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Regent Road Retrofit Final Report

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Executive Summary

This report presents the findings of a research programme by Leeds Beckett University (LBU) and the University of Leeds (UoL) as part of Skipton Building Society's (Skipton) Big Retrofit project at 49 Regent Road (49RR), Skipton. The project aim was to educate Skipton members about retrofit and associated processes while trialling a "with you all the way" retrofit service for the private homeowner market. Energy efficiency measures (EEMs) for the property included loft, ground floor and cavity wall insulation, triple-glazed windows, double-glazed patio doors, solar panels (PV) with a battery, an air source heat pump (ASHP), and ventilation upgrades. The work was completed over 12 weeks between August and November 2024.

This research comprises two elements: first, pre- and post-retrofit building fabric tests, and second, interviews with key project stakeholders to understand the retrofit process. Taken together, we discuss the effectiveness of multiple building fabric EEMs, which of those EEMs are most effective for this property, and the challenges faced by stakeholders when surveying residential properties then designing, installing and evaluating appropriate retrofit measures.

Pre-retrofit, the energy performance certificate (EPC) score for 49RR was 58 (D rated), slightly below the national average of 60, making the house a fitting case study to investigate potential improvements from EEMs. However, EPCs only give a rough estimate of a building's thermal performance. For this project, LBU conducted several detailed tests to determine the impact of installed EEMs on the building fabric. Tests determined the overall heat loss, airtightness testing for air leakage, U-value measurements (the rate of heat transfer through individual building elements), and thermal imaging to identify areas of unusual heat loss at pre- and post-retrofit stages. Pre-retrofit tests were conducted between November and December 2023, and post-retrofit tests were conducted between November and December 2024.

The heat transfer coefficient (HTC) describes the overall heat loss of a property. The lower the HTC, the less heat is lost from the inside to the outside of the property. The pre-retrofit HTC of 322±15 W/K measured at 49RR is typical for a property of this age and size. The building fabric EEMs have reduced overall heat loss by 175±17 W/K, amounting to approximately a 54% reduction. The retrofits have reduced air permeability by 5.4±1.3 $m^3/(h.m^2)$@50Pa, amounting to approximately a 47% reduction and drastically reducing the amount of heat lost through air leakage. All elements achieved considerable reductions in U-values. The U-values for the floor, ceiling, walls and fenestrations (windows and doors) fell by 80%, 77%, 67% and 45%, respectively. The post-retrofit EPC score for 49RR was 87 (B rated) which is higher than the median EPC score for a newly built home.

The project was highly successful in improving the energy efficiency of 49RR. While many innovative and complex insulation retrofits exist, the building fabric EEMs installed here were simple. The energy savings achieved are encouraging and suggest significant savings can be made by installing basic fabric measures **to a high standard**. The area where retrofit activity needs to be strengthened, therefore, is not in the debate over technologies and materials but in how to ensure quality installations are carried out in a way that meets specific property and household requirements. The success of the 49RR project provides evidence that retrofit, alongside renovation, offers a viable opportunity to decarbonise Skipton's and other providers' loan books.

Over the project's duration, stakeholders described the impacts of around 50 key decisions, the majority needing to be made by Skipton as the “homeowner”. Decisions before and after the construction and installation stage were largely made by Skipton's Group Sustainability Team, but during the construction and installation stage, Skipton's Building Shared Services Team assumed greater responsibility in influencing decisions based on their expertise. This suggests that diverse competencies are required at specific stages of a larger or more complex retrofit project. While one of the project's objectives was to trial a retrofit provider’s "with you all the way" service, Skipton as a business entity could not replicate a homeowner's journey.

Six distinct themes were identified from stakeholder interviews encompassing, client, design, project management and delivery perspectives. These themes have different questions associated with them, and different priorities to be addressed, at different stages of the project. The themes are:

- **All retrofit projects will entail risks and uncertainties** which are inevitable in undertaking work that changes an existing building.

- **While achieving a reduction in bills is perceived to be the primary customer concern, retrofit projects cannot clearly guarantee this saving.** Energy bills are affected by tariffs and energy costs, suggesting an emphasis on the wider merits of retrofit, such as noise reduction and health benefits through improving comfort levels, and, potentially, increasing a property’s value.

- **Retrofit work needs to be positioned as part of a programme of home improvement and repair,** where the value might also be achieved in terms of increasing usable space or dealing with other challenges in the property, such as damp.

- There are many people involved in a retrofit project or programme, so mapping **who does what, and who knows what**, providing a general pattern of who is advising the homeowner and who is managing the risks of different stages is essential.

- **Comprehensive, and comprehensible, communications** are required throughout the project or programme. Setting homeowner expectations about disruption, what activities happen when, with what result, and how any inevitable changes to the programme will be decided upon and managed is also crucial.

- **Project handover and post-completion support for customers** in getting the most value and comfort from their retrofitted homes is vital; retrofit improvements do not end when the contractors’ vans leave.

Based on these evidence-driven insights, the final section of the report offers suggestions for further action that Skipton and the wider Group could take to increase customer retrofit action thereby reducing the carbon intensity of Skipton’s loan book.

Further Actions

Support and guidance to customers, potentially as part of cross-sector collaboration which Skipton could spearhead, could include:

Developing a full retrofit / renovation plan and deciding if this is most achievable measure by measure, room by room or all at once as a 'whole house retrofit'.

