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Assessing the quality of retrofits in solid wall dwellings

Abstract

The purpose of the paper is to provide a detailed appraisal of the quality of domestic retrofits.

This paper presents the results of technical surveys on 51 retrofits undertaken before, during and after the retrofits.

Failures are observed to be endemic and characterised into five themes; 1) 72% showed moisture issues pre retrofit, 2) 68% had moisture risks post retrofit, 3) 62% did not adopt a whole house approach, 4) 16% showed inadequate quality assurance protocols, and 5) 64% showed evidence of insufficient design detailing. Each theme is further sub categorised with a view to identifying implications for future policy.

The findings suggest the 10% Ofgem retrofit failure rates predictions are an underestimate and so there may be a need for additional investigations to understand the trend across the UK.

Recommendations to reduce the failure rates may include making changes to the current inspection regime, widening understanding among installers; providing standard repeatable designs for repeated features; and empowering occupants to trigger inspections.

The sample is representative of a substantial proportion of the homes in the UK suggesting that retrofit quality may in many instances be below the required standards.

Risks of moisture issues and under-performance in domestic retrofit are a concern for government industry and households. This research shows that many installation failures are the result of not implementing existing guidelines and a change to the enforcement of standards may be needed to enact a fundamental change in installer practice and process control.

1. Introduction

Dwellings account for 29% of UK primary energy use (BEIS, 2016a), domestic thermal efficiency has been the focus of government policy for the past 20 years manifesting currently as a commitment to insulate 1 million homes between 2015 and 2020 (BEIS, 2016b). Table 1 describes the scale and success of previous domestic energy efficiency policies which, cumulatively, have improved the fabric and heating services of around 5% of all households in Great Britain (DECC, 2016).

Table 1 Overview of previous domestic energy efficiency policy in the UK (OFGEM, 2013b, DECC, 2014, OFGEM, 2008, Rosenow, 2012, NAO, 2016, Carbon Trust, 2011b, OFGEM, 2011)

Policy		Duration	Lifetime Saving	Total Cost	Cost Effectiveness
Energy Efficiency Standards of Performance 1,2 and 3	EESoP	1994 to 2002	13.7 TWh	£250m	£0.018 / kWh (approx. £51-76 / tCO$_2$)[1]
Energy Efficiency Commitment 1 and 2	EEC	2002 to 2008	192 TWh	£1,700m	£0.009 / kWh (approx. £25-36 / tCO$_2$)[1]
Community Energy Saving Programme	CESP	2009 to 2012	16.31 MtCO$_2$	£403m	£25 / tCO$_2$
Carbon Emissions Reduction Target	CERT	2008 to 2012	296.9 MtCO$_2$ (104THh)	£4,500m	£15 / tCO$_2$
Green Deal	GD	2001 to 2015	0.4 MtCO$_2$	£240m	£600 / tCO$_2$
Energy Company Obligation 1 and 2	ECO	2013 to 2017	33.7 MtCO$_2$	£3,000m	£89 / tCO$_2$

The methodologies used to calculate savings shown in Table 1, were not consistent across schemes thus, comparisons should be made cautiously, although the relative success of the policies is apparent. These savings are only modelled estimates, (e.g. using rdSAP (BRE, 2012)) which, in reality are rarely achieved; a phenomenon known as the *performance gap* which has been observed in new build as well as retrofit projects (ZCH, 2014, Johnston et al., 2016, Marshall et al., 2017,

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[1] Based on 1kWh of gas = 0.1836 kgCO$_{2e}$ and 1 kWh of electricity = 0.5246 kgCO$_{2e}$ (Carbon Trust, 2011) and assuming the savings are applied according to OFGEM (2011) average consumption estimates of 83% gas and 17% electricity (high estimate) vs an even 50% gas 50% electricity (low estimate)

Wingfield et al., 2007). To reflect this, in-use factors are applied to adjust the predictions (DECC, 2012). Reviews have identified causes of the performance gap including imperfect models; specification uncertainty; occupant behaviour; poor workmanship and processes on site; poor hand overs; complex controls; lack of whole house strategy; no construction stage testing; and inadequate or complex designs and systems (van Dronkelaar et al., 2016, Innovate UK, 2016a, Carbon Trust, 2011a, Johnston et al., 2016).

Furthermore, retrofit performance gaps have been observed to result in energy penalties, moisture problems and other unintended consequences, especially for solid wall retrofits (TSB, 2014, Innovate UK, 2016b, BRE, 2016). There is some indication that despite in-use factors, retrofits may still fail to meet their predicted energy savings (Gupta et al., 2015). This underperformance exists despite installers and designers undertaking training and achieving PAS2030 certification (BSI, 2014). PAS2030 requires that each retrofit undertakes multiple surveys, moisture assessments, bespoke detailed designs, checks on installer practice during inclement weather, supplementary ventilation provision and additional consideration of building physics and designs where energy efficiency measures meet other building elements (e.g. wall to ceiling junctions etc.). In response to why failures persist, despite these standards, the Government commissioned the Hansford review (BIS, 2015) and the Each Home Counts report (Bonfield, 2016), the recommendations also align with the existing PAS2030 guidance.

