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Building Performance Evaluation of a 14th Century Pargetted House:

Hygrothermal comfort and energy efficiency

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ABSTRACT: Building performance evaluation (BPE) provides the tools to begin to understand the operational efficiency and resultant occupant satisfaction of the built environment. This is particularly important with historic and traditionally constructed buildings, where perceptions of their performance are often based on preconceptions and generalisations. It is therefore important to undertake BPE of these buildings in order to establish their actual performance and inform the often difficult decisions regarding their ongoing use. This paper presents the BPE of a 14th century timber-framed house, with 17th century decorative pargetting in Saffron Walden, Essex. In situ monitoring and digital simulation were used to assess its current performance and inform the ongoing conservative repair work. The results show that although the thermal conductivity of the pargetting is not particularly low, the increased thickness, and more importantly the sealing of the commonly poor junction between the timber-frame and infill materials, do result in an external envelope with a higher thermal performance than many historic timber-framed buildings. The simulations show that whilst applying internal wall insulation would further improve this performance, it would also increase the risk of frost damage. This highlights the challenges of sustainable building conservation and the role of BPE.

KEYWORDS: Building Performance Evaluation, Hygrothermal monitoring, Energy Simulation; Energy Use In Historic Buildings, Conservation

1. INTRODUCTION

In order to understand the operational efficiency of our built environment and the levels of environmental comfort provided to its occupants, it is necessary to undertake Building performance evaluation (BPE). Through the combination of monitoring and simulation it is possible both assess the current conditions and make recommendations for improvements. When considering traditionally constructed and historic buildings, this becomes all the more important due to the preconceptions that exist as to their performance. It is generally accepted that the older the building, the less energy efficient it is. However, the results of some studies challenge this assumption [1-3]. Nevertheless, it is important that these studies do not themselves become the basis for further generalisations. It is therefore necessary to undertake BPE on all historic and traditional buildings, as part of their sustainable conservation, in order to inform decisions regarding their ongoing use, aiming to satisfy the needs of the buildings' users, whilst maintaining their heritage value.

This paper presents the BPE of a 14th century timber-framed mediaeval hall house (Figure 1) in Saffron Walden, Essex, in the East of England. The most significant feature of this property is its 17th century decorative pargetting, a layer of sculpted lime plaster externally covering the timber-frame.

In situ monitoring and digital simulation have been used to assess the buildings current performance and inform the ongoing conservative repair work currently being undertaken.

Figure 1. Laser Scan of North elevation. Eastern cross wing to the left and western to the left. Source: (Author's Own, 2017)

1.1 History

Described by Pevsner as "amongst the most precious of Saffron Walden" [4], the Grade I listed building was originally built in the late 14th century [5] as a single "hall house". In the 17th century it became part of the Sun Inn, later being divided into two dwellings, both remaining related to the inn until its closure in the 1870s. The cottages were then extended to the rear, with Tudor styled doors and windows being fitted at this time [6]. In 1930 the ownership of both buildings was transferred to the Society for the Protection of Ancient Buildings (SPAB), who in turn vested the freehold in the National Trust, who own it to this day [6]. The leasehold of the cottages was acquired by the present owner in 2009, who embarked on the current ongoing conservative repair which aims to reunite the two cottages into one home fit for 21st century residential occupation.

1.2 Built Fabric

The structure of the main building is timber-framed, with closely spaced vertical timber members, forming tall vertical infill panels, a technique known as “close studding”. The ground floor has been underbuilt with brick, with the Victorian outshut also of brick construction. The infill panels to the upper stories are mainly wattle and daub, consisting of a clay plaster (daub) over a framework of woven thin timber elements (wattle work) wedged into the main structural timber-frame. It has been identified that some infill panels have been replaced at a later date with brick nogging [6]. The main roof is covered with clay peg tiles and the roof of the outshut is slated. As previously noted, the most distinctive feature is the main façade to the street which is covered in 17th century pargetting. The decorative elements include fruit, foliage, avian forms, a stocking and most notably two human figures. Since the acquisition of the property by the current owner, the pargetting has undergone extensive conservation repairs.

2. BPE METHODOLOGY

In order to understand the current and potential operative performance of this property, BPE was undertaken. The methodologies employed were internal hygrothermal comfort monitoring (dry-bulb air temperature and relative humidity), airtightness, thermography, in situ U-value measurements and digital energy demand simulation. As the property is currently uninhabited, occupant thermal perception surveys were not conducted.