Navigating the complexities of their specific project. Four useful tools were identified in this research:

- A checklist that enables the customer to appreciate the complexities of the project and, as well as strategies for dealing with issues as they arise,
- A platform or app which acts as the single source of information and reference point for decisions (and implications of those decisions) during project delivery
- A map of "who does what" (and why) in renovation.
- A further checklist for handover and what happens post-completion.

Providing **an accessible portal for homeowners to get advice on current funding grants and incentives,** searchable by location as well as technology type and property type, and tenure.

Stating with confidence **that retrofit does improve energy performance of homes, if it's done with attention to detail and quality**. However, financial payback cannot always be assured as there are too many other variables which affect energy bills. Energy efficiency could be positioned as a side benefit from going about home improvement in a way that makes the home more comfortable, usable or valuable, reflecting homeowner priorities.

Two considerations are identified to make new financial products for retrofit effective, in addition to the existing lending assessment criteria. First, reflecting the uncertainties of retrofit / renovation loans could automatically include a contingency based on checklists of risks known to arise once a project is on site. Second, loan products and associated repayments could include professional fees for effective scoping, design, project management and evaluation into the overall project cost, as using professional expertise reduces the risk in achieving the intended project outcomes.

Developing mechanisms which unlock a greater scale of retrofit and carbon reduction should also be explored, such as identifying opportunities to group properties which could benefit from retrofit and work with designers/contractors to package these up into more cost-effective projects, connected to a programme of financial support. Such packages of activity might be area-based, and developed in collaboration with local or combined authorities, taking the learning from social housing decarbonisation into the private owner-occupier market. While the focus of this research is private homeowners, a bespoke product offer for landlords may also be worth evaluating.

The need to find mechanisms to position retrofit as part of a programme of home improvement work has been a repeated theme in this research. A suggested approach is to explore how a retrofit plan might become part of the property sale process, expanding on the EPC into a more meaningful list of actions, opportunities and possible benefits, as a standard part of purchasing a property, similar in cost to the HomeBuyer Report.

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List of abbreviations

49RR	49 Regent Road, Skipton
AECB	Association for Environment Conscious Building
ASHP	Air Source Heat Pump
EEM(s)	Energy Efficiency Measure(s)
EnerPHit	Passive House retrofit standard
EPC	Energy Performance Certificate
ESCO1	External Stakeholder Contractor Organisation 1
ESCO2	External Stakeholder Contractor Organisation 2
ESG	Environmental, Social and Governance
ESRPO	External Stakeholder Retrofit Provider Organisation
GCH	Gas Central Heating
HFP	Heat Flux Plate
HTC	Heat Transfer Coefficient
JCT	Joint Contracts Tribunal
LBU	Leeds Beckett University
MCS	Microgeneration Certification Scheme
O&M	Operations and Maintenance
PAS	Publicly Available Specification
PHPP	Passive House Planning Package
PV	Photovoltaic
RAO	Retrofit Architect Organisation
RdSAP	Reduced data Standard Assessment Procedure
RIBA	Royal Institute of British Architects
Skipton	Skipton Building Society
SME	Small and Medium-sized Enterprise
UoL	University of Leeds
VAT	Value Added Tax
WSGO1	Wider Skipton Group Organisation 1
WSGO2	Wider Skipton Group Organisation 2

1 Introduction

1.1 This research

This report presents the findings of a research programme by Leeds Beckett University (LBU) and the University of Leeds (UoL) as part of Skipton Building Society's (Skipton) Big Retrofit project at 49 Regent Road (49RR), Skipton. In December 2023, stakeholders Skipton, Wider Skipton Group Organisation 1 (WSGO1), Wider Skipton Group Organisation 2 (WSGO2), External Stakeholder Retrofit Provider Organisation (ESRPO), and Retrofit Architect Organisation (RAO) formally began working on the Big Retrofit project. In summer 2024, External Stakeholder Contractor Organisation 1 (ESCO1) and subcontractor External Stakeholder Contractor Organisation 2 (ESCO2) joined the project team.

This report is divided into five sections. This section introduces the 49RR project. Section 2 outlines the results of the pre- and post-retrofit building fabric tests. Section 3 presents the findings from interviews with key project stakeholders to understand the retrofit process as they experienced it. Section 4 discusses the effectiveness of multiple energy efficiency measures (EEMs), which EEMs are most effective for this property, and the challenges faced by stakeholders when assessing, designing, installing, and evaluating retrofit measures, leading to suggestions for further action that Skipton and the wider Group could take to support customers in improving their homes and reducing the carbon intensity of Skipton's loan book.

1.2 Project overview

The project unfolded over five stages:

1. Concept development and scoping;
2. Design, project planning and tendering;
3. Receiving tenders and confirming the project plan;
4. Construction and installation; and
5. Commissioning and post-completion.

We have collated stakeholders' accounts of their experiences and compiled the following overview of the project.

Concept development and scoping

In 2022, Skipton's Building Shared Services Team explored remodelling 49RR as an eco-home of the future, as the property required maintenance. Architects who had worked with Skipton were appointed to propose options for the property. The Group Sustainability Team became involved but were unsure about the brief, costs, and how the effectiveness of energy efficiency improvements might be measured. Project responsibility was transferred to the Group Sustainability Team, and in autumn 2023, they began discussing retrofits with wider Group colleagues (WSGO1 and WSGO2) and external stakeholders (LBU and UoL).

