The impact of modernization of a 16th century timber-framed farmhouse, Suffolk, UK

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Abstract – Well intentioned modifications to traditional buildings can potentially be detrimental if the full implications of the work are not fully understood. This paper presents the case of a 16th century Suffolk farmhouse. Extended in the 1700s, the timber-framed building was clad in cement render in the early 20th century. At a later date the timber sole plates were encased in concrete and painted with an impervious resin. Finally in 2005 the panel infills were replaced with rigid polyisocyanurate (PIR) thermal insulation. In-situ environmental monitoring and digital simulation are used to assess the impact of these measures on the performance of the building. The outcomes of this research are now being used to enhance the informed conservation of this building.

Keywords – timber-framed; energy retrofit; moisture monitoring; performance; unintended consequences

1. INTRODUCTION

Over the years those who care for historic buildings have sometimes taken decisions that, with hindsight, are now understood to have caused more harm than good. As we aim to make our historic buildings more energy efficient, we must take care that our actions enable the long term survival of these buildings and do not endanger their historic fabric [1]. Although in the UK, historic and traditional buildings are not required to fully comply with the energy efficiency requirements of the building regulations [2, 3], they must still aim to "improve energy efficiency as far as is reasonably practicable" and not diminish the buildings performace [2]. In addition, building owners and occupants wish to improve the thermal performance of their properties to reduce heating bills and improve thermal comfort. As such, both the extent and detail of any retrofit remains at the discretion of the building owner. Whilst it is hoped that they will seek advice from qualified professionals, the lack of knowledge in the construction industry with regard to energy retrofit in general [4], and especially related to historic and traditional buildings [5], combined with a reduction in historic environment specialist within local authorities [6], means that too often they do not. The building considered in this paper is one such case.

2. HOUSE, BATTISFORD, SUFFOLK, UK

2.1 INTRODUCTION

The case study, located in Battisford, Suffolk (Figure 1 & Figure 2) is a Grade II listed former farmhouse, whose origins date back to the 16th century [7]. The property is now a private residence with two occupants.

Figure 1. North entrance elevation of case study. Source: Author's own, 2017.

Figure 2. South, elevation. Source: Author's own, 2017.

2.2 HISTORY

The oldest section of the house, the lower wing (right in Figure 1), contains a small section of 16th Century plain crown post roof structure [7]. A second, taller wing is thought to have been constructed at right angles to the first in around the 17th Century, with an axial red brick chimney with sawtooth shaft (ibid). Subsequent additions were added in the 1980s with a porch to the north (Figure 1), an en-suite bathroom at the junction of the two wings (Figure 2) and a service block to the west.

2.3 CLIMATE

Along with the rest of the UK, Battisford 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) [8]. The heating season typically lasts from November until March with no requirement for mechanical cooling during summer months. Figure 3 shows that compared to the UK average, Battisford experiences warmer temperatures throughout the year, and lower relative humidity in summer. The precipitation pattern also differs, with Battisford's maximum rainfall recorded in the summer, rather than the winter. This pattern is due to the reduced influence of westerly Atlantic fronts and an increase in summer thunderstorms, driven by convection [9].