In addition, Ofgem[2] undertake quality assurance on retrofits, providing technical monitoring on 5% of all installations although the exact number varies according to the product type and the previous performance of the installing organisation. They have found that around 10% of installations do not pass their quality checks first time, although this rate varies by several per cent each year (OFGEM, 2015). Extrapolating this to all 2 million ECO installations undertaken to date (BEIS, 2017b), suggests at least 200,000 retrofits may be deficient failing in some way (OFGEM, 2015). However, the

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[2] https://www.ofgem.gov.uk/system/files/docs/2016/02/m_monitoring_questions_v1.1.xlsx

technical monitoring consists of simply a series of “yes / no” questions undertaken after the retrofit is competed (OFGEM, 2013a) and therefore the failures which are not visible, such as thermal bridging, non-contiguous insulation, infiltration pathways behind wall and floor coverings, interstitial condensation etc. may not be reported.

1.1. Evidence to date

The quality of house building being undertaken in the UK has previously been investigated, for example, Lowe and Bell (2000), who undertook surveys, design reviews and thermal performance testing to discover common causes of failures in new build dwellings caused by inadequate construction processes and monitoring. The issues that Lowe and Bell identified almost 20 years ago are still seen today in new builds but also in retrofits and, as a result, measured performance remains below design standards (Byrne et al., 2016). It is difficult to infer industry performance from a small sample of case studies, however De Selincourt (2015) interviewed a range of industry experts and retrofit surveyors and found they consistently observed inadequate detailed design and poor workmanship, resulting in homes being left with substantial thermal bridges and potential thermal underperformance and moisture risks.

Such concerns that existing retrofit practice is resulting in design and workmanship errors and consequential moisture problems in solid wall properties, prompted Historic England and the Sustainable Traditional Buildings Alliance to develop a guide to retrofits in an attempt to improve standards and raise awareness and knowledge among practitioners based on the findings from surveys of retrofits where poor practice was observed (May and Griffiths, 2015).

One of the largest collection of independent retrofit site observation case studies was conducted by the Building Research Establishment (BRE), which compiled findings from a range of different surveys across 27 sites in the UK covering around 1,800 homes where EWI was being installed at various points of the installation over multiple years; this reported that a lack of adequate surveys and detailed designs, and problems with workmanship and process control were prevalent; from which they surmised that 19 generic unintended consequences can manifest, mostly around moisture issues and underperformance (BRE, 2016).

Specific case studies conducted by building performance evaluation practitioners and surveyors have also been commissioned by concerned registered social landlords and housing charities to understand how to avoid these problems. For example, observations from surveyors and building performance evaluation practitioners into a Joseph Rowntree Housing Trust exemplar retrofit project revealed that even where extensive and deliberate care is made to the design and installation process, unavoidable issues or complications in translating designs into practice on site will inevitably result in some gap in thermal performance between the retrofit design and what is achieved (Miles-Shenton, 2012); suggesting existing light touch monitoring may not be sufficient to identify problems (JRHT, 2012).

In addition to the above survey investigations, the UK Government funded the Retrofit for the Future project where building performance evaluation techniques, such as coheating tests, U value measurements and air tightness testing, were undertaken (TSB, 2014). The data confirmed that underperformance was common across all the sites, and although a guide to retrofits was produced to inform best practice and avoid common problems, surveys were not the main focus of the research and so it was not able to fully analyse the root causes of the failure.

This paper presents the findings of intensive surveys on 51 predominantly solid wall dwellings, receiving retrofits under Government funding schemes between 2013 and 2015.

2. Method

In this research, surveys undertaken pre, during and post retrofit, were selected as the most useful data collection method because they provide a systematic approach to record actual construction and condition rather than using proxy data or assumptions to infer quality. Surveys, at the pre-works stage, allowed researchers to identify repair needs, which may adversely affect the retrofit measure, and areas where detailed design will be needed. Surveys undertaken during works further add to understanding of deficiencies, in practice and process. Surveys conducted after the works have been finished, are useful for identifying if previously identified issues have been addressed as well as to spot any defects.

Previous research in this area has made use of building surveys at different points in the construction process to good effect. For example, the BRE (2016) research included site observations and the Bonfield (2016) review highlights importance of analysis and consideration of location, exposure, history, architectural context, usage and state of repair, prior to any retrofit measures.

2.1. Sample

Over 25 Registered Social Landlords (RSLs) and Local Authorities (LAs) across the North of England receiving government funded retrofits were invited to take part in this research. Sourcing sample homes was challenging owing, largely due to the fast turnover of retrofits (often notification of new sites was given to researchers only after work had commenced) and willingness of occupants to take part. Despite a £20 householder incentive occupants were not always willing to engage with the study. Thus, convenience sampling through RSL networks may have introduced bias, however, logistics around which houses became available at the right times was the prevailing recruitment factor. Over 1,000 properties were invited to take part in the project, and all willing respondents were included; eventually 51 homes were secured. 84 surveys were then undertaken; 37 pre refurbishment (P), 12 during refurbishment (D) and 35 post refurbishment (A). It was only possible to undertake before and during/after visits on 27 of the homes as shown in Table 2. The retrofits taking place included external wall insulation (EWI), internal wall insulation (IWI), loft insulation (LI), party wall insulation (PWI), new boilers, and new windows, though in some instances no retrofit eventually took place. The sample is summarised in Table 2.