WSGO2 familiarised Skipton colleagues with their retrofit service and WSGO1 introduced ESRPO's "with you all the way" service under development. The Group Sustainability Team explored the PAS 2035[1] process which includes post-retrofit evaluation and is routinely used for social housing upgrades. As the architect had no experience of using this standard, they were not involved in further project development.

The project aim changed from remodelling 49RR to educating members about retrofit by simulating a customer's journey using ESRPO's service. In October 2023, the Group Sustainability Team successfully presented a paper for the project to Skipton's Group Executive Committee. The project was approved and to mitigate the risks associated with trialling this new service, the Group Sustainability Team appointed an architect to also pursue a traditional retrofit pathway. WSGO1 recommended RAO as they were Passivhaus designers with experience in designing domestic retrofit projects.

The Group Sustainability Team appointed LBU and UoL to measure the impact of the retrofit measures and to support the research and educational aims of the project. Before the design work started, LBU conducted pre-retrofit building fabric tests.

Design, project planning and tendering

During the design stage, between 15 December 2023 and 31 May 2024, Skipton and stakeholders explored broad options for the house which culminated in tender packs being issued to contractors. The design brief focused on two questions: What environmental performance standards should Skipton aim for? And, what should be included in general home improvement works? To speed up decision-making, a member of the Group Sustainability Team became the nominal "homeowner" to represent the customer. The design options comprised EEMs and general refurbishment works.

Multiple stakeholders surveyed the house at the design stage to gather information, with inevitable duplication of work. WSGO2 and WSGO1 produced an initial energy performance certificate (EPC). RAO conducted a feasibility study and in January 2024, the property was valued at £335,000.

For the environmental standards, RAO modelled three potential outcomes to achieve: EPC Band 'C'[2], AECB level 2[3], and EnerPHit[4]. Routes to achieving these outcomes were modelled using the Passive House Planning Package (PHPP). WSGO1 conducted a PAS 2035 retrofit assessment, establishing heat loss calculations, which ESRPO used to model the house in RdSAP[5] with the aim of achieving an EPC Band 'C'.

For general refurbishment work, Skipton considered options for the garage, chimney removal, and roof replacement. Skipton stakeholders also discussed how to improve accessibility if the house was used as a showcase post-retrofit.

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[1] https://www.bsigroup.com/en-GB/insights-and-media/insights/brochures/pas-2035-retrofitting-dwellings-for-improved-energy-efficiency/
[2] https://energysavingtrust.org.uk/advice/guide-to-energy-performance-certificates-epcs/
[3] https://aecb.net/aecb-carbonlite-retrofit-standard/
[4] https://www.passivhaustrust.org.uk/competitions_and_campaigns/passivhaus-retrofit/
[5] https://bregroup.com/documents/d/bre-group/rdsap_2012_9-94-20-09-2019

RAO and ESRPO proposed nearly identical EEMs. However, there were divergences between both proposals as both aimed for different standards (AECB level 2 and EPC Band 'C') and had different costs as they used different software packages to predict performance. For example, both specified different sizes of hot water tank and heat pump.

The workstreams of RAO and ESRPO overlapped and then converged to meet an agreed performance target of EPC Band 'B'. The pros and cons of each measure's contribution to achieving this standard were explored. Cost, performance and "what would a homeowner do?" were all considered, but cost was the primary driver. This formed the basis of the tender specification.

The scope of works included the following:

Energy efficiency measures (EEMs)

- Loft insulation top up
- Install photovoltaic panels and battery
- Insulate cavity walls
- ASHP and new radiators
- Insulate under the suspended timber ground floor
- Change windows and insulate using airtight measures
- New bathroom and kitchen extractor fans

General works

- Reroof with breathable membrane
- Strip out and block up chimney
- Car charging point

ESRPO used the contractor framework associated with their service to select and contact contractors. In the tender return documentation, Skipton requested cost estimates for double- and triple-glazing options, itemised for easy comparison by stakeholders. RAO's detailed specification was sent to four contractors for pricing. ESRPO's specification was sent to a fifth contractor as a price comparison exercise.

Receiving tenders and confirming project plan stage

The tender return deadline for interested contractors was 31 May; however, it was extended into June. At the end of June, ESCO1 was appointed as the successful contractor. Before this, Skipton and ESCO1 carried out a value engineering (VE) exercise to change the specification and reduce the overall cost, as ESCO1's tender was over Skipton's budget. After reviewing the drawings and specifications, ESCO1 proposed cost-saving measures to Skipton and offered ongoing recommendations during the construction phase.

Construction and installation stage

Construction work commenced on 27 August 2024. On site, several unanticipated findings within the house, such as discovering asbestos, resulted in stakeholders having to make changes and approach measures differently. In addition, some design assumptions were different when explored on-site, meaning that anticipated changes like moving an internal wall were unnecessary. Unanticipated extras were added to the scope of works during the construction stage, such as replacing the kitchen. In October 2024, Skipton stakeholders successfully requested more funds from Skipton's Board to increase the budget. The property was handed back to Skipton on 15 November 2024.