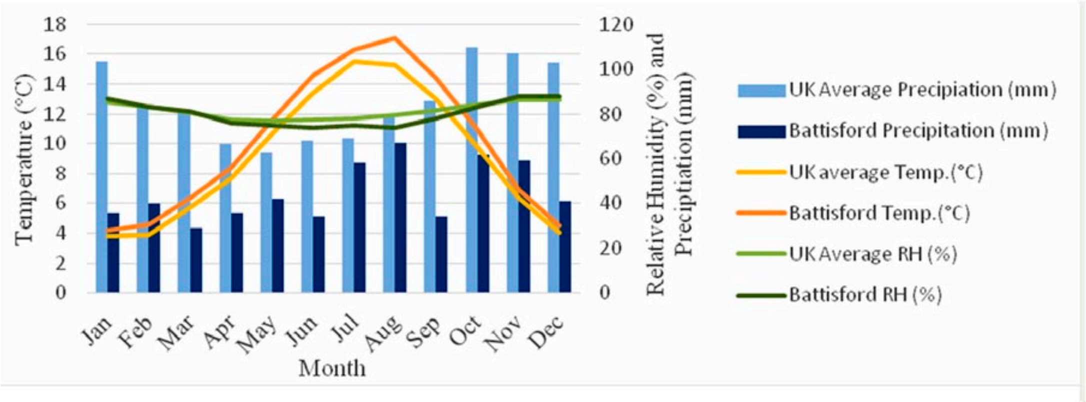

Figure 3. Climatic data for Battisford, Suffolk, UK. Source: (Meteonorm 6.0 and Met. Office UKCP09).

2.4 BUILT FABRIC

The timber-frame was overclad in cement render in the early to mid-20th century. The timber sole plates were then encased in concrete and their interior faces painted with an impervious resin. In around 2005 most of the lath and plaster infill panels were replaced with rigid polyisocyanurate (PIR) thermal insulation (Figure 4). In this detail, the cold-bridging of the historic timber-frame is exacerbated by the introduction of additional timber battening to take the plasterboard. The PIR insulation is not mechanically fixed or bonded and is left free-standing within the opening with large gaps around the sides in many instances.

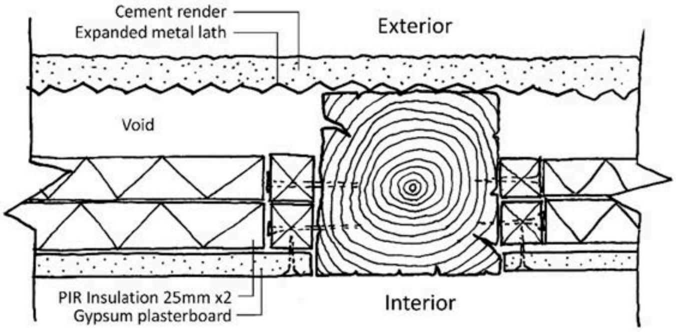

Figure 4. Sketch plan detail of replacement panel infill at case study. Source: Author's own, 2017.

Figure 5. Internal face of cement render. Source: Author's own, 2017.

On opening up the walls, it can be seen that the expanded metal lath used to carry the cement render has in many places completely corroded away and the original oak laths are also in a state of advanced decay (Figure 5). There are also areas where the external cement render is cracked allowing rain penetration into the wall and building interior.

It is likely that the cement render was applied to reduce the need for maintenance of the previous lime render and the PIR insulation installed to improve internal comfort conditions and reduce energy consumption. Both actions were presumably undertaken believing that they were improvements; however, neither have been undertaken with a full understanding of the performance of the historic built fabric, and have now resulted in the poor current condition of the building. Today many of the timbers are rotten and will require replacing and the cement render is in danger of collapse.

2.5 PROPOSED RENOVATION

The current owner proposes to remove all external cement render, PIR thermal insulation and gypsum plasterboard infill. The timber-frame will then be fully assessed and any necessary repairs will be undertaken. The house will be re-rendered in lime render on split oak lath, however some uncertainty over the preferred insulation material remains.

3. IN SITU MONITORING

3.1 INTRODUCTION

In order to assess the current performance of the building, the following in situ monitoring was undertaken; U-value measurement; pressure testing; thermography; timber surface moisture measurements; interstitial hygrothermal monitoring; hygrothermal monitoring of habitable spaces; and thermal comfort questionnaires.

3.2 IN SITU U-VALUE MONITORING

3.2.1 Methodology

A location on the North façade was selected to minimise the influence of direct solar radiation. The wall of the study was chosen due to the continual heating of this space. The monitoring equipment was installed midway between two vertical studs. The methodology employed was according to BS ISO 9869-1:2014 [10] using Hukseflux® HFP01 heat flux plates and thermistors connected to Eltek® wireless telemetry transmitters, relaying data to an Eltek® Squirrel® data logger, with data recorded at 5 minute intervals. The external thermistor was held in place with adhesive tape and internally with an extendable building prop and plastic clip. The in situ U-value monitoring was undertaken between 11/03/2017 and 03/04/2017, with a measurement period of 23 consecutive days.