Table 2 Overview of dwellings

Dwelling	Wall type	Construction	Main retrofit	Measure 2	Measure 3	Measure 4	Survey type
1	Solid Brick	1900	IWI	Boiler	Air tightness	LI	PA
2	Solid Brick	1900	IWI	Boiler	LI		PA
3	Cavity Brick	1950	PWI	LI			A
4	No-fines concrete	1960	EWI	LI			DA
5	No-fines concrete	1960	EWI				DA
6	No-fines concrete	1960	EWI				DA
7	Solid Brick	1890	IWI	Boiler	LI	Windows	A
8	Solid Brick	1900	IWI	Boiler	LI	Windows	A
9	Solid Brick	1900	IWI	Boiler	LI	Windows	PD
10	No-fines concrete	1970	EWI	Boiler	Windows		PA
11	No-fines concrete	1970	EWI	Boiler	Windows		PA
12	In situ Concrete	1950	EWI				PA
13	In situ Concrete	1950	No retrofit				P
14	In situ Concrete	1950	No retrofit				P
15	Precast Concrete	1950	No retrofit				P
16	In situ Concrete	1950	No retrofit				P
17	Concrete	1950	EWI				P
18	Concrete	1950	EWI				P
19	Concrete	1950	EWI				P
20	Stone	1950	LI	Windows			PA
21	Solid Brick	1900	EWI	IWI			PA
22	Solid Brick	1900	EWI	IWI			A
23	Solid Brick	1900	No Retrofit				PA
24	Solid Brick	1950	EWI				PA
25	Solid Brick	1950	EWI				PA
26	Solid Brick	1950	EWI				PA
27	Stone	1950	IWI				P
28	No-fines concrete	1960	EWI				DA
29	No-fines concrete	1960	No retrofit				P
30	Solid Brick	1900	EWI				A
31	Solid Brick	1900	EWI				A
32	Solid Brick	1930	EWI				PA
33	Solid Brick	1900	EWI	IWI			DA
34	Solid Brick	1900	EWI				DA
35	No-fines concrete	1970	EWI				PA
36	No-fines concrete	1970	EWI				PA
37	No-fines concrete	1970	EWI				PA
38	No-fines concrete	1970	EWI				PA
39	No-fines concrete	1970	EWI				PA
40	No-fines concrete	1970	EWI				PA
41	Solid Brick	1910	EWI				PA
42	Concrete	1970	EWI				PA
43	Concrete	1940	EWI				A
44	Solid Brick	1900	IWI				D
45	Solid Brick	1900	IWI	LI	Windows	Floor	PDA
46	Solid Brick	1900	IWI				PDA
47	Solid Brick	1900	IWI	Boiler	Windows		P
48	Solid Brick	1900	EWI	IWI			PD
49	Solid Brick	1940	IWI				P
50	Solid Brick	1900	IWI				PDA
51	Solid Brick	1900	IWI				PA

The retrofit installers were not pre-warned about the research visits and a variety of large national contractors, subcontracting organisations were involved, and thus no single approach to retrofit dominated. 51 homes is relatively substantial for a domestic retrofit field trial (Seguro, 2016), though would not be considered representative of the entire industry nor would it be representative of a building type or retrofit system approach. As can be seen the findings will be mostly applicable for dwellings receiving solid wall insulation (SWI). To date, 7% of ECO measures have been installed in solid wall properties though 91% of solid walls in England remain uninsulated (BEIS, 2017b). Thus, the potential total SWI retrofit market may be up to 6.3 million homes, although some of these may be unsuitable for insulation e.g. listed buildings (DCLG, 2016) and, furthermore, SWI minimum quotas are planned for future policy (BEIS, 2017a).

Two main property archetypes and retrofits make up the sample; late Victorian terraces and 1950s-70s concrete homes, receiving EWI or IWI. The survey therefore, has wide implications since the English Housing Survey (EHS)[3] suggests 1.7 million homes were built between 1900 and 1918 and 4.6 million built between 1945 and 1964 in England which cumulatively makes up 27% of the housing stock. In addition, the results may be appropriate for other countries undertaking retrofit programs on solid wall properties, particularly those subject to the European Directive for the Energy Performance of Buildings (European Commission, 2010).

2.2. Survey

A desktop survey was first undertaken using Google street view to establish the building archetype and local context. This pre-survey investigation is common practice in the building surveying profession (RICS, 2010). Following this site surveys were conducted in accordance with best practice guidance (RICS, 2013, RIBA, 2013, RICS, 2016). Visits also allowed opportunities to discuss issues with occupants.

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[3] http://housingdata.bre.co.uk

A pro forma was used, broadly in line with RICS guidance note *Surveys of Residential Property* (RICS, 2013b) and rdSAP data collection forms, capturing data on wall and floor types, building age, insulation types and thicknesses, use of cellars and lofts, spot moisture measurements and noting extensions. It also evolved throughout the process to include additional pertinent data, for example; presence of dormer cheeks, knee walls and eaves loft insulation. Photographs were used to support observations and thermal images were used when temperature differences between the inside and outside of homes might reveal variations in surface temperature that may be indicative of missing insulation or other thermal anomalies.

Where possible, follow-up site surveys were undertaken after or during the retrofit and again discussions with installers and householders took place. Additionally, schemes were often neighbourhood-wide so kerb side observations of neighbouring dwellings were utilised to identify systematic issues.

3. Results and Discussion

3.1.Survey findings

Survey notes were written up following each visit. These were collated so that all the observations made for all the homes could be visualised in one central place. This was essentially a long list of individual issues that were observed (rising damp, failing flashing, condensation etc.) for each house. In order to rationalise these data, the observations were grouped according to their associated features, for example if a house had an EWI retrofit but the loft insulation was not also upgraded and no additional ventilation was provided either, these were both deemed to be examples of a whole house approach not being adopted. This categorisation allowed a more strategic understanding of the themes and characteristics of the failures being observed.

