiency improvements” (English Heritage., 2012), although these need not reach Building Regulation standards. As such, the level of intervention often remains at the discretion of the building owner and their professional advisors, in discussion with the local conservation officer. This paper reviews three historic timber-framed case studies where differing approaches have been taken. Dynamic building energy simulation has been used to evaluate the decisions taken and compare them to possible alternative scenarios. By doing so conclusions can be drawn as to the effectiveness of each approach and the consequence of this on the retrofit of the UK’s 68,000 historic timber-framed buildings (Historic England., 2014, RCAHMW, 2014) and historic and traditional buildings in general. The research in this paper forms part of an ongoing research programme.

Case Studies

The three case study buildings presented in this paper are, Hacton Cruck (Figure 1), a mediaeval peasant hall, now let as holiday accommodation; The Oaks (Figure 2), an estate cottage built over three centuries, now owned by the National Trust and let as a single-family residence; and The Old Mayor's Parlour (Figure 3), a gallery space, managed by a charitable trust, whose origins date back to the 14th century. As such, the case studies represent a variety of ownership models, tenancies and uses. Hacton Cruck and The Old Mayor's Parlour have undergone substantial retrofits and display a variety of different panel infills, both old and new. The work on these properties was designed and overseen by a local, sole practitioner architect. In contrast, The Oaks has had minor retrofit interventions with no change to the existing wall construction, and the works were specified by the estate surveyor in line with the National Trust's environmental standards. The construction work at The Oaks was undertaken by a small building contractor; at The Old Mayor's Parlour by a conservation contractor; and at Hacton Cruck by the building owner in collaboration with professional conservation contractors.

Figure 1 Hacton Cruck, Preston-on-Wye Figure 2 The Oaks, Brockhampton and Figure 3 The Old Mayor's Parlour Hereford. Source: (Author's own, 2015)

Location

All three case studies are all located in the county of Herefordshire, in the English West Midlands, on the border with Wales. Hacton Cruck is situated in the west of the county, The Oaks in the northeast and The Old Mayor's Parlour in the heart of Hereford, the county town, which lies at the centre of the county (latitude 52.06, longitude -2.72). The predominant panel infill materials of the region are brick (47%), plaster (44%) and wattle and daub (8%) (Figure 4). 16% of the buildings with modern infill materials also lie within the county boundaries.

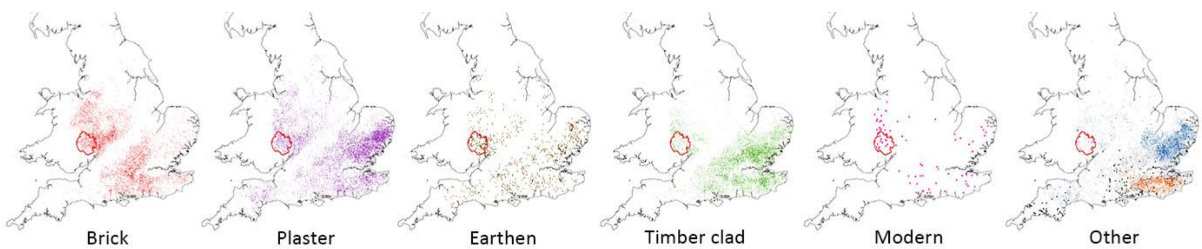

Figure 4 Distribution of timber-framed panel infill materials, with Herefordshire highlighted in red. Source: (Author's own based on data from (Historic England., 2014, RCAHMW, 2014))

Hacton Cruck Hall, Preston-on-Wye, Herefordshire

Hacton Cruck is a 15th century cruck hall in the Wye Valley, Herefordshire, UK (NGR SO 38783 41829). For much of the 20th century it lay abandoned and derelict, yet from 2000 until 2012 it was restored by its owner and now provides holiday accommodation. The renovation involved three different approaches to wall infill panels. On the northern elevation the surviving oak lath and lime plaster panels were retained and repaired. Elsewhere the original infill had been lost and new panels were installed. For most of these it was decided to improve the thermal efficiency by introducing a modern multi-foil insulation, consisting of reflective foils separated by polyester fleece. The foil is held by upright staves within a void and is finished internally and externally with lime plaster on expanded metal lath. In a few locations the thickness of the wall was insufficient for this construction. Led by a desire to experiment with traditional building techniques, the owner decided to recreate wattle and daub for these few panels. The distribution of these panels is shown in Figure 5.

