Upgrading the UK Housing Stock

Insights into the Performance of Ready for Market Retrofit Solutions

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Abstract

While the UK government withdrew from the zero carbon building agenda, the need to provide a high quality, controllable and comfortable internal environment remains. Regardless of the shifting government sands, the thermal performance and energy efficiency of new buildings has improved, creating a gap between new and the 28 million existing properties in the UK. In Britain, many of the existing buildings are draughty and poorly insulated, making the buildings difficult to control and condition; positioning the UK housing stock amongst the most expensive to heat in Europe. Uninsulated thermal elements, bypassing of the insulation layer, and excessive thermal bridging, are present in many of these properties. The resultant cold temperatures and risk of condensation and mould have an impact on the health and wellbeing of the occupants, contributing to excessive winter death rates. To achieve thermal upgrade at scale, affordable and reliable 'off-the-shelf' solutions are required. This research provides the results from a deep retrofit project, where off-the-shelf measures were introduced in stages, under controlled conditions, on a hard to treat property. At each stage, significant reductions were achieved in the energy required to heat the property. The whole retrofit provided a more air-tight, thermally efficient fabric that brings many of the environmental benefits associated with new builds.

Introduction

The Paris Agreement (UNFCCC, 2016) reaffirms the position that reducing carbon emissions remains a global priority. Notwithstanding the recent departure of the USA (Merica, 2017), the position from the United Nations is clear, emissions must be significantly reduced to limit global warming and anthropogenic climate change (IPCC, 2014). However, the possible departure from the European Union and recent policy changes make UK's commitments to a reduction in building emissions uncertain (Watson, 2017).

Regardless of the changes, there are significant problems with the UK's aging building stock. While the sustainability arguments continue, the issues associated with current housing are acute. Many of the properties tested are difficult to heat, with occupants experiencing draughty dwellings and problems of condensation (Fylan et al. 2016; Gorse et al. 2015). The fabric condition of the most existing houses are far from that regulated for new build. Some buildings are so cold and damp due to their fabric thermal performance that they represent a health risk to the occupant. In winter, a cold home impacts on a wide section of the community. Of the 40,000 excessive winter deaths in the UK, 9000 are associated with cold homes (ACE, 2015; NEA, 2016). Over a five-year period (up to 2015) 46,716 deaths were attributed to cold dwellings, with the annual death rate similar to that caused by alcohol, and almost as high as breast cancer (ACE, 2015). Yet, mortality is a weak indicator of the impact of cold homes on the occupant; the years of healthy life lost and illnesses related to living in cold damp environments have much wider impact on society; ill health caused as a result of the living conditions costs the NHS £1.36 billion per year (NICE, 2015).

The recent changes to legislation are also having an impact on UK markets, leading firms, - including Kingfisher, BAM and ARUP - have lobbied the UK Government to use its Clean Growth Plan to tackle emissions from buildings (refer to the letter to Greg Clark Secretary of State, WWF,2017). The Head of Energy and climate change at WWF, called for clarity to enable UK business to invest in appropriate technologies (Bairstow, 2017).

As one third of anthropogenic greenhouse gas emissions world-wide are attributable to the built environment (UNEP, 2012), it provides a significant opportunity to reduce emissions. For new build dwellings in the UK, the Building Regulations have been used as the main tool for reducing emissions. And, in a direct response to the UK climate conditions, emphasis is placed on a fabric first approach, reducing space heating energy needs. However, little is regulated with regard to fabric retrofits. The Green Deal failed to incentivise the fabric retrofit market. The economic benefits and piecemeal voucher approach did not capture sufficient interest. The Energy Company Obligation scheme delivering carbon savings through cost effective measures, is in a period of transition and from 2018 the Minimum Energy Performance Standard (Private Rented Sector) will only require landlords to ensure rented properties achieve E or above.

What is lacking is the potential to demonstrate what a fabric first approach can achieve in terms of comfort, wellbeing and energy related savings. The research undertaken here sought to measure the improvement in thermal performance that could realistically be achieved using standard 'off-the-shelf' products to retrofit a solid wall terrace considered typical of the UK's "Hard to Treat" (BRE, 2008) housing stock.