3.2.2 Results and Analysis

The U-value measurements showed an average U-value of 1.72 W/m^{2}K, with a standard deviation of 0.10 W/m^{2}K. This is much worse than the calculated design U-value of 0.340W/m^{2}K. Even when the timber frame is taken into account a U-value of 0.921 W/m^{2}K is still calculated. This discrepancy is most probably a result of the poor detail design and installation of the insulation. Both the rigid PIR insulation and the gypsum plasterboard are ill suited to the irregularities of the timber frame. Opening up showed the PIR panels to be freestanding with a clear gap around the edges, allowing heat transfer around the panel by both convection and air movement. To compound this problem, there is no mechanical connection between the face of the insulation and the back of the cement render, thereby forming a ventilated cavity. This highlights the need for replacement infill panel details to acknowledge the complex three-dimensional geometry of historic timber-frames. Infill materials must be capable of adapting to these geometries without relying on careful craftsmanship and should form a seal between frame and insulation.

3.3 PRESSURE TESTING

3.3.1 Methodology

Pressure testing was undertaken on 11/03/ 2017, following BS EN ISO 9972:2015 [11] using a Minneapolis® Blower Door. It should be noted that during the testing some building work was being undertaken in the western section of the house, including new plasterboard partitions, which were not taped or skimmed. As such, it is possible that the airtightness of the house is better than the test results suggest.

3.3.2 Results and Analysis

The pressure testing indicated an air permeability index of 19.0 $m^3/h/m^2$, an air change rate of 18 ac/hr@50 Pa or 0.9 ac/hr unpressurised, and an effective leakage area of 9.43 m^2. Under current UK building regulations new-build dwellings must achieve an air-permeability index of no more than 10 $m^3/hr/m^2$ [12] with average air change rate for pre-1900 UK buildings of 12.3 ac/hr@50 Pa [13]. The poor performance of this case study may in part be due to the aforementioned ongoing building work, however the lack of airtight seals between infill panels and timber frame will be a major contributor.

3.4 THERMOGRAPHY

3.4.1 Methodology

Thermography was undertaken of the whole house using a FLIR® B250 on 11/03/2017 starting at 9:00 am. The building was unpressurised. An average temperature differential between inside and out of 7 °C was maintained throughout. This exceeds the minimum differential of 5 °C as recommended by Young [14].

3.4.2 Results and Analysis

Figure 6 shows the higher internal temperatures of the ground floor, especially the study (bottom-right) where a 10 °C temperature differential was achieved. The single glazed windows of the study and master bedroom are the weakest thermal element of this façade. The concrete encased brick plinth is shown to be a thermal bridge, as is the close studded timber frame which is clearly visible through the cement render.

The internal thermography (Figure 7) confirms the previously noted weakness of the junction between the modern PIR thermal insulation and the timber-frame. This detail has no sealant or taping and as such, thermal transfer through air movement is occurring. The low radiant surface temperature of the infill panel to

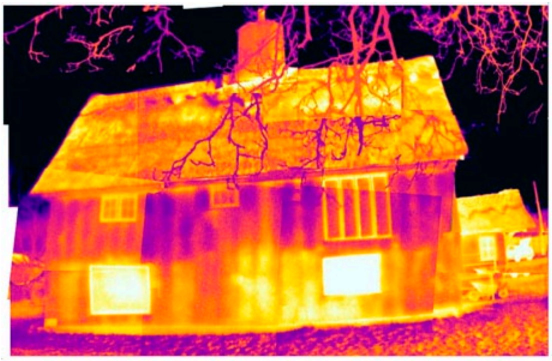

Figure 6. External thermography of east façade. Source: Author's own, 2017.