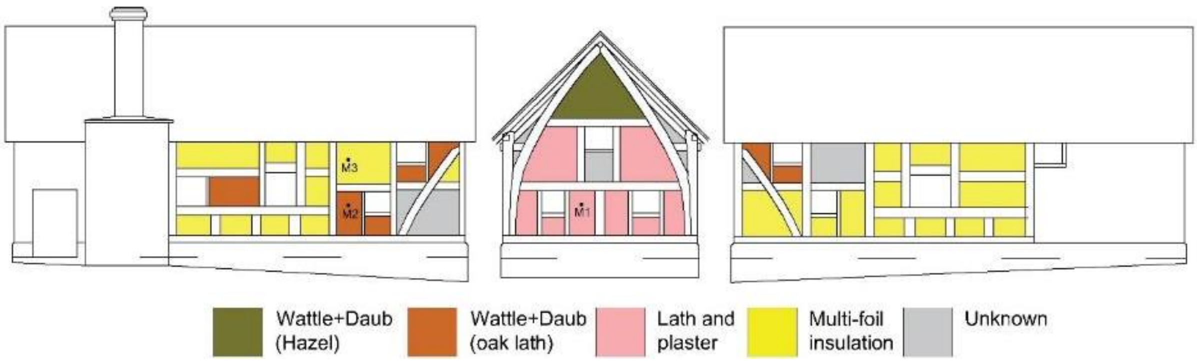

Figure 5 Hacton Cruck. Diagram showing location of each infill panel type. Source: (Author's own, 2016)

The building was completed with a new thatched roof using reed from the Tay Estuary and Sedge, for the ridge, from the Norfolk Broads (Williams, 2011). From 2012 until 2015 the central bay of the hall was left with no internal finish to the underside of the thatch. Following pressure testing by the authors in 2015 it was decided to torch (lime-plaster) the underside of this central section.

In situ measurements

In situ u-value monitoring using Hukseflux HFP01™ heat flow plates, thermistors and an Eltek™ Squirrel data logger, and pressure testing using a Minneapolis Blower door, were undertaken in 2015 (Whitman and Prizeman, 2016). A summary of the results are shown in Table 1.

Table 1. Results of in situ monitoring at Hacton Cruck, March & November 2015

U-value		
Material	**Measured U-value (W/m²K)**	**Calculated U-value (W/m²K)**
Repaired original lath and plaster	2.51	2.40
New Wattle and daub	3.25	2.99
Lime plastered Multi-foil insulation	0.71	0.41
UK building regulations Part L1B	-	0.70†
Airtightness	**Air changes per hour @50 Pa**	**Air permeability @50 Pa (m³/(h·m²)**
Pre-torching	130	154
Post-torching	68	80
UK Building Regulations Part L1A	-	5*

† U-value for existing building with change of use. In this case from farm building back to house

* An air permeability index is stated only for new constructions

The Oaks, Brockhampton Estate, Bromyard, Herefordshire

The Oaks (NGR: SO 70112 55441), is a National Trust let property on their Brockhampton Estate. The small, two bedroom, timber-framed cottage has sections dating from the 16th, 17th and 19th Centuries (Coope, 2015). In February 2015 The National Trust launched a new set of environmental standards specifically for their let estate. These standards aim to ensure that their housing is healthy and affordable to heat, has a lower environmental impact, and achieves an Energy Performance Certificate (EPC) of E or above (National Trust, 2015). In line with this policy, in the summer of 2015 The Oaks had secondary glazing installed and the roof insulated. No interventions were made to the walls, although thermography indicated that most infills were of modern concrete block with only a few surviving in wattle and daub.