Commissioning and post-completion stage

After completing the works, ESCO1 showed Skipton colleagues how to use the new technology and recording the operating instructions in videos for future reference.

Between the end of November 2024 and the middle of January 2025, LBU conducted post-retrofit fabric tests, and WSGO2 carried out and lodged a post-retrofit EPC. WSGO1's retrofit coordinator completed the post-construction inspection for ESRPO's final report.

The Group Sustainability Team appointed an interior dresser. Their role was to style the interior design of the house re-using existing furniture where possible and buying new where it was not. They also selected paint colours and floor finishes.

Commissioning the new technology so that it could be monitored remotely was more challenging than anticipated, as the house had no ready access to broadband internet. The Building Shared Services Team was unable to move the home onto a more favourable electricity tariff, as a homeowner would, as Skipton buys their electricity in bulk. At the time of data collection, Skipton was addressing both issues.

Finally, after all data collection had taken place, 49RR was valued by two additional Wider Skipton Group Organisations and two local estate agents. The four valuations ranged between £390,000 and £479,000.

2 Fabric tests

2.1 Introduction

This section describes the findings from a programme of building fabric tests, performed by Leeds Beckett University. Fabric tests were conducted in two stages, one pre-retrofit and one post-retrofit. Pre retrofit tests were conducted between 17 November 2023 and 18 December 2023, and post-retrofit tests were conducted between 28 November 2024 and 20 December 2024. Figure 1 and Figure 2 show the front façade and floorplans of 49RR.

Figure 1. 49 Regent Road pre-retrofit, (November 2023).

Figure 2. Original floorplans (From RAO, Existing Plans).

Pre-retrofit, the EPC certificate described the home as having a score of 58 (D rated). This placed the home slightly below the national average of 60, making it a fitting case study to investigate the potential improvements that can be gained by retrofits on a typical home. The post-retrofit EPC score for 49RR was 87 (B rated) which is higher than the median EPC score for a newly built home. However, standard EPCs only give a rough estimate of a building's thermal performance. This project therefore conducted several detailed tests to determine the impact of any measures which were installed. These tests included a coheating test to determine the overall heat loss, U-value measurements to determine heat loss of individual building elements, airtightness testing to determine the air leakage of the property, and thermal imaging to identify areas of unusual heat loss.

2.2 Overall building performance

The overall thermal performance of a home is described by its Heat Transfer Coefficient, or HTC. The HTC describes the heat energy required to maintain a single degree of temperature difference between the external and internal environments, and takes units of Watts per Kelvin (W/K). Measurement of the HTC can be achieved via several methods, the most robust and accurate of these methods is widely agreed to be the coheating test.

The coheating test measures the HTC by heating the internal environment to an elevated temperature, typically above 20°C, using electric heaters. The power required to maintain this temperature is monitored, alongside the internal and external temperature. In addition to the heaters, circulation fans are used to increase the air mixing and therefore remove potential cold air zones. The average difference in temperature and the power used over a 24-hour period can then be used to estimate the HTC. However, due to variability introduced by the sun and weather, it is protocol to conduct the coheating test over a prolonged period, typically in excess of 21 days. The average power and temperature difference for each day is then calculated, and a linear regression performed to account for environmental effects. The gradient of the resulting line is then equal to the HTC.

Figure 3 shows the HTC of the property before and after retrofit. The pre-retrofit HTC of 322±15 W/K is relatively high compared to modern homes, which typically have HTCs less than 100 W/K. However, for a home of this age and construction, an HTC of this value is to be expected. The retrofit measures have more than halved this figure, reducing the HTC by 175±17 W/K.