Research method and experimental set up

The Energy House, a full scale test facility at the University of Salford consisting of a replica pre-1919 solid-wall Victorian end-terrace house constructed inside an environmental chamber, was used to test the retrofit measures. The Salford Energy House test facility was selected as it provides a controlled environment in which a steady-state can be achieved and maintained and replication of test conditions. Such an environment enables any change in thermal performance resulting from retrofit to be measured with a higher degree of confidence than in the external environment. The test house was built using reclaimed materials and methods of the time. Table 1 provides the construction details of the test house prior to retrofit (baseline test stage). Figure 1 shows an image of the Salford Energy House.

Table 1. Baseline test house construction details

Thermal element	Construction assembly and components
External walls	222.5 mm brick arranged in English bond with 9mm lime mortar and 10.5 mm British Gypsum Thistle hardwall plaster with a 2mm Thistle Multi-Finish final coat.
Roof	Purlin and rafter cold roof structure. 100 mm existing mineral wool insulation (λ 0.044 W/mK) between 100x50 mm ceiling joists running parallel to the gable wall at 400 mm centres above lath (6 mm) and plaster (17 mm) ceiling. 3 uninsulated timber loft hatches.
Floors	Suspended timber ground floor, with underfloor vented void. 22 mm floor boards fixed to 200 x 50 mm floor joists at 400 mm centres. Ground and intermediate floor joists run between the gable and party wall with joists ends built into masonry walls.
Windows	Double glazed in PVCu frames with trickle vents. Typical 1980's replacement double glazing (single glazed timber sash windows)
Doors	UPVC, typical of a 1980's replacement (uninsulated timber doors units with single glazing)
Party wall	Solid wall construction, unplastered on the Guard House side.

Figure 1. The Salford Energy House

The retrofit process involved thermally upgrading either one, or a combination, of its thermal elements. Table 2 presents the configuration of the test house at each stage of the experiment.

Table 2. Test construction at each test stage of the experiment

<table>
<tr><th rowspan="2">Test stage</th><th colspan="4">Construction of element at each test stage (shading denotes intervention & upgrade)</th></tr>
<tr><th>External wall</th><th>Roof</th><th>Glazing</th><th>Floor</th></tr>
<tr><td>1 Full retrofit</td><td rowspan="3">Hybrid solid wall insulation system
90 mm EPS EWI to gable and rear walls
80 mm PIR IWI to front wall</td><td rowspan="2">270 mm mineral wool</td><td rowspan="2">A+++ glazing, argon fill, low e</td><td>200 mm mineral wool + membrane</td></tr>
<tr><td>2 Full retrofit with original floor</td><td rowspan="5">Uninsulated suspended timber (original construction)</td></tr>
<tr><td>3 Solid wall retrofit</td><td rowspan="2">100 mm mineral wool (original construction)</td><td>1980s style double glazing units (original construction)</td></tr>
<tr><td>4 Glazing retrofit</td><td rowspan="3">Uninsulated solid wall - (original construction)</td><td>A+++ glazing, argon fill, low e</td></tr>
<tr><td>5 Loft retrofit</td><td>270 mm mineral wool</td><td rowspan="2">1980s style double glazing units (original construction)</td></tr>
<tr><td>6 (Baseline)</td><td>100 mm mineral wool (original construction)</td></tr>
</table>

At each stage of the experiment the following measurements of thermal performance were obtained:

- Heat loss coefficient (HLC) – The HTC (also referred to as the heat transfer coefficient) is the *"heat flow rate divided by temperature difference between two environments"* (BSI, 2007). It represents the steady-state aggregate for the total fabric and background ventilation heat loss across the entire thermal envelope of a building in Watts, per kelvin of temperature difference between the internal and external environments, expressed in W/K. The HLC was measured using an electric coheating test (Johnston *et al*., 2013).

- *In situ* U-values - The thermal transmittance of a building element (U-value) is the "Heat flow rate in the steady state divided by area and by the temperature difference between the surroundings on both sides of a flat uniform system" (BSI 2017; ISO 7345:1987), expressed in W/m²K. *In situ*, U-value measurements were undertaken in accordance with ISO 9869:1994 (BSI, 2014).
- Air permeability - Blower door tests in accordance with Technical Standard L1 (ATTMA, 2010) were performed to measure the air permeability (q_{50}) of the test house, expressed in m³/(h.m²) @ 50 Pa.