In situ measurements

Pressure testing using the same Minneapolis Blower Door was undertaken in June 2015 prior to the retrofit and in November 2015 following its completion. The results are presented in Table 2.

Table 2 Results of in situ monitoring at The Oaks, June & November 2015

Airtightness	**Air changes per hour @50 Pa**	**Air permeability @50 Pa ($m^3/(h{\cdot}m^2)$)**
Pre-retrofit	16.5	17.8
Post-retrofit	10.8	11.7
UK Building Regulations Part L1A	-	5*

* An air permeability index is stated only for new constructions

The Old Mayor's Parlour, Church Street, Hereford

The Old Mayor's Parlour, 24 Church Street, Hereford is a gallery space owned by the Church Street Charitable Trust, along with the adjacent property, 25 Church Street (NGR SO 50981 39895). The original description by The Royal Commission on Historical Monuments (RCHM, 1931) records the building as probably built early in the 16th century but with a stone-built cellar under the north part of the building, containing 15th century doorways. The gallery is located on the first floor and is access via an unheated semi-external staircase. The east façade onto Church Street is timber-framed at first floor with underbuilding and 20th century shopfronts. The west façade is tile-hung timber-frame with modern concrete block infill. The most recent refurbishment work was carried out in two phases. The first phase consisted of internally lining the east wall, thereby removing the cold-bridge formed by the timber frame. Originally, it was not intended to replace the infill panels, however, during this first phase of work it was discovered that the infill was of very loose concrete blockwork (Demaus, 2015). A second phase of refurbishment, was therefore undertaken to replace the concrete block infill from the timber-framed east façade and replaced with wood-fibre insulation using the detail published by Historic England (McCaig and Ridout, 2012) (Figure 6). In addition a multi-foil insulation was installed between the tile-hanging and the concrete block of the west façade. No work was undertaken to the roof due to the elaborate 17th century plaster ceiling.