The internal hygrothermal comfort was measured using TinyTag Ultra 2 TGU-4500 sensors, in addition to the owner’s Lascar® EasyLog® EL-USB-2 sensors, which were already in place. The sensors were located in seven internal locations and one external (Fig.2) and measured at half hour intervals from 11/03/17-16/08/17.

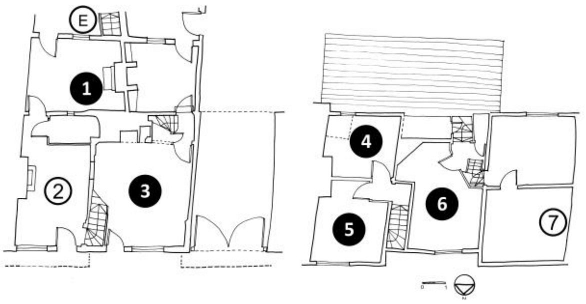

Figure 2. Ground (left) and first floor (right) plans showing hygrothermal monitoring locations. Open circles Lascar® sensors, solid circles TinyTag®.

Pressure testing to measure airtightness was undertaken on 12/03/17 according to BS EN ISO 9972:2015 [7] using a Minneapolis® blower door with analogue Magnehelic pressure gauges. The measurement procedure was conducted twice, once for the whole property and again for only the eastern portion, formerly number 25, in order to allow the comparison of the results with those undertaken previously in 2012 [8], prior to the reconnection of the two properties and removal of 20th century internal finishes. For this second measurement, the interconnecting door between the two halves was sealed with plastic sheeting and builder’s tape.

Thermography took place at 6:30am the same day following best practice guidance [9, 10], using a FLIR® B250 thermal imaging camera. During the measurements the building was unpressurised but electric heaters were used to augment the internal air temperature, achieving a temperature difference between inside and out of 11.5˚C for the eastern cross wing and 5.5˚C for the western.

The in situ U-value measurements were undertaken on two separate occasions (12/03/17-02/04/17 and 15/12/19-22/01/20) with two monitoring positions each time. The monitoring positions were chosen to measure two different thicknesses of pargetting. These are described in more detail in paragraph 3.4). The methodology followed BS ISO 9869-1:2014 [11] using Huxeflux HFP01 heat flux plates, held by pressure against the wall surface with a flexible plastic clip braced against adjustable building props. The surface of the plates was covered with paste to ensure complete physical contact, with the use of thin PVC film to avoid damage to the internal wall finish. Internal and external air temperatures directly adjacent to the wall surface were measured using type T thermocouples. On the first occasion the sensors were wired back to an Eltek® Squirrel® datalogger, whilst the second time a Campbell Scientific® CR1000 data logger was used. Both times the data was recorded with a five minute interval.

Digital simulations of the building’s current energy demand and potential future energy retrofit actions were undertaken using the software DesignBuilder®

Version 4.2.0.54, with measured U-values and airtightness imputed to improve accuracy. A climate file was created using the software Meteonorm® version 6.1 using the time period 1996-2005. Simulations were also conducted with the two-dimensional conduction heat transfer software THERM® version 7.5.

3. RESULTS

3.1 Internal Hygrothermal Comfort

Measurements were taken at half hour intervals from 11/03/17-16/08/17. During this time the property was unoccupied due to the ongoing conservation work. As such the results show that only the front bedrooms (locations 5 & 7 Fig.2) achieved any hygrothermal comfort during March. This was due to the electric heating used in both rooms to reduce the risk of frost damage to the 17th century pargetting. The heating was maintained for longer in front bedroom 5 to enable the in situ U-value monitoring. Being uninhabited, no space heating is provided in the rest of the house and hygrothermal comfort is only achieved in mid-May once external ambient conditions had also reached comfort conditions.

The reasons for hygrothermal comfort not being achieved are a combination of low temperatures and high relative humidity (Fig.3), with high relative humidity being a common problem on the ground floor. In two monitoring positions (2&3) relative humidity was recorded in excess of that measured externally. This may be partly due to the current uncontrolled connection of these spaces to a subterranean cellar.

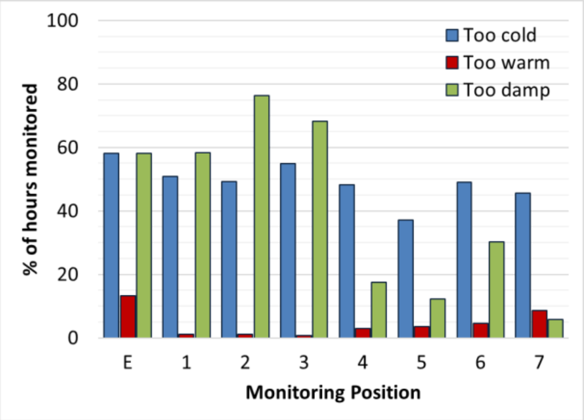

Figure 3. Graph showing percentage of time conditions do not achieve hygrothermal comfort conditions. 11/03/17-16/08/17 Refer to Fig.2 for location of monitoring positions.