The thermal performance attributable to a retrofit thermal upgrade was calculated as the measured change from the baseline value. Figure 2 shows an image of the experiment set-up in the test house.

Figure 2. Typical experimental set up in the test house (red disks show in situ U-value measurement locations)

A mean internal air temperature of 20 °C was maintained during each test stage, which represents the average central heating thermostat set-point for homes in England was set (Shipworth *et al.*, 2010). The chamber (external) air temperature was held at 5 °C. This setting was considered optimum for the chamber HVAC system while close to the mean external air temperature (6.6 °C) for North West England during the October to May heating season (Standard Assessment Procedure, BRE, 2012).

Results

The full retrofit resulted in reduction of 63% heat loss through the fabric (Figure 3). Solid wall insulation was the thermal upgrade measure which resulted in the largest reduction (46%) from the baseline (Figure 4) representing 72% of the total heat loss reduction in the retrofitted house.

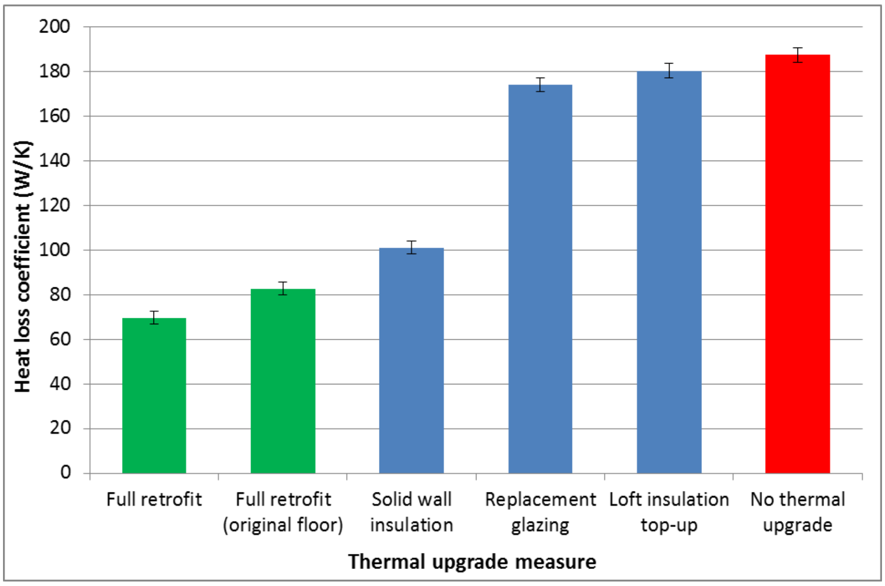

Figure 3. Measured HLC of the test house at each test stage (blue bars represent the test house heat loss following a single thermal upgrade measure, green bars represent thermal upgrade measures in combination)

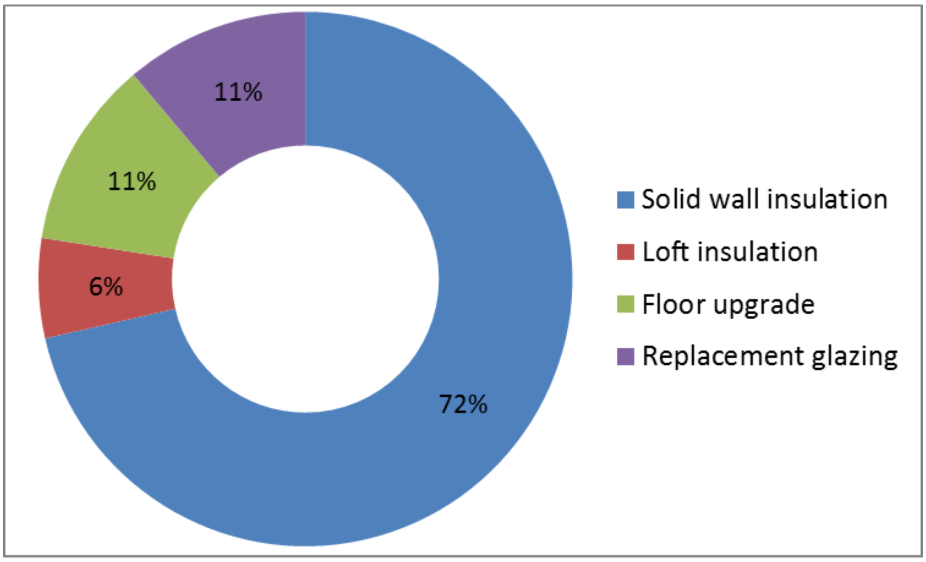

Figure 4. Contribution of each thermal upgrade to the reduction in whole house heat loss of the fully retrofitted test house