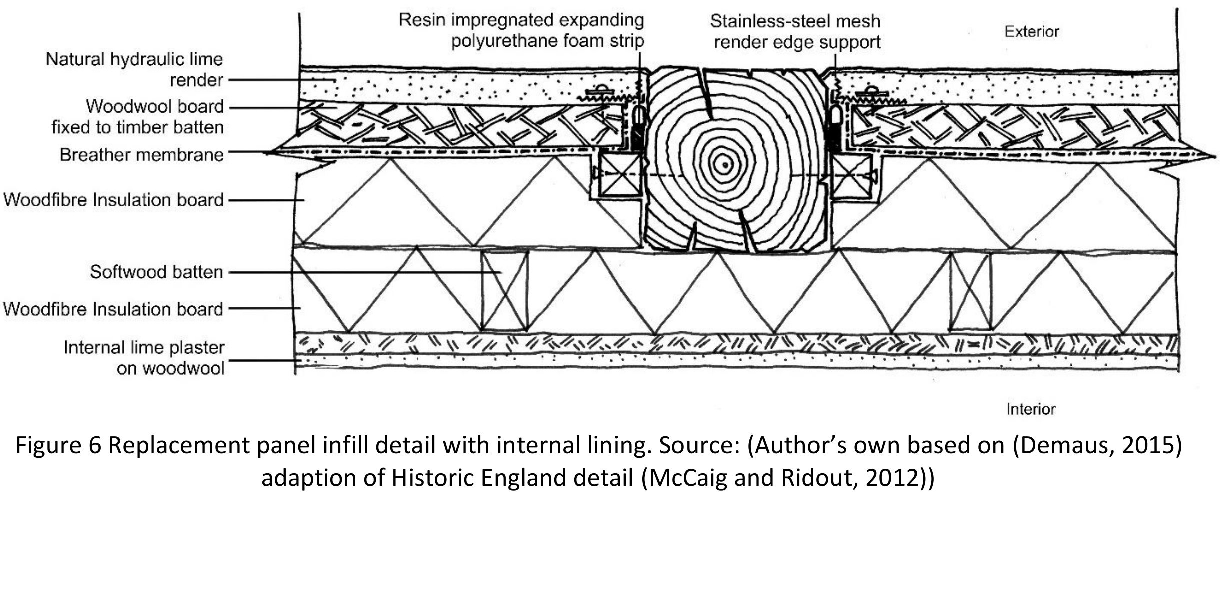

Figure 6 Replacement panel infill detail with internal lining. Source: (Author's own based on (Demaus, 2015) adaption of Historic England detail (McCaig and Ridout, 2012))

In situ measurements
In February 2016 in situ u-value monitoring of the new infill panels and internal lining of the east façade and pressure testing were undertaken using the same previously detailed equipment. The results are presented in Table 3.

Table 3 Results of in situ monitoring at The Old Mayor's Parlour, March 2016

U-value		
Material	**Measured U-value (W/m²K)**	**Calculated U-value (W/m²K)**
Historic England detail with woodfibre	0.13	0.13
UK building regulations Part L2B	-	0.28
Airtightness	**Air changes per hour @50 Pa**	**Air permeability @50 Pa (m³/(h·m²)**
Old Mayor's Parlour	22.5	17.6
UK building regulations Part L2A	-	5

† U-value for replacement thermal element (wall) for an existing non-residential building
* An air permeability index is stated only for new constructions

Energy Simulation

Methodology

The simulations presented in this paper were undertaken using the software DesignBuilder Version 4.2.0.54. This software provides the graphical interface for the dynamic simulation engine EnergyPlus DLL v8.1.0.009 (Design Builder, 2014), a building energy simulation software developed by the University of Illinois and the University of California, for the Office of Building Technology of the Department of Energy of the United States of America (US Department of Energy, 2016 p3).

For the building thermal zone calculation, EnergyPlus uses a heat balance model based on the assumption that the air in each building zone is homogenous with no stratification of temperature (Crawley et al., 2001 p323). As such there is no requirement for the height of differential wall materials to be accurately modelled. The complicated timber-frame was therefore simplified to block sub-surfaces, the area of which accurately represents the area of timber-frame, if not its precise location and configuration (Figure 7).

Figure 7. DesignBuilder models of (from left) Hacton Cruck, The Oaks and The Old Mayor's Parlour. Source: (Author's own, 2017)

Climate Conditions and Weather Files
Like the majority of the UK, Herefordshire is located in a temperate maritime climate with warm summers and cold winters. The climate is classified under the Köppen-Geiger climate classification system as Cfb (C-Warm temperate, f-fully humid, b-warm summers) (Kottek et al., 2006). Average climatic data for the West Midlands, the larger region in which Hereford is located, are presented in Figure 8. The heating season typically lasts from November until March with no requirement for mechanical cooling during summer months. Meteonorm version 6.1 was used to create weather files for each site using the time period 1996-2005.