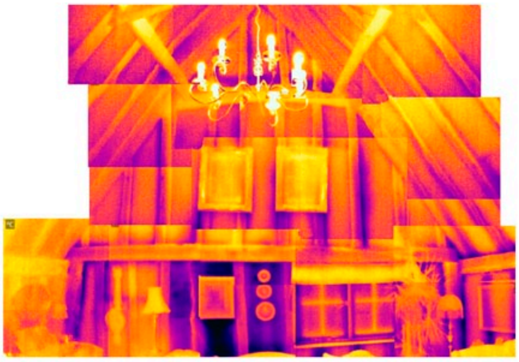

Figure 7. Interior thermography of north wall of drawing room. Source: Author's own, 2017.

the bottom centre left of the image is however unexplained and requires further exploration.

3.5 TIMBER SURFACE MOISTURE CONTENT

3.5.1 Methodology

Surface moisture content measurements were taken using a Testo® 606–2 resistance moisture meter for two ground floor walls, the east wall of master bedroom and the north wall of the study. The measurements were undertaken on 02/08/2016 and the 11/03/2017.

3.5.2 Results and Analysis

Figure 8 shows high moisture content in the sill beam of both walls due to their encasement in cement rendered brick externally and resin coated internally. Evidence of drying can be seen between the summer (upper) and winter (lower) measurements.

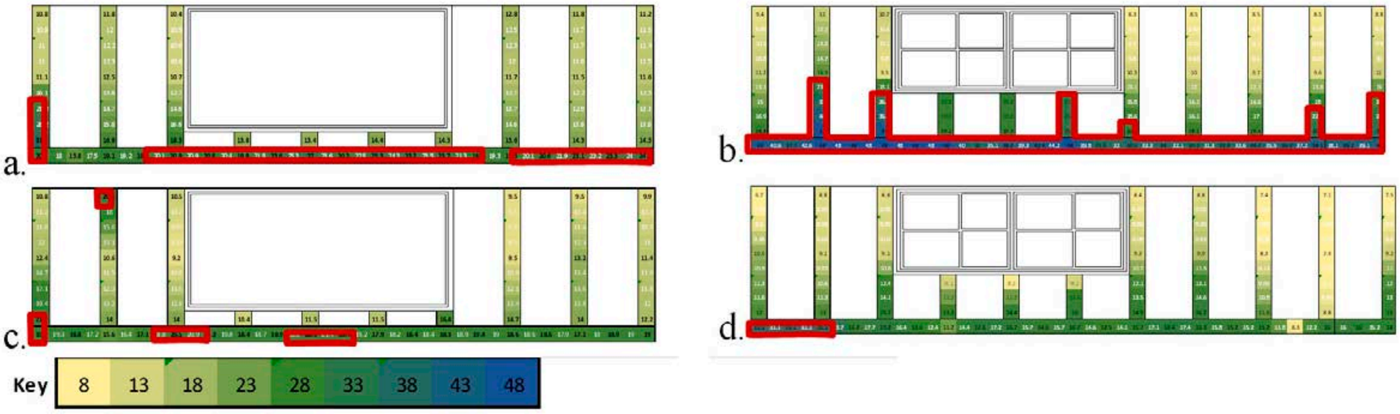

Figure 8. Surface moisture content (%) of timber-frame. Ground floor. Bedroom east wall (a.02/08/2016 and c.11/03/2017) Study north wall, (b.02/08/2016 and d.11/03/2017). Source: Author's own, 2017.

3.6 HYGROTHERMAL MONITORING

3.6.1 Methodology

Omnisense® GE Hygrotrac™ S-4 Wireless Dual Channel wireless sensors were used connected to electrical resistance sensors for measuring timber moisture content of the timber frame, and Hygrosticks™ measuring temperature (°C) and relative humidity (%) within the wall and habitable spaces. Each S4 sensor transmitted data at 30 minute intervals to an Omnisense® GE Hygrotrac™ Gateway connected to the internet. The monitoring was undertaken over a year from 02/08/2016 to 07/08/2017.