From this process five retrofit failure categories emerged which characterised the vast majority of all the observations; 1) Moisture issues pre retrofit, 2) Moisture risk post retrofit, 3) Lack of whole house approach, 4) Inadequate quality assurance, 5) Insufficient design detail. Figure 1 shows the proportion of homes exhibiting each of the 5 issues; the majority exhibited multiple failure types. The following sections describes each category in turn.

Figure 1 Proportion of dwellings with observed faults

3.1.1.Moisture issues pre retrofit

Figure 1 suggests 72% of the properties had damp issues prior to installation, an example of which is shown in Figure 2. Mould was observed to generally be removed prior to applying IWI, though not for EWI. Remedial action to address causes of damp was not seen to be systematic and only observed in the 'deep' retrofits. Table 3 describes the types of issues observed.

Table 3 Pre retrofit moisture problem observations

Observation	No. Dwellings
Rising damp	18
Penetrating damp	16
Pointing and render in defective condition	15
Failing flashings	5
Brick deterioration	5
Condensation and mould	13
Roof and gutter leaks	5
Draughty doors / windows	4
Tree interference	2

Figure 2 Examples of moisture issues observed prior to retrofit

3.1.2.Moisture risk post retrofit

Moisture issues can manifest following retrofit because changes to the building fabric affect the way moisture and moisture laden warm air moves through the structure. These can take years to manifest, for example, as condensation on inner surfaces eventually resulting in mould or fungal growth, damp patches appearing in internal walls, or spoilt decorations. Interstitial condensation may be hidden for even longer periods, only discovered if timbers rot or experience beetle attack, or if metal parts corrode or organic materials decompose. Despite this, 68% of dwellings in this study showed signs of the risk of damp post retrofit. Table 4 lists the types of risks observed. No observations directly attributed to moisture laden warm air were made in the post retrofit surveys, probably because surveys were undertaken typically within a few months of the retrofit and were not always undertaken in the heating season.

Table 4 Postretrofit moisture risk observations

Observation	No. Dwellings
Rising damp	6
Penetrating damp	11
Pointing / render in defective condition	6
Failing flashings	6
Condensation and mould	18
Lack of ventilation	4
Service leaks	2

In addition, product or process failure can cause moisture problems (e.g. leaks). This was identified in one of the post retrofit surveys; rain water ingress occurred due to inadequate sealing between the EWI top capping and the wall causing damp patches, as shown in Figure 3.

Figure 3 Photographic and thermographic observation of damp and schematic to show route of water ingress behind EWI

3.1.3.Lack of whole house approach (ventilation and complementary solutions)

PAS2050 and the Hansford (2015) and Bonfield (2016) reviews state that retrofits should take a whole house approach. This does not necessarily refer to improvements for every element in the dwelling, but that installations should consider the building as a single system. For example, when installing wall insulation the infiltration rates fall to an unacceptably low level (Innovate UK, 2016b) meaning additional ventilation may be needed. Also, it is common that installing insulation to plane elements causes intensification of thermal bridging around junctions which may need addressing. Inconsistencies in retrofits approaches does lead to variations in performance across the building envelope. From the study, 62% of dwellings appeared not to adopt a whole house approach. The piecemeal, or what may appear unsystematic, approaches to retrofit observed are described in Table 5.

Table 5 Lack of whole house approaches

Observation	No. Dwellings
Insufficient insulation to party wall returns creating thermal bridges	17
No thermal separation between basement and upper floors	4
No floor insulation	18
No improvement to roof insulation	19
Roof ventilation blocked	4
External stores uninsulated creating large thermal bridges	10
Sloping roof soffits not insulated	6

Despite this, in some instances a whole house approach was adopted where insulation and ventilation strategies were considered together. For example, in some observations the ventilation pathways, such as air bricks, were maintained following a EWI retrofit, as shown in Figure 4, and in one instance, additional ventilation was installed, where previously there were no trickle vents on the windows.

Figure 4 Maintenance and addition of ventilation post EWI retrofit

However, often no additional ventilation was provided and, in some of the properties air bricks were covered over by the EWI, as shown in Figure 5.

Figure 5 Air brick covered over after IWI installed

Only where a dwelling was undergoing a 'deep' retrofit, and was void for a period of time, were complimentary insulation measures installed or other existing measures checked for effectiveness. Figure 6, shows an example of inadequately maintained loft insulation that was not rectified by the installers as part of the EWI retrofit. A cold strip at the eaves is also evident here, representing missing insulation from the retrofit, this phenomenon will be discussed later.

Figure 6 Incomplete loft insulation after EWI retrofit

Figure 7 Raked eaves without (left) and with (right) mineral wool cavity batt inserted

Another example of a lack of consideration of adjacent elements is shown in Figure 7 illustrating raked eaves (sloping roof detail at the external wall junction) where a significant thermal bridge only emerged once the wall and loft were insulated, as prior to retrofit the raked eaves and external wall displayed similar surface temperatures. A solution to this one particular installation was recommended by the research team and a standard mineral wool cavity wall batt was inserted from inside the loft between the rafters to insulate this ‘forgotten’ area while still allowing airflow over the top to ensure the loft space remained adequately ventilated. As can be seen in Figure 7, this appeared to resolve the problem and the final solution was separately as part of this research project eventually calculated to no longer pose a condensation risk according to BR 497 (Ward and Sanders, 2007).