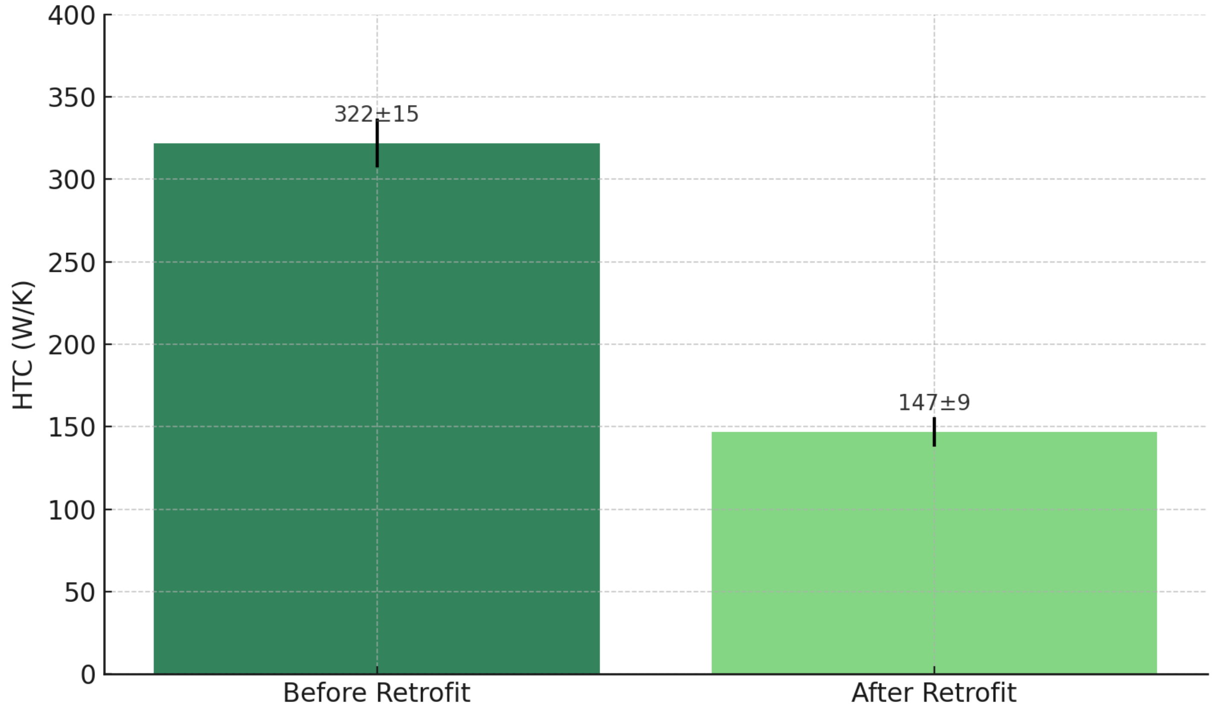

Figure 3. Measured HTC of 49RR, before and after EEMs.

2.3 Thermal imaging observations

Thermal images provide valuable, qualitative information on heat loss in a property. Thermal imaging cameras are sensitive to light in the infrared spectrum, which indicates how much heat is radiating off a surface. If conducted externally, any warmer areas on a thermal image therefore show locations where heat is likely escaping. If conducted internally, the reverse is true – any warmer areas show where heat is being retained, and instead cooler areas are locations where heat is escaping.

Thermographic surveys were conducted on 49RR both pre and post retrofit. The full results of these surveys are available in the separate reports (See Annex 2 and Annex 3). Below, the results are compared to determine any apparent impacts of the work carried out. These images were taken under natural conditions (i.e. with no induced pressure differential) and therefore represent heat loss which could be expected in a lived-in state.

External observations

Pre-retrofit, a warm strip was visible at the eaves (Figure 4). This warm strip was significantly reduced post-retrofit (Figure 6). Additionally, heat loss through a filled-in window in the dining room was very apparent pre-retrofit (Figure 5). Post retrofit, this has been reduced to the point of almost being undetectable in the thermal images (Figure 7).

On the North side façade at the eaves junction, two warmer spots remain (Figure 6), possibly the sites of old air bricks. These are only now visible as the rest of the eaves junction has improved significantly, previously the whole junction showed up as warmer.

<table>
<tr><th>Pre-retrofit</th><th>Post-retrofit</th></tr>
<tr><td>

Figure 4. Warm strip visible at the eaves
(For more detail, see page 73)

</td><td>

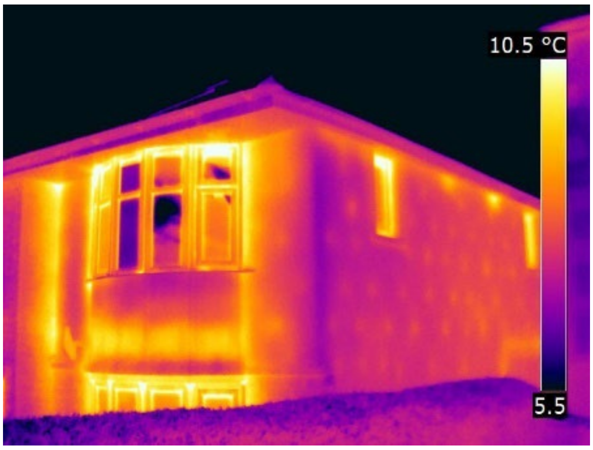

Figure 6. Warm strip no longer visible but heat loss through two points along that wall is now visible
(For more detail, see page 90)

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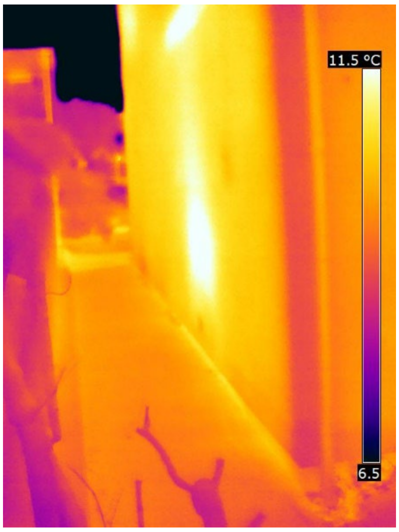

Figure 5. Filled in window visible on the external wall
(For more detail, see page 73)

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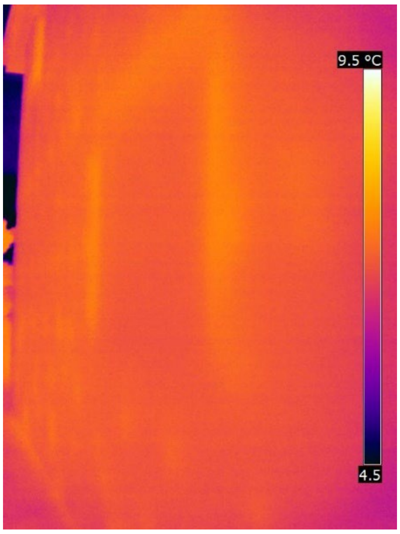