Based on the assumptions provided in Table 3, a notional dwelling of similar heat loss characteristics, subject to a similar thermal upgrade programme, could reduce annual space heating costs from £554 (no thermal upgrade) to £206 (full retrofit) with annual CO_2e emissions associated with space heating reducing from 2.31 tonnes (no thermal upgrade) to 0.86 tonnes (full retrofit).

Table 3. Impact of thermal upgrades on a similar house in the external environment located in Manchester, UK (annual space heating demand and cost, and CO_2 equivalent emission reductions)[1]

Thermal upgrade measure	**HLC (W/K)**	**Reduction on baseline (W/K)**	**Annual space heating energy reduction (kWh)**	**Annual space heating cost reduction (£)**	**Annual space heating CO_2e reduction (kg)**
Full retrofit	69.7	117.8	6497	348	1449
Full retrofit (original floor)	82.7	104.8	5777	310	1289
Solid wall insulation	101.2	86.4	4761	255	1062
Replacement glazing	174.2	13.4	737	39	164
Loft insulation	180.5	7.1	390	21	87
No thermal upgrade	187.5	n/a	n/a	n/a	n/a
Floor upgrade	n/a	13.1	720	39	161

Results from the *in situ* U-value and air permeability measurements provide greater insight as to how the reductions in HLC were achieved.

Figure 5 illustrates the reductions in heat loss from each thermal element following retrofit. The greatest reductions were measured from the hybrid solid wall insulation system which involved the application of internal wall insulation (IWI) to the front external wall and external wall insulation (EWI) to the rear and gable external walls. The relatively modest reduction in heat loss from the roof can be explained by the pre-existing insulation contained within the loft of the baseline house reducing its potential for improvement.

[1] All values calculated for reduction in annual heat demand are based on the 5 years prior to the experiment (2008 – 2012) mean annual heating degree day value of 2297 measured at Manchester Airport (base temperature 15.5oC). Assumes average UK condensing gas boiler efficiency of 82.5% (EST, 2009). Cost based upon average gas price for Manchester during 2012 of 4.42p per kWh (data sourced from DECC, 2013). Based upon June 2013 value for natural gas of 0.18404 kgCO2e per kWh (data sourced from the Carbon Trust, 2013).

The only retrofit measure where there was a significant difference between the calculated improvement in thermal performance and that measured was the EWI. However, the underperformance was the result of the temporary nature of the installation meaning an adhesive coat could not be applied to the EWI, this allowed air movement between the EWI and outer leaf of the gable wall, and bypassing of the insulation layer.