3.1.4. Inadequate quality assurance (workmanship and process control)

Causes of the performance gap in retrofits have been shown to be varied, though many are related to poor quality assurance processes (ZCH, 2014). This project observed workmanship errors in 16% of dwellings; these are summarised in Table 6.

Table 6 Quality control issues observed

Observation	No. Dwellings
Incorrect insulation placement	4
Insulation missing to large areas	7
New render of deficient quality or misapplied	10
Inconsistent or lack of sealing at insulation edges	2
Inconsistent or lack of sealing at EWI edges	3
Air leakages around doors	1

Insulation missing to large areas	7
Missing IWI at floor voids	4
Inadequate support to vertical insulation	2

One common observation was a lack of sealing around breaches in the air barrier, in particular around service penetrations as shown in Figure 8. Another issue shown in Figure 9 was inadequate and inconsistent contact between EWI and the external wall surface, which could allow air to circulate behind the insulation, reducing the EWI's effectiveness, as had previously been observed on other projects (Siddall, 2009).

Figure 8 Inadequate sealing of penetrations (extract fan) through IWI seen during depressurisation

Figure 9 Poor contact of EWI and brickwork

In some instances, thermal bypasses (where warm air is able to escape through gaps in the fabric) will not be visible; Figure 10 shows a solid wall that had an embedded bypass which permitted external air to seep into the dwelling. This was not rectified by the IWI since dot and dabs were used, i.e. the insulating batts were not bonded and sealed to the external wall. This is likely to reduce the overall effectiveness of the retrofit, and allow moist air to travel into this relatively colder cavity behind the insulation, and foster potential interstitial condensation.

Figure 10 Thermal bypass showing external air entering the dwelling behind the IWI on the external wall under dwelling depressurisation and moving into the void behind the plasterboad on the adjacent internal partition wall.

3.1.5. Insufficient design details

PAS2050 requires that complex details should be supported by detailed drawings for installers, yet this study found that in 64% of cases installers adapted installations on-site without reference drawings. These are listed in Table 7 and some examples are shown in Figure 11.

Table 7 Examples of inadequate or missing detailed designs

Observation	No. Dwellings
Thermal bridge at ground floor level	21
Thermal bridge at eaves	24
Insulation not provided at gables where houses are at different vertical levels	7
Irregular or oversized EWI cut-outs for services	16
Excessive EWI cut-outs at doors	4
Excessive EWI cut-outs at porch, single storey extension roofs etc.	22
EWI cut-outs at external walls/ fences, where abutments could have been adjusted	10
Some lack of thermal separation between basement and upper storeys	12
Thermal bridge at door/ window reveals/ frames	15
Room in roof thermal bridges	10

Figure 11 Unusual bespoke EWI detailing solutions designed onsite

While unusual features cause problems for installers, this project also observed unusual or bespoke solutions for common or repeatable designs. For example, window and door sills, jambs, lintels and ground floor perimeters were often left uninsulated; instances of this are shown in Figure 12. In these examples, it may have been possible to adopt a generic solution for these to improve performance as is the case with the use of accredited construction details[4] in new build properties.

Figure 12 Common EWI details causing thermal bridging

No dwellings surveyed in this project had EWI extending below internal ground floor level, all stopped at finished floor level or above the DPC. Although it is not a requirement in OFGEM technical monitoring to continue the EWI to the ground it is recommended in best practice by some manufacturers e.g. (2013) and STO (Undated). Methods for doing this are also included in INCA (2015). Installers reported this to be due to concerns around animal burrowing and more significantly, rising damp, through it was not clear how they valued the consequences resulting from the increased thermal bridging and its potential to increase the risk of condensation at this junction.

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[4] http://webarchive.nationalarchives.gov.uk/20151113141044/http:/www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/bcassociateddocuments9/acd

In three dwellings (all installed by the same contractor) IWI insulation was not continued through the intermediate floor voids. This is shown in Figure 13 where the floor joist adjacent to the external wall is visible, meaning it has not been relocated to allow the IWI continue uninterrupted.

Figure 13 IWI does not extend into intermediate floor void

The implication is that condensation risk could be introduced in some dwellings in hidden locations, where timber joists are likely to be present; this increases the potential for timber rot. Other hidden areas that may therefore go untreated may include behind kitchen units, baths or boxed-in pipework. Hidden discontinuities in insulation layers are not observable via Ofgem inspections since they do not include thermal imaging.

Another regularly repeated design problem was observed where there was architectural detailing around the eaves or where the rainwater gutter system would be in the way of the EWI unless the roof was extended outwards. This resulted in EWI not being fully installed up to the eaves, as shown in Figure 14 (and also in Figure 6), this resulted in a strip of uninsulated masonry, introducing a long thermal bridge, at what may already be considered an exposed interface at risk of condensation.

Figure 14 EWI commonly missing at eaves

Corbelling, and other details like this, are relatively common on pre-war solid wall properties built prior to the 1940’s and so this omission may be replicated across the country on a relatively large scale, indeed it can also be seen in the properties in Figure 4 and has previously been observed in the literature (Glew et al., 2017, Hopper, 2012).