3.2 Airtightness

The results (Table 1) showed that the work undertaken since 2012, removing inappropriate, 20th century, vapour impermeable internal finishes has decreased the airtightness of property 1 by almost 50%.

Table 1: Airtightness results. (API) Air Permeability Index, (ACR) Air Change Rate @ 50 Pa

Property	API ($m^3/h.m^2$)	ACR (/hr)
1*	7.3	10
1	14.2	18.8
1&2	58.6	56.6

* Previous measurement undertaken in 2012 [8]

The replacement internal finishes had not been installed at time of testing. It is assumed that these will result in increased airtightness. The reconnection of the two cottages has resulted in a particularly high air change rate, due to uncontrolled connections to roof voids and the cellar in property 2. Both the reinstatement of internal finishes and the closing off of the connection to the cellar are issues that will be addressed prior to the completion of the conservative repair process. Further testing is recommended following this work.

3.3 Thermography

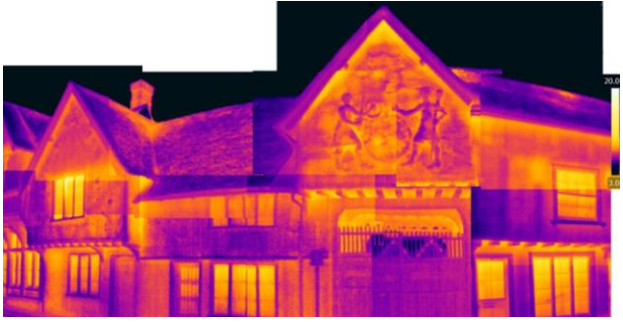

Figure 4. Thermography of north façade 12/03/17 6:30am. External temperature 10.5˚C. Source: (Author's Own, 2017)

The thermography was undertaken unpressurised with an external air temperature of 10.5°C and internal temperatures between 13-22°C. A complete view of the whole north façade (Fig.4) appears to show that the pargetted upper façade is allowing less thermal transmittance than the lower brick underbuilding of the ground floor. Given the unequal heating of the corresponding internal spaces there may be some degree of error in this conclusion, however, the internal temperature of the ground floor was substantially lower at 13°C compared to the 16°C of the upper west cross wing bedroom (left) and 22°C of the upper east cross wing bedroom (right). Therefore, it could perhaps be presumed that if all spaces were at an equal temperature the difference in the thermal performance between the pargetting and the brick underbuilding would be even more apparent. Figure 4 also shows the differing thermal performance within the pargetted façade, with the thinner, plainer sections recording a higher surface temperature and therefor greater heat loss as compared to the thicker sculpted features. The greatest thermal weaknesses of the envelope are however undoubtedly the single glazed windows, the protruding floor of the jettying and the exposed floor over the carriageway .

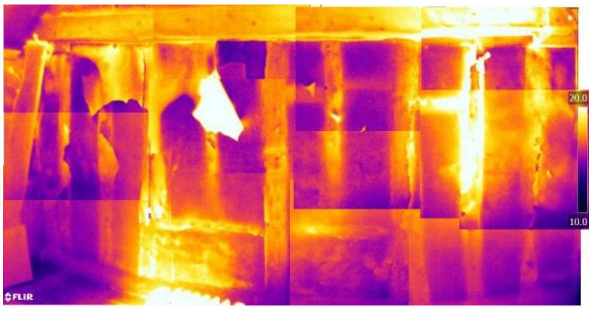

Figure 5. Internal thermography of west cross wing at 1st floor. 12/03/2017 6:30am. Internal temperature 16°C. Source: (Author's own, 2017)

Internal thermography of the north façade of the western cross wing upper bedroom (Fig.5) shows the higher thermal transmittance of the infill panels in comparison to the timber frame. Interestingly, by highlighting the timber-frame, otherwise hidden by the internal wallpaper, it also suggests the previous presence of a central window that may have predated the external pargetting. This demonstrates the advantages of BPE in understanding buildings, above and beyond reviewing their energy efficiency.