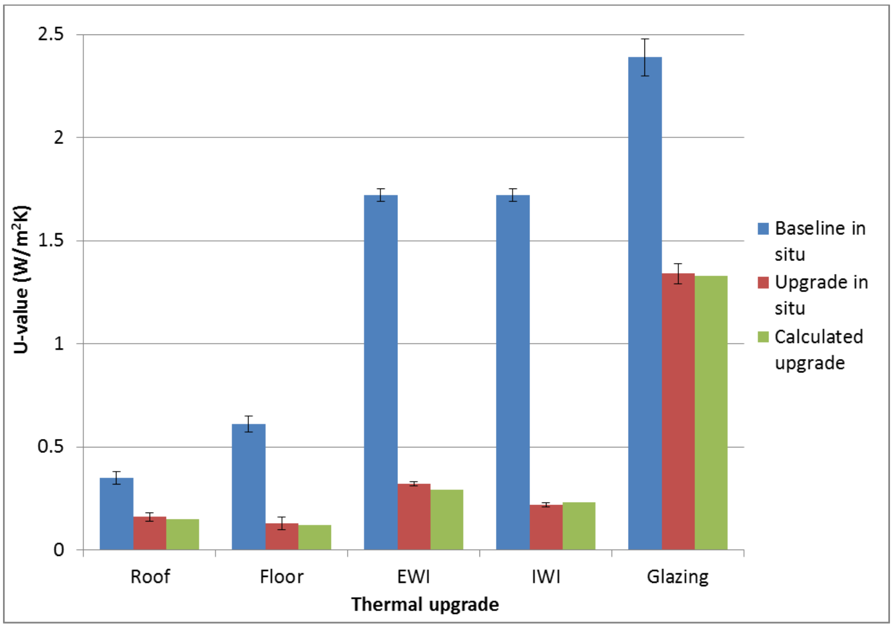

Figure 5. Summary of the in situ baseline and upgrade U-value measurements. Upgrade U-value measurements are compared to those predicted by U-value calculations

Table 4 shows that all the retrofitted thermal elements performed within the in-use factor applied by UK Government funded retrofit schemes to account for underperformance.

Table 4. Measured in situ U-value performance vs. in-use factors

Thermal upgrade	Calculated upgrade U-value (W/m^2K)	Measured upgrade *in situ* U-value (W/m^2K)	Discrepancy from calculated upgrade U-value (%)	In-use factor (DECC 2012) (%)
Roof	0.15	0.16 (± 0.02)	+ 7	35
Floor	0.12	0.13 (± 0.03)	+ 7	15
EWI	0.29	0.32 (± 0.01)	+10	33
IWI	0.23	0.22 (± 0.01)	- 4	33
Glazing	1.33	1.34 (± 0.05)	+ 1	15

The full retrofit of the test house resulted in a 50% reduction in air permeability from its original condition. From Figure 6 it can be seen that the upgrade measures to the floor provided the greatest increase in airtightness, a reduction of 42% from the baseline value. The increase performance can be primarily attributed to the airtightness membrane.

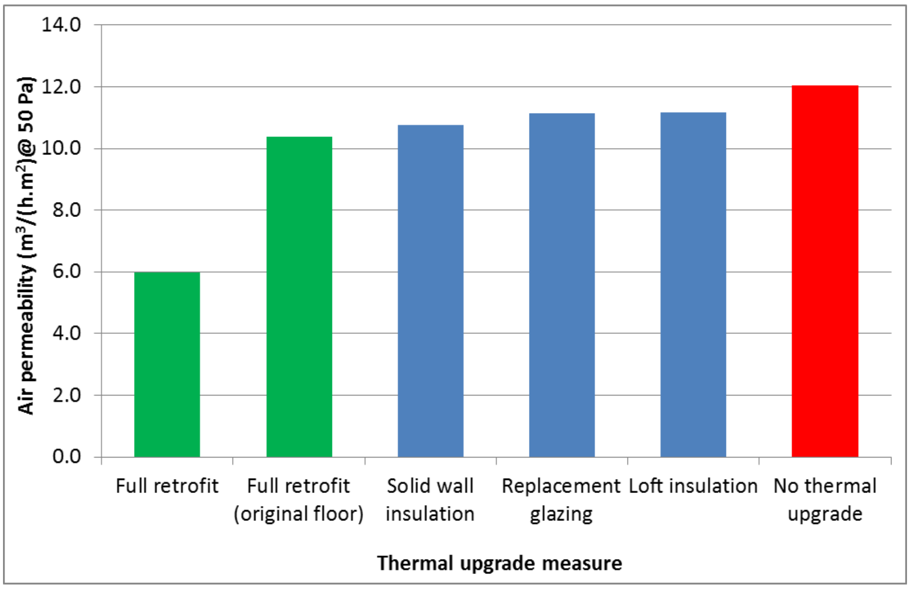

Figure 6. Air permeability value of the test house in each condition (Blue bars represent the test house following a single thermal upgrade measure, green bars represent thermal upgrade measures in combination

Conclusion

The research presented in this paper has demonstrated that dwellings of this type, which represent a significant proportion of the UK's hard to treat housing stock, have the potential to be retrofitted using off-the-shelf thermal upgrade measures to a standard which can significantly reduce their requirement for space heating and currently associated CO_2 emissions.

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