Design issues relating to site wide features that can influence the retrofit were also observed. PAS2030 requires appropriate surveys to identify any concerns in advance of the installation. However, this study observed several instances where these were missed, ignored or poorly dealt with, especially for EWI detailing around where flue gas extractors, gas meters, external stores, external lights, drainage pipework and fences. According to PAS2030 each of these items should be remounted after the EWI is fitted; however, this was not always undertaken (as shown in Figure 15.), potentially causing adverse thermal bridging. It was not clear why this was the case, for example, a lack of understanding, confusion over responsibilities of installer roles, or cost. It is important to note that in some instances externally mounted features were observed to have been appropriately integrated into the design as in.

Figure 15 EWI discontinuities at internal bin store and wall mounted gas meter and pipework

Another site wide observation, relates to the consequence of ECO policy where funding may be provided to one of a pair of semi-detached houses or perhaps 'pepper potting' in a terrace. In these instances, confusion around closing off insulation at party walls was observed; some finishing in the centre of party walls, others extended to cover the entire party wall, and these differing solutions affected the degree of thermal bridging occurring.

3.2. Recommendations

This study suggests that existing retrofit implementation practices and monitoring results in substantial failure rates and that Ofgem predictions are underestimates. Table 8 summarises proposed recommendations to address the observations in this study.

Table 8 Recommendations

	Failure category	Recommendation
1	Moisture issue before retrofit	• Require systematic on-site observations of the property to inform design. • Produce protocols for addressing and remediating specific moisture issues. • Require documentation from installer that no adverse moisture issues exist. • Improve awareness of implications of inadequate moisture management.
2	Moisture risk after retrofit	• Ensure retrofit warranty period is sufficient to protect for delayed moisture issues. • Incorporate a mechanism for customers to trigger inspections if moisture problems manifest in future years. • Provide additional Ofgem inspections after several years to check moisture issues.

3	Lack of whole house approach	• Ensure trickle ventilation is supplemented by mechanical extract ventilation in wet rooms (e.g. kitchens, bathrooms, ensuites, utility rooms) for all retrofits. • Require that air bricks are replaced by mechanical extract ventilation in wet rooms for all retrofits. • Require documentation from installer describing how ventilation has been improved. • Require loft insulation condition to be inspected and made adequate for all retrofits. • Development of thermal and hygroscopic 4D movement models to predict inconsistencies of the design, to assist the designers.
4	Inadequate quality assurance	• Incorporate a structured assessment for identifying thermal bypass e.g. Energy Star (2008). • Improve installer and operative awareness around thermal bypasses. • Improve installer and operative awareness of airtightness. • Provide guidance on sealing penetrations and insulation. • Undertake technical monitoring during installation stages while insulation is visible (e.g. intermediate floor void). • Adopt a two tier inspection regime (sub sample with more detailed assessments e.g. pressure tests to identify non visible air leakage) • Provide a handover booklet for householders to spot technical failings from which they may trigger an Ofgem inspection. • Integrate thermographic surveys into technical monitoring (to spot cold spots or air leakage).
5	Insufficient design detail	• Design external insulation to extend to ground (to avoid thermal bridging), with all EWI products resistant to vertical wicking, and a break at the DPC. • Require Ofgem monitoring to check EWI extends below ground floor level. • Provide a free library of detailed designs for common problems such as lintels, gas flue extract pipes, guttering and party wall details, akin to Accredited Construction Details scheme used in Building Regulations (NBS, 2010). • Raise awareness of site wide issues among installers and householders. • Ensure bespoke solutions observed during inspections have supporting design drawings • Require detailed design drawings produced for ensuring insulation continuity at junctions such as ground level wall and floor junctions, eaves level wall and ceiling junctions, and external and internal wall junctions (horizontal and vertical).

Incorporating any additional requirements, such as those listed in Table 8, addressing the failure rates observed in this study, may add cost to the delivery of the policy. This could reduce the number of dwellings able to have retrofits, affecting government installation targets. However, additional installation costs need to be balanced alongside consumer protection against risks being embedded in homes, especially in the wake of the recent CWI debate in the House of Commons[5] and in the context of Ofgem figures suggesting 200,000 homes have some form of failing retrofits.

3.2.1. Alternative policy mechanisms

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[5] http://www.publications.parliament.uk/pa/cm201415/cmhansrd/cm150203/halltext/150203h0001.htm

Strengthening existing training, guidance or monitoring may be one option to reduce the instances of failures in retrofits, however, alternative policy mechanisms may also be considered to address the problems observed. For example, a whole house approach may be encouraged by setting targets on the number of measures installed rather than the number of homes being retrofitted; this may mean installers are incentivised to investigate the condition of lofts and other elements for example. Although there is danger that unnecessary works would be done. Another approach could be to pursue alternative policy funding mechanisms such as a 'pay as you save' scheme previously considered (UKGBC, 2009) or the Energiesprong[6] and iLife[7] concepts. These are similar to energy performance contracts currently used in non-domestic markets where anchor tenants reduce risks for investors (DECC, 2015) and bespoke metering and billing can be set up. In domestic situations this may require communitywide projects and wider smart meter ownership.

3.2.2.Limitations and future investigations

Although this project was concerned with EWI in solid wall properties because these are a notoriously difficult retrofits, it would nevertheless be interesting to expand this survey approach to a wider variety of retrofit measures, including loft insulation, cavity wall insulation, floor insulation and new heating systems, as well as to capture a wider variety of house types. In addition, longer term monitoring of the homes or the use of additional BPE techniques following the surveys would describe the implications of the failures that were being observed. This would require a substantial increase in the scope and cost of any research project, and implementation problems and difficulties around occupant cooperation to monitoring homes for extended periods of time have previously be identified (Olivia and Christopher, 2015).