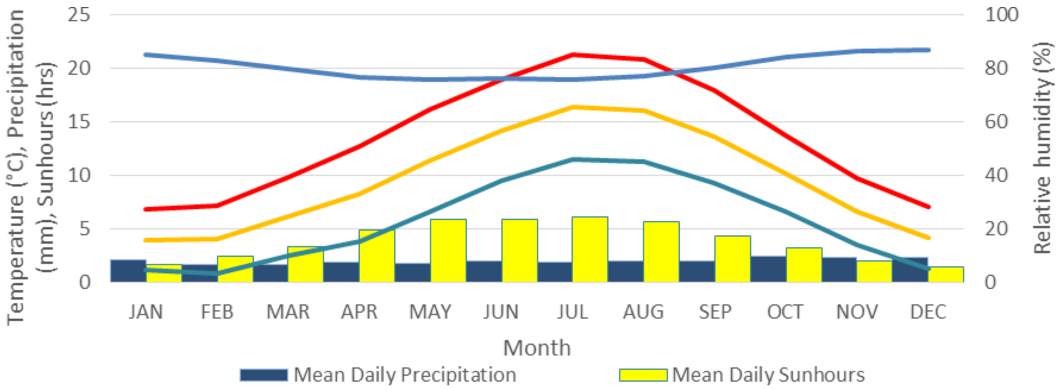

Figure 8 Climatic data for the West Midlands, UK 1981-2010. Source: (Met Office, 2016)

Hacton Cruck

Four scenarios of infill panels were simulated. The first imagined that all original lath and plaster panels had survived; the second imagined that all panels had been replaced with new wattle and daub; the third that all had been replaced with the new multi-foil panels; and the fourth simulated the as built situation with a mixture of all three panel types. The measured u-vales were used for each panel type. These four scenarios were simulated with both the pre- and post-torching air-change-rates and a third hypothetical air-change-rate of 0.5 ac/h@50Pa.

The Oaks

The two retrofit actions (secondary glazing and roof insulation) were simulated separately. In addition two hypothetical retrofit actions were modelled the first replacing all concrete block infill panels with woodfibre insulation and the second replacing all infill panels, including historic wattle and daub with woodfibre. Scenarios with combinations of all retrofit actions, both real and hypothetical, were also simulated.

The Old Mayor's Parlour

As with The Oaks, each retrofit action was simulated separately, in addition to the hypothetical actions of insulating the roof and installing secondary glazing. Again scenarios combining retrofit actions were also simulated. As the gallery is located on the first floor between adjacent buildings, these and the ground floor were modelled as adiabatic volumes.

Results, Analysis and Discussion

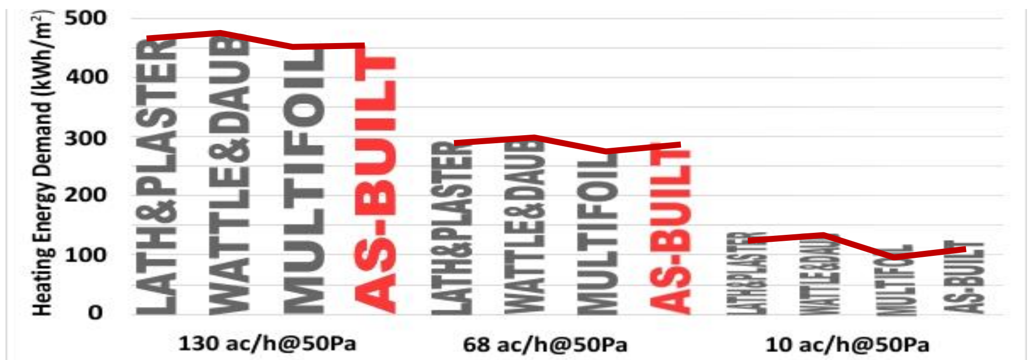

Figure 9. Simulated Heating Energy Demand (kWh/m^2) for Hacton Cruck. Hypothetical scenarios in grey

Figure 9 clearly shows that the performance of the infill panels has little effect on the heating energy demand with a variation of only +4% and -0.01% when compared to the current situation. It is however the simple act of torching the underside of the thatched roof, thereby improving the airtightness, which sees a 36% reduction. If further work, such as improving the joints between panel and timber-frame and plugging post-holes, was undertaken to improve the airtightness to a hypothetical 10ac/h@50Pa then a reduction of 72% could be achieved. Whilst for this specific property no historic fabric was lost in the upgrading of the infill panels, the results of these simulations should have significant weighting in the planning of future retrofits of historic timber-framed buildings.