3.4 In situ U-Value

On the first occasion (12/03/17-02/04/17) the U-value was measured in two locations (M1 and M2 in Fig.6) on the first-floor elevation of the east cross wing (left in Fig.1).

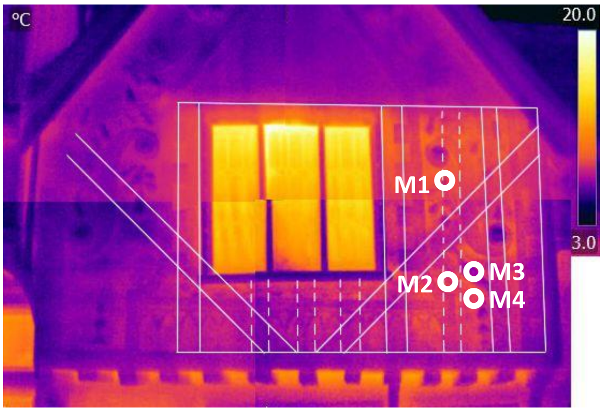

Figure 6. Thermography of eastern cross wing showing location of monitoring positions. M1 & M2 monitored 12/03/17-02/04/17 and M3 & M4 monitored 15/12/19-22/01/20. Source (Author's own, 2020)

The locations were chosen to measure two different thicknesses of pargetting, one plain section (M2) and a sculpted gourd or pear standing 40mm proud of the plain surface (M1). On first reading of the thermography it was believed both locations to be in the middle of an infill panel. Unfortunately, closer inspection following completion of the measurements revealed faint signs of further timber-framing (dotted lines Fig.4), which was subsequently confirmed with the use of an electronic stud detector. This error was exacerbated by the heat flux plate in position M1 being accidentally dislodged after only five days. A second period of monitoring was therefore undertaken (15/12/19-22/01/20), again through two thicknesses of pargetting but this time avoiding the now identified timber-frame members. Position M3 was located to measure the body of an avian form, also 40mm proud of the surrounding plain surface, where M4 was located. The results of all four measurements are presented in Table 2.

Table 2: Measured U-Values

Monitoring location	Wall thickness (m)	U-value (W/m²K)
M1*	0.170	0.85
M2	0.130	0.64
M3	0.170	1.29
M4	0.130	1.33

***** Only measured over 5 days and so high error factor

The measured U-value at position M2, over a timber-frame member was 0.64 W/m2K, and as such below the UK Building Regulations threshold value (0.70 W/m2K) for retained thermal elements [12]. In the centre of a panel (M3 & M4) the values are higher, however, these are considerably lower than measurements of other historic timber-framed properties, with typical U-values 1.69-2.88 W/m2K [13, 14] for un-pargetted walls, suggesting that pargetting may be considered an early form of external wall insulation (EWI).

That said, the improvement in U-value provided with the increased thickness of pargetting is marginal in monitoring position M4. Assuming that this improvement is purely down to the additional pargetting, this would suggest the pargetting has a thermal conductivity of 1.72W/mK, similar to a hard limestone [15] and therefore not a particularly effective EWI. In the case of monitoring position M1, for the short period that monitoring did occur, the measured U-value was consistently higher than the thinner M2. Some speculation has been made over the influence of increased external surface area of the mouldings, however, further research is required to confirm this.

4.0 DIGITAL SIMULATION

4.1 DesignBuilder®

The simulation with DesignBuilder®, using the measured U-values and air-change-rates, showed a current heating energy demand of 179kWh/m2. If the airtightness could be returned to that measured in 2012 this could be reduced to 96.6kWh/m2, with a further 17% reduction possible by insulating roofs and exposed floors. Insulating external walls internally with internal wall insulation (IWI) would result in an additional 12-20% reduction, however, there is concern over the potential increased risk of frost damage to the decorative 17th century pargetting.

4.2 THERM®

In order to assess this increased risk, simulations with THERM® were undertaken. Modelling was conducted, both in its current state uninsulated and with differing thicknesses of IWI, of a cross section of pargetted wall, including decorative sculpted elements, the profile of which was determined by data acquired through laser scanning.