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[6] http://energiesprong.eu/

[7] https://ilifebuildings.wordpress.com/

4. Conclusion

This project presents the findings of detailed surveys on 51 properties to gain a snapshot of domestic retrofit quality. Government monitoring suggests 10% of retrofits may not achieve required standards, equivalent to 200,000 homes funded under ECO; however, this project suggests this may be an underestimate. The implications of this are that the implementation and enforcement of domestic energy efficiency policy has been introducing risk in to people's homes and has missed opportunities to maximise fuel bill savings. Since this research was undertaken the Each Homes Counts review has been undertaken by Government and industry to address the sorts of issues identified here. Any outcomes of this review should concentrate on solutions which bind the themes observed here, namely that building specific designs and pre and post surveys are given a low status in the current regime, despite their potential to avert the manifestation of the majority of the problems identified.

Observed problems may have consequence on carbon targets and consumer protection. The observations are categorised into the five themes;

1) Moisture issues pre retrofit (exhibited by 73% of dwellings)
2) Moisture risks post retrofit, (68% of dwellings)
3) Lack of whole house approach, (62% of dwellings)
4) Inadequate quality assurance, (16% of dwellings) and
5) Insufficient design detail (64% of dwellings).

Changes are needed to the enforcement of the standards, and more data gathering by inspectors, may provide greater reassurance in the system. Recommendations from the findings in this study suggest that improvements may be achieved by; increasing inspection rates, changing when inspections are made; increasing the number of inspections per home; widening the scope of monitoring checks and tools; widening understanding among installers of issues related to moisture and thermal bridging; providing standard repeatable designs for repeated features; adopting a two tier monitoring approach and finally empowering occupants to trigger inspections. In addition, to validate if and how particular installation problems affect a household there may need to be more systematic BPE programs and conditions monitoring of a large number of retrofitted dwellings to add weight to the evidence currently gathered by a large number of individual case studies.

The surveys in this study were undertaken on retrofits undertaken by multiple installer organisation types and sizes, incorporating a range of solid wall retrofit solutions in predominantly Victorian and mid-20th century concrete dwellings across the North of England. While the conclusions may not be replicated in all dwelling archetypes and retrofits, the sample is representative of a substantial proportion of the homes in the UK suggesting that retrofit quality may in many instances be below the required standards.

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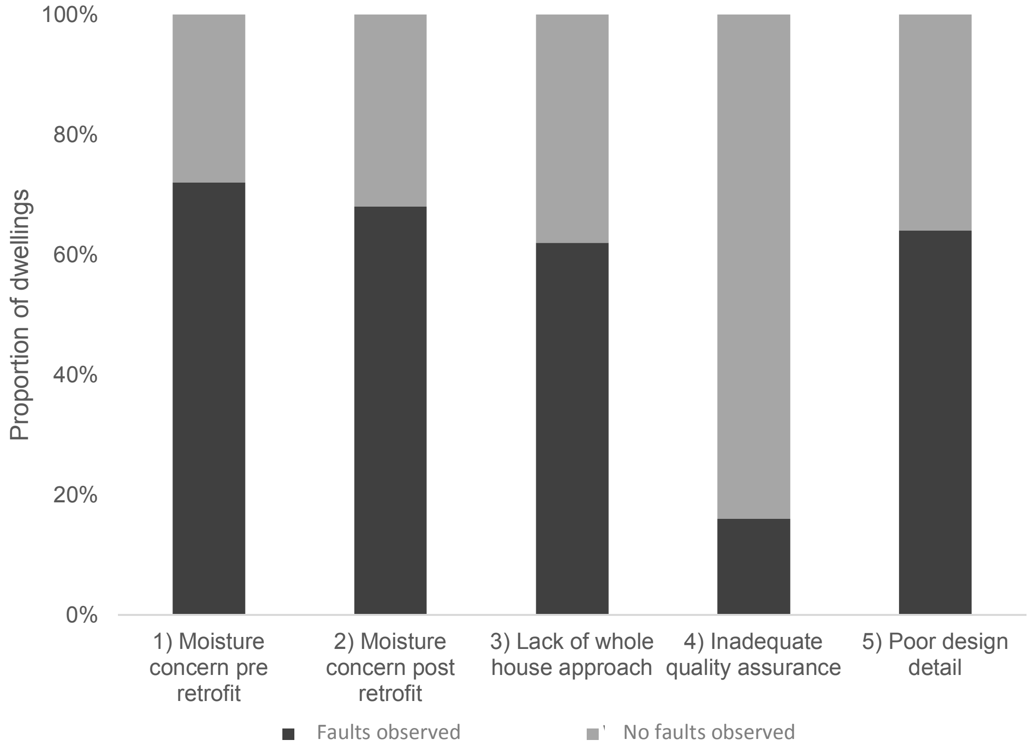

Figure 1 Proportion of dwellings with observed faults

Figure 2 Examples of moisture issues observed prior to retrofit

Figure 3 Photographic and thermographic observation of damp and schematic to show route of water ingress behind EWI