Figure 7. Filled in window barely visible
(For more detail, see page 93)

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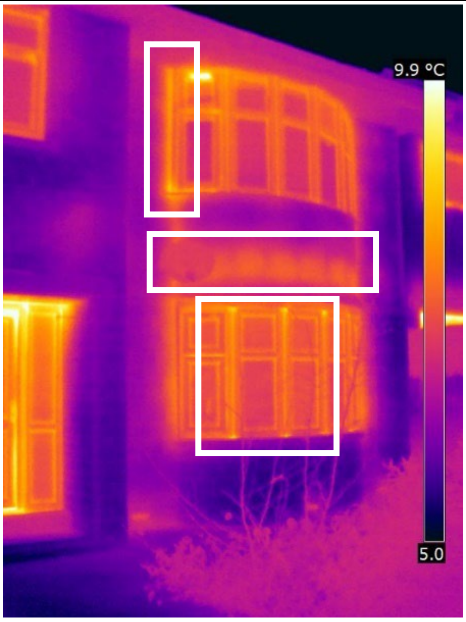
Post-retrofit, issues were noticeable around the bay windows in three areas (Figure 9). First, warmer strips at the jambs are potential thermal bridges, with the edge frame units positioned in line with the outer leaf of the external wall rather than with the cavity and insulation layer (area illustrated by top white box). Second, the mullions between each window glazing unit appear warmer than the actual window frames (see bottom white box). Last, the bay wall appears warmer than other external wall surfaces at intermediate floor level, but not at the ground floor level (see middle white box). However, it should be noted that these issues appear to all have existed pre-retrofit as well, but they were harder to see as heat loss through the external walls was greater, masking the effect. As the walls are now better insulated, these areas of heat loss are clearly evident (Figure 8).

Pre-retrofit	**Post-retrofit**
 *Figure 8. Heat loss through external walls and bay windows visible*	 *Figure 9. Heat loss still noticeable around parts of the bay window (For more detail, see page 90)*

Prior to retrofit, warmer areas were visible above the front door (Figure 10 and Figure 12). Post retrofit, this warm strip remained (Figure 11) and still displayed the warmest surface temperatures visible on the front elevation (besides warm air exiting through the trickle vent in the upstairs bay window). However, the absolute temperature of this strip was lower post-retrofit.

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<tr><th>Pre-retrofit</th><th>Post-retrofit</th></tr>
<tr><td>


Figure 10. Heat loss visible above front door
(For more detail, see page 74)
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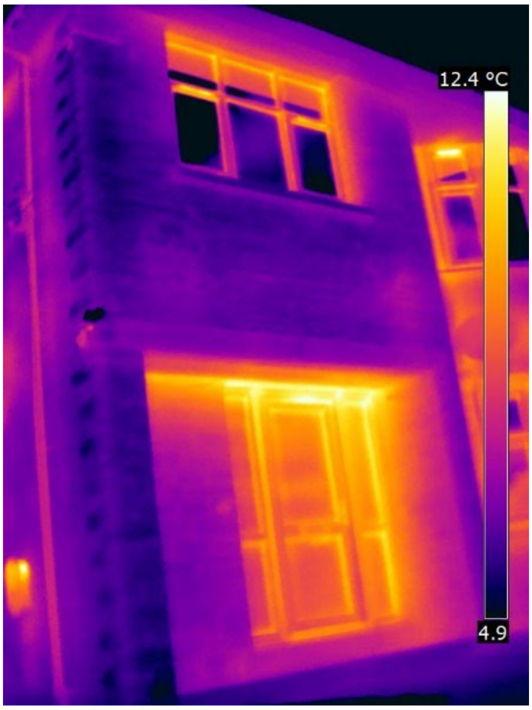

Figure 11. Heat loss still visible above front door
(For more detail, see page 90)
</td></tr>
<tr><td>


Figure 12. Close up of heat loss visible above front door
(For more detail, see page 74)
</td></tr>
</table>

The previous patio door frame appeared to perform particularly poorly from a thermal perspective (Figure 13), the replacement performed markedly better (Figure 14). Some thermal bridging was observed around the ground floor perimeter (Figure 15), but again this did not appear excessive. Interestingly, a warmer area became visible on the rear elevation, where there appeared to have been a previous doorway, now filled in (yellow rectangle on Figure 15). This area was likely missed by the cavity wall insulation, though its small area means it will not contribute considerably to the heat loss of the property.

<table>
<tr><th>Pre-retrofit</th><th>Post-retrofit</th></tr>
<tr><td>


Figure 13. Heat loss visible through patio door
(For more detail, see page 73)
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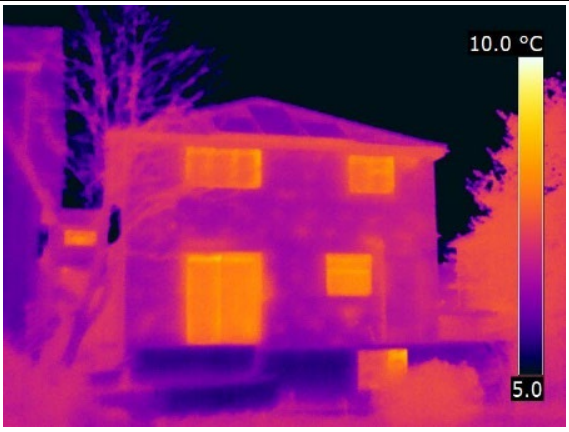

Figure 14. Less heat loss visible through new patio door
(For more detail, see page 92)
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<tr><td></td><td>


Figure 15. Heat loss through thermal bridging between walls and floor visible along with warmer rectangular area associated with a previous doorway
(For more detail, see page 93)
</td></tr>
</table>

Loft Thermal Images

Pre-retrofit, the loft hatch was uninsulated and unsealed, appearing to consist of just a sheet of MDF (Figure 16). The loft hatch was replaced with a proprietary insulated hatch, with boxing to allow insulation to be properly fitted (Figure 17).