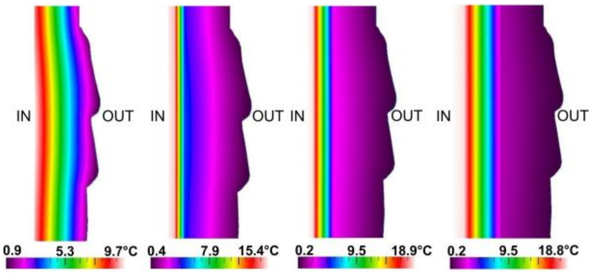

Figure 7. Simulations with THERM® version 7.5 of wall section through decorative pargetting showing temperatures with (left to right) no insulation, 25mm, 50mm and 100mm of wood fibre IWI. Exterior temperature 0°C and interior 21°C. Source: (Author's own, 2017)

The simulation demonstrated (Fig.7) that currently with no insulation, with an internal air temperature of 21°C and an external air temperature of 0°C, the external surface of the most protruding features of the pargetting would be almost 1°C higher than the surrounding air at 0.9°C. Any introduction of insulation will reduce this external surface temperature, thereby raising the risk of frost damage. In the case of the 25mm IWI, the external surface temperature is halved to 0.4°C when the external air temperature is 0°C. With the application of 50mm and then 100mm IWI this drops to 0.2°C, with much of the historic wall being below 1°C. Given the heritage value of this historic pargeting it is unlikely that this potential increase in risk of frost damage can be outweighed by the reductions in energy demand that would be achieved. As no decorative pargetting is present on the ground level, potentially this could be internally insulated with 25mm of IWI resulting in a 7% reduction in energy demand.

5. DISCUSSION

The monitoring at this un-retrofitted property has highlighted areas for improvement but has also shown that at times the historic fabric can perform better than expected. The measured u-values indicate that the pargetted wall is performing better than other infill panels of historic timber-framed buildings, including some which have been replaced with modern insulation materials as part of energy retrofits [14]. The thermal conductivity of the pargetting is most likely only partially responsible for this performance, with the sealing of the joints between panel and timber-frame, thereby reducing infiltration and air movement also being influential.

The pressure testing showed that currently the property is not very airtight and that the work so far undertaken by the owner to remove 20th century finishes has made it even less so. If the property is to be an inhabitable dwelling, this is an area that will require careful consideration. The owner's intention is not to leave the property without internal finishes but rather to replace the impermeable 20th century finishes with traditional vapour permeable finishes that will be more sympathetic, both technically and aesthetically, to the historic building fabric. It is assumed that the reinstatement of complete internal finishes will lead to an improvement in airtightness. Whether these achieve a higher or lower airtightness is an area that a future BPE should investigate. At the same time the uncontrolled connection between the basement and attic spaces will be addressed, thereby further improving hermeticity. As shown by the DesignBuilder® simulation, even just returning the property to the airtightness levels measured in 2012 would see a 17% reduction in energy demand.

The thermography showed the single glazed windows and exposed floors, both over the carriageway and the jettying, to be the areas of greatest thermal weakness. These areas would be relatively easy to address, with little adverse impact on the heritage value of the property. The current windows date from 1870 [5] and as such not one of the most significant features of the building, however it is unlikely that they would be replaced. Although, it would however be possible to repair the windows to increase airtightness, install secondary glazing, insulated internal shutters or thick curtains, all of which would improve the thermal performance of these elements [16]. The insulation of the exposed floors may be more difficult as this would most likely require the lifting of the existing floorboards, with the potential risk of damage that this entails. However, insulating the exposed floors and the roof do not pose the same risks of increased frost damage to the 17th century pargetting that would be involved in the use of IWI, as shown by the THERM® modelling. Given the high significance of the pargetted façades, a trade off could be made in allowing beneficial heat loss through the associated walls, whilst insulating elsewhere, even if this involved some limited loss or damage to historic fabric.

The hygrothermal monitoring shows that in its current unoccupied state, few rooms in the house achieve comfort levels. This is to be expected and the measurements in the front bedroom of no.27 show that with heating, comfort can be achieved. Equally the controlling of the connection to the cellar should assist in resolving the high levels of relative humidity measured on the ground floor. However, further monitoring is recommended as the conservation of this building progresses

4. CONCLUSION

The use of BPE has enabled a greater understanding of this historic property which can now inform the continuing decisions in its conservative repair. Keys findings are:

- That the pargetting appears to improve the U-value of the timber-frame wall, acting as an early form of EWI.
- Conservative repair work removing inappropriate internal finishes has reduced the airtightness. The new finishes will hopefully rectify this.
- Improving airtightness and insulating roofs and floors could see a reduction in energy demand of 55%. However, the use of IWI on the pargetted walls would increase the risk of frost damage to this historically significant element and as such is not advisable.

The research presented in this paper has highlighted the role that BPE can play in understanding the complex performance of our historic built environment and the challenges that face us in balancing the conservation of heat and power and the sustainable conservation of our heritage.

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