Figure 4 Maintenance and addition of ventilation post EWI retrofit

Figure 5 Air brick covered over after IWI installed

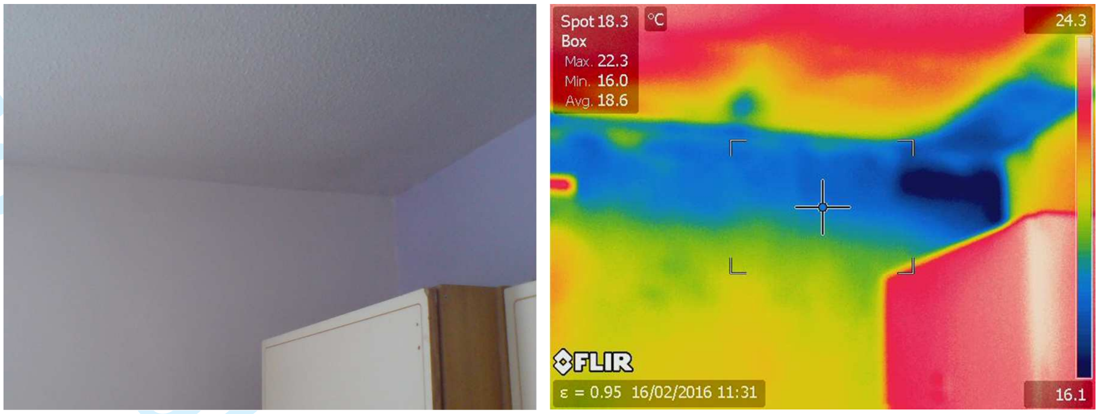

Figure 6 Incomplete insulation at loft and eaves after EWI retrofit

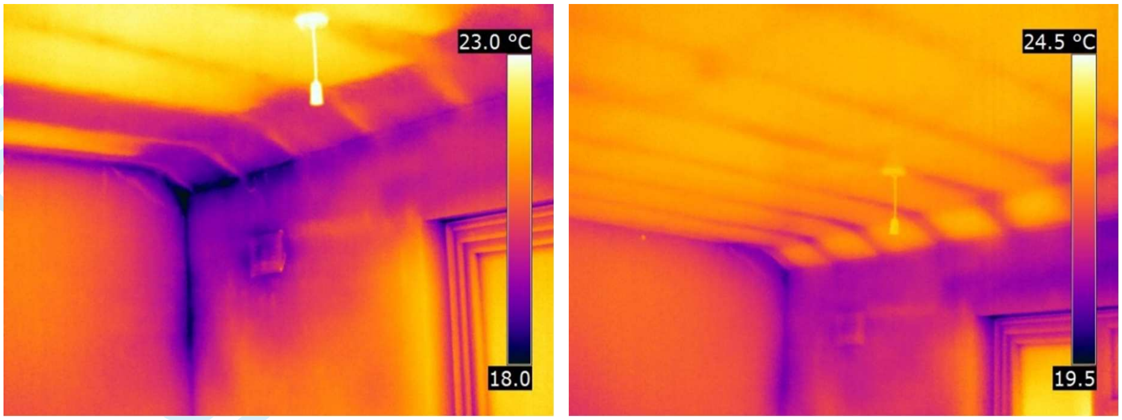

Figure 7 Raked eaves without (left) and with (right) mineral wool cavity batt inserted

Figure 8 Inadequate sealing of penetrations (extract fan) through IWI seen during depressurisation

Figure 9 Poor contact of EWI and brickwork

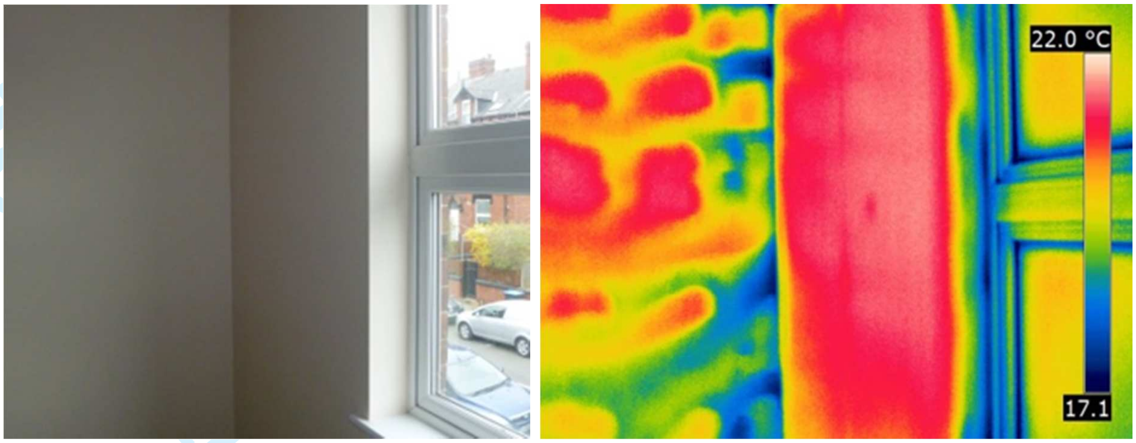

Figure 10 Thermal bypass showing external air entering the dwelling behind the IWI on the external wall under dwelling depressurisation and moving into the void behind the platerboad on the adjacent internal partition wall.

Figure 11 Unusual bespoke EWI detailing solutions designed onsite

Figure 12 Common EWI details causing thermal bridging

Figure 13 IWI does not extend into intermediate floor void

Figure 14 EWI commonly missing at eaves

Figure 15 EWI discontinuities at internal bin store and wall mounted gas meter and pipework