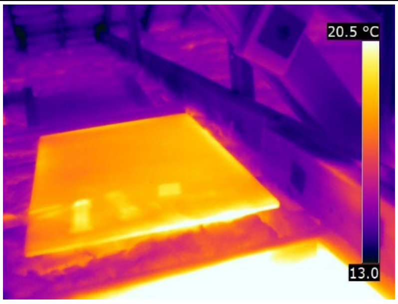
<table>
<tr><th>Pre-retrofit</th><th>Post-Retrofit</th></tr>
<tr>
<td>

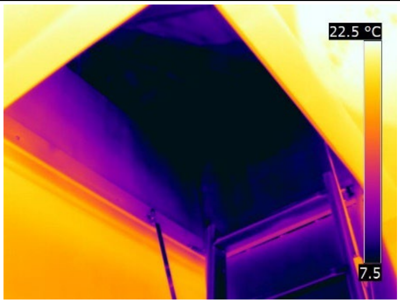
Figure 16. Uninsulated loft hatch
(For more detail, see page 74)</td>
<td>

Figure 17. New insulated loft hatch
(For more detail, see page 94)</td>
</tr>
</table>

Pre-retrofit, loft insulation was compressed in many areas by boards lying on the surface (Figure 18). Breaks in insulation occurred where deeper joists ran and where the blockwork for internal partition walls extended through it. The water tank above the bathroom was covered with a polythene covered insulation quilt, but there appeared to be no insulation beneath it. Insulation had been moved away from the bathroom downlighters to prevent them overheating, consequently leaving areas of uninsulated ceiling (Figure 20).

Post-retrofit, with the water tank now removed and new decking covering the downlighters there was little to observe in the loft. The insulation appeared even and fitted right up to the eaves, with just a few warmer areas around the ceiling junctions with trusses (Figure 19).

<table>
<tr><th>Pre-retrofit</th><th>Post-Retrofit</th></tr>
<tr>
<td>

Figure 18. Boards compressing insulation</td>
<td rowspan="2">

Figure 19. Less heat loss visible as insulation fitted into eaves where possible
(For more detail, see page 94)</td>
</tr>
<tr>
<td>

Figure 20. Uninsulated areas of loft
(For more detail, see page 76)</td>
</tr>
</table>

Kitchen

Pre-retrofit, air leakage was detected around the kitchen door frame and between the door and frame (Figure 21). Post-retrofit, this was considerably reduced (Figure 23). The rear threshold displayed the lowest surface temperatures in the kitchen, potentially low enough to be a condensation risk without adequate ventilation. Likewise, the external floor/wall junction in the utility room showed a major infiltration pathway pre-retrofit, with air emerging under the skirting flowing underneath the lino floor covering (Figure 22). The retrofit appears to have reduced this impact, though the external floor/wall junction still appears noticeably cooler (Figure 24).

Interestingly, the interior of one of the cupboards shows low surface temperatures (Figure 25). This location corresponds to the suspected filled-in doorway (see Figure 15) which appeared as much warmer in the external thermography. This effect was not picked up on in the pre-retrofit survey, suggesting it is a new phenomenon. As the surrounding external wall is now warmer, this cupboard, which is against a colder part of the wall may present a condensation risk if not well ventilated.

<table>
<tr><th>Pre-retrofit</th><th>Post-Retrofit</th></tr>
<tr><td>

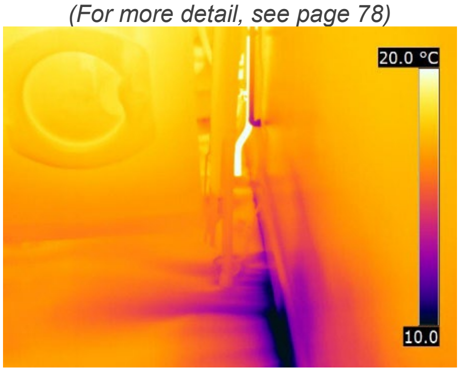

Figure 21. Air leakage visible around kitchen door frame (For more detail, see page 78)


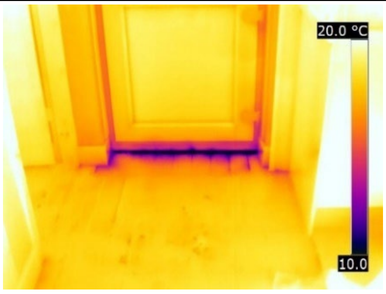
Figure 22. Air leakage between utility room wall and floor (For more detail, see page 79)
</td><td>