3.6.2 Results and Analysis

The results indicate that many of the monitoring locations are experiencing hygrothermal conditions favourable to biological attack (Figure 9). The most frequent risk is from deathwatch beetle, with the sill beam in the SE corner of the

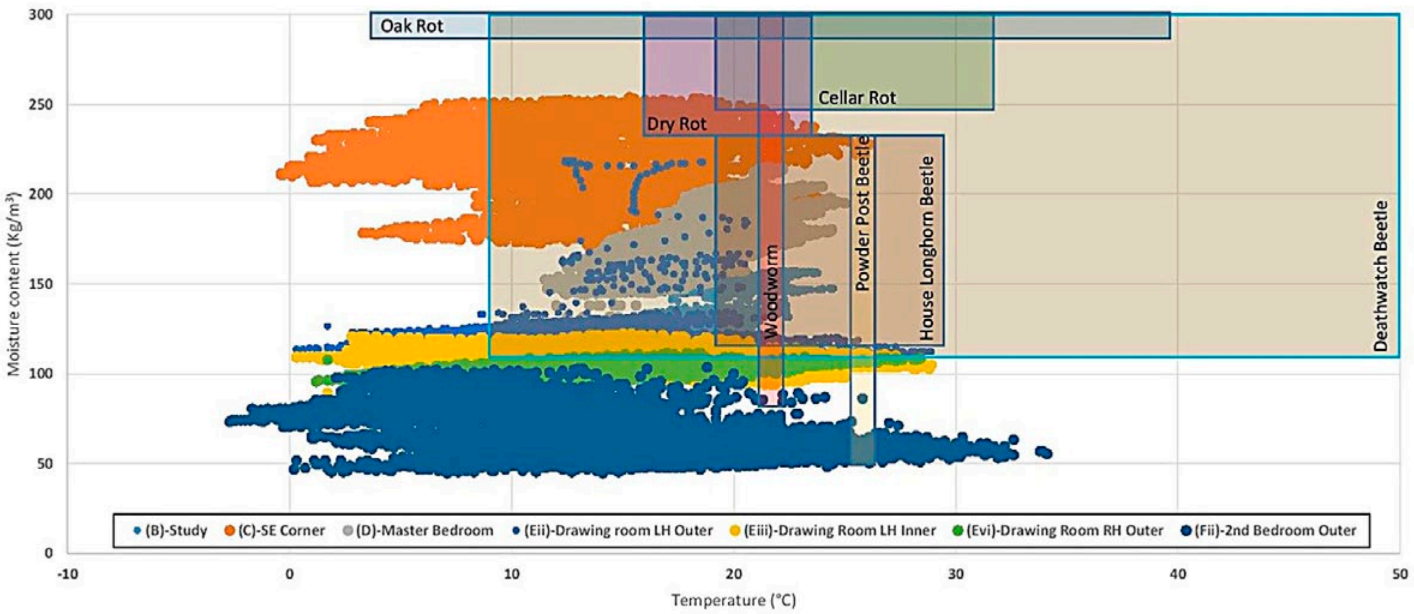

Figure 9. Hygrothermal conditions at monitoring positions with conditions favourable to biological attack overlaid. Source: Author's own 2017, with conditions favourable to biological attack based on [15].

master bedroom being open to this threat 99 % of the time. This location is also at threat from house longhorn beetle more than 1,000 hours per year. Within the same wall there also exists 249 hours when conditions are favourable for dry rot and 35 hours favourable to cellar rot. This further increases the risk of insect attack as both deathwatch and house longhorn will only inhabit wood previously damaged by decay. An instance of penetrating damp due to wind driven rain was recorded, with the affected area taking 9 months to return to its previous moisture levels.