At The Oaks (Figure 10 left) it can be seen that just the installation of secondary glazing is more effective (10% reduction) than replacing all the infill panels (9% reduction). Whilst it can be argued that secondary glazing is visually intrusive it is however a fully reversible retrofit action and does not result in the loss of historic fabric. The insulating of the roof is the retrofit action with the greatest individual benefit (25% reduction) which when combined with the secondary glazing results in an overall reduction of 34% and is the solution that was applied in reality. With the disruption involved it is questionable whether the additional 11% reduction, achievable by replacing infill panels, would ever be justifiable. Whilst the increase in airtightness resulting from the installation of the secondary glazing is beneficial with regards to energy efficiency, there could be some issues concerning increased internal moisture levels. Initial testing has shown an increase in the surface moisture content of the exposed timber-frame, however further monitoring is ongoing to establish if this is a seasonal variation or a result of the retrofit and further research into this area is ongoing.

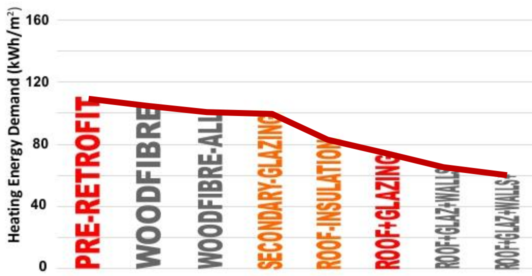

Figure 10. Simulated Heating Energy Demand (kWh/m^2) for The Oaks (left) and The Old Mayor's Parlour (right) Hypothetical scenarios in grey, individual retrofit actions in orange and as-built in red

At the Old Mayor's Parlour it was however only the upgrading of the walls that was undertaken, resulting in just a 6% reduction for each wall and a combined reduction of 12%, even with the avoidance of cold-bridging. It is interesting to note that, assuming secondary glazing would achieve a similar increase in airtightness as seen at the oaks, secondary glazing alone could potentially achieve a reduction of 15%. The introduction of 200mm woodfibre insulation to the roof could potentially have achieved a 17% reduction alone, or 42% when combined with the walls, and 58% combined with walls and secondary glazing. It is however understandable the architect's reluctance to intervene in the roof given the historic value of the 17th century plastered ceiling, however thermography has identified a marked difference in surface temperature between insulated walls and uninsulated ceiling. Potentially this could lead to increased condensation on the ceiling. Intervening in the walls with their poor quality modern infill and avoiding work to the historic fabric of the ceiling would appear a sensible conservation approach, however if humidity within the room is not carefully controlled this decision may have detrimental consequences. Internal hygrothermal monitoring by the authors is ongoing at this property.

Conclusion

The results of these simulations and associated in situ monitoring have highlighted that apparently small measures such as plastering ceilings and installing secondary glazing can have the most significant impact on reducing the heating demand of historic timber-framed buildings. It is interesting to note that the property with the least intervention and the highest achieved reduction in heating demand was the property owned by National Trust. It is perhaps not surprising that an organisation with a large property portfolio of historic buildings should achieve the best balance between intervention, outlay and payback.

In all the cases it was shown that improving the thermal performance of the walls did not dramatically improve the building's thermal performance. Whilst no historic fabric was lost in these case studies, this may not be the case in the retrofit of other historic timber-framed buildings. Care must be taken not to create large discrepancies in internal surface temperatures that in turn could put at risk uninsulated historic building fabric, however simple monitoring and simulation such as that presented in this paper could have aided in the correct selection of retrofit strategies and avoid the unnecessary loss of historic fabric.

Given the relatively small number of timber-framed buildings in the UK (68,000) these energy retrofits are more important with regards to the ongoing use and survival of these buildings, rather than significantly reducing energy consumption at a national level.

Monitoring is ongoing at all three case studies and associated research into the interstitial hygrothermal conditions of retrofitted timber-framed walls is underway as part of the wider research programme.

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