Figure 23. Reduced air leakage around kitchen doorway although door threshold is at a lower temperature (For more detail, see page 94)

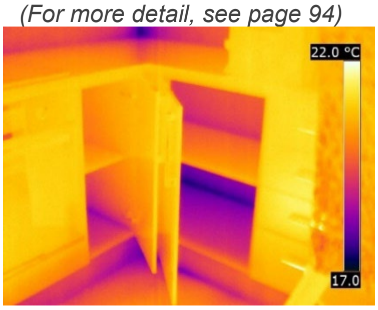
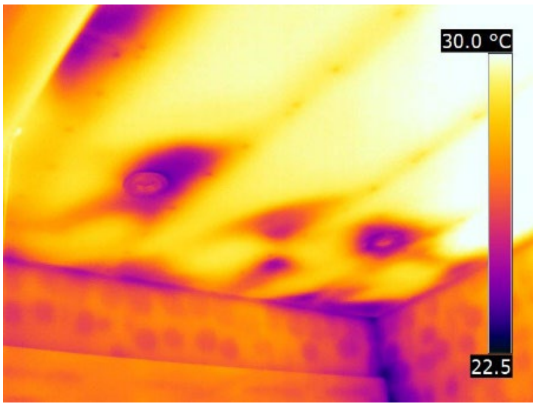
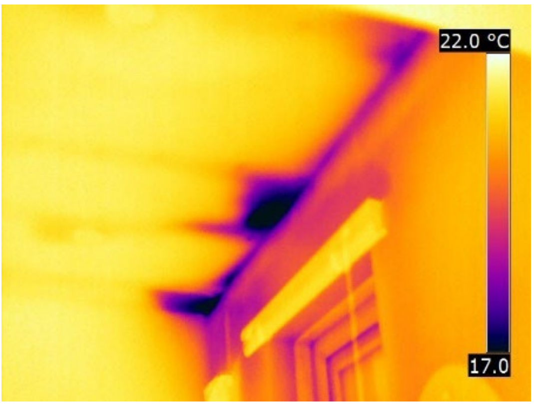
Figure 24. Reduced utility room air leakage but heat loss still occurring (For more detail, see page 94)


Figure 25. Lower temperature of kitchen cupboard could present condensation risk (For more detail, see page 94)
</td></tr>
</table>

First floor ceiling

Pre-retrofit, the WC ceiling showed an uninsulated area around the downlighters and where insulation in the loft had been rolled back. Likewise, gaps in loft insulation around downlighters and underneath the water tank in the loft (see Figure 20) were apparent the bathroom (Figure 26 and Figure 28). Post-retrofit, the WC ceiling showed cooler areas at the eaves suggesting that while heat loss has reduced along this junction, the new loft insulation does not fully extend to the eaves (Figure 29 and Figure 19). Gaps in loft insulation around the downlighters and underneath the water tank in the loft had been resolved. The external corner in the bathroom is visibly the coolest surface area. This is not surprising as the shape of the hipped roof makes this corner extremely difficult to insulate.

Pre-retrofit	Post-Retrofit
 *Figure 26. Heat loss around the downlighters and hot water tank in the loft above* *(For more detail, see page 81)*	 *Figure 27. Cool surfaces in the corner of the bathroom where two external walls meet the roof* *(For more detail, see page 98)*
 *Figure 28. Heat loss visible along the wall to ceiling junction* *(For more detail, see page 81)*	 *Figure 29. Some heat loss still visible along the wall to ceiling junction* *(For more detail, see page 98)*

2.4 Airtightness and air leakage pathways

2.4.1 Overall airtightness

Homes require some degree of air exchange with the outside environment. Such exchange allows the moist air from cooking, bathing etc. to be removed and thus reduces the risk of damp and mould. However, air exchange also involves losing heat. Energy efficient properties manage air exchange by installing purpose-built ventilation such as extraction fans and cooker hoods to expel moist air, while sealing up any uncontrolled sources of ventilation such as gaps around windows and floors.

Older properties are notorious for possessing many air infiltration pathways, which often manifest in draughts and in residents feeling cold. To assess the levels of airtightness of 49RR, blower door tests were conducted. A blower door test involves opening an external door and replacing it with a membrane in which a powerful fan is hung. With purpose provided ventilation (such as extraction fans and trickle vents) temporarily sealed, the fan is switched on and the property either becomes pressurised or depressurised, depending on which way the air is flowing. By monitoring the air flow going through the fan and the pressure differences between the inside and outside, a measure of how much uncontrolled air is being forced through gaps in the building fabric is obtained; this is the building's airtightness.

Pressurisation tests were undertaken on 49RR on 17 November 2023, and again on 20 December 2024. The blower door test was conducted under both depressurisation (when air is drawn out of the house) and pressurisation (when the fan pushes air into the house). The mean air permeability[6] before and after the retrofits is shows in Figure 30. For context, new-build homes require an air permeability of below 8 $m^3/(h.m^2)$@50Pa for building regulations compliance. The value obtained for 49RR pre-retrofit suggests it was over-ventilated, wasting both heat and energy. The retrofit has decreased unwanted air infiltration to almost half of the original figure.

[6] Air permeability is the air movement into or out of a building at a defined pressure (in this case 50 Pascals) per m^2 of building envelope area. Mean air permeability is the average of both pressurisation and depressurisation tests.