The measurements within habitable spaces indicate that hygrothermal comfort was only achieved 38 % of the time in Master Bedroom, 26 % in the Study and just 4 % in the Guest Bedroom. In the Drawing Room hygrothermal comfort was achieved 50 % of the time, although it should be noted that no measurements were taken in this location over the winter months (02/11/2016–11/03/2017) due to the failure of a sensor. Despite these poor results, thermal perception questionnaires undertaken with the occupants concluded that both occupants found the ground floor of the house to be comfortable in winter but slightly warm in summer due to the underfloor heating and thermal mass of the ground floor. The converse was true with the upper floors, with both finding them comfortable in summer but slightly cool in winter in the case of one occupant and cold in the case of the other. The discrepancy between measured conditions and the occupants' perceptions may in part be due to the effect of radiant heating that was not measured but it may also indicate the occupants' willingness to accept lower comfort criteria in order to allow them to realise their ambition of living in a historic timber-frame building in a rural location.

4. ENERGY SIMULATIONS

4.1 METHODOLOGY

To assess the impact on energy demand of the changes that have already taken place, and to predict the potential for future retrofit measures, energy demand simulation was undertaken using the software DesignBuilder® Version 4.2.0.54. A weather file was created using the software Meteonorm version 6.1. The scenarios simulated are listed in Table 1 along with the change in energy efficiency, taking the current situation as a baseline (increase in efficiency (+) and decrease in efficiency (-)).

Table 1. Summary of scenarios simulated and results. Actual situation in red. All others are hypothetical

Scenario	**Description**	**Air Pressure ac/h @50Pa**	**Air Pressure ac/h**	**Change in efficiency**
1a	Assumed original lath and plaster with current airtightness	18	0.9	+1
1b	As 1a but with improved airtightness	10	0.5	+10
2a	**Current situation as measured**	**18**	**0.9**	**0**
2b	Calculated design u-value of wall but with airtightness as measured	18	0.9	+26
2c	As 2b but with improved airtightness	10	0.5	+35
3	Current situation (2a) but with all windows replaced with triple glazing	18	0.9	+2
4	Current situation (2a) but assuming improved airtightness	10	0.5	+9
5a	All infill replaced with sheep’s wool lime plaster/render finishes.	18	0.9	+23
5b	As 5a but with improved airtightness	10	0.5	+32

4.2 RESULTS AND ANALYSIS

The simulations suggest that had the original lath and plaster not been replaced, the energy demand for the house could have been slightly better than the current situation. If the assumption that the original lath and plaster provided a more airtight junction with the timber-frame than the current unsealed plasterboard butt-jointed detail, then potentially the house may even have been 10 % more efficient. Obviously, the decrease in energy efficiency was not the intended outcome. If the thermal performance of the walls had achieved their calculated design value of 0.921 W/m^{2}K, rather than the measured 1.8 W/m^{2}K then a 26 % or 35 % reduction in heating energy demand would have been accomplished depending on the airtightness achieved. This highlights the need for the design of achievable details and good workmanship.

Of the future potential retrofit actions, replacing the cement render and PIR thermal insulation with an air tight vapour permeable solution such as sheep’s wool and lime render on oak lath could improve the energy efficiency by up to 32 %. Given that this construction detail could adapt to the irregularities of the timber frame, it is more likely that a greater airtightness can be attained and that the design thermal performance can be achieved.

5. CONCLUSIONS

The monitoring has shown the damage that can be done through energy retrofitting without the correct guidance. The measured U-value is well below the calculated design value, most probably due to the poor detailing and excessive air movement around the insulation panels. This is confirmed by the thermography. Energy simulation shows that the house may well have been more efficient before the retrofit took place.

The timber moisture measurements and the interstitial hygrothermal measurements show that the historic timbers are saturated in many places due to the sealing of the building with impermeable finishes.

The hygrothermal comfort monitoring suggests that comfort conditions are achieved infrequently. This is however at odds with the occupants perceptions. This inconsistency may be due to comfort being provided by radiation which was not monitored or to lower comfort expectations. It is however clear that the radiant heating, from both the underfloor heating and the wood burner, do little to raise the air temperature.

Overall the decisions taken during the 20th Century and early 21st, although well intentioned, have led to a current situation where the historic structure is in danger of biological attack and collapse. It is hoped that the replacement of the cement render and PIR with finishes and insulation that are vapour permeable, coupled with repair, where necessary, of the timber frame, will save this building and provide it with a sustainable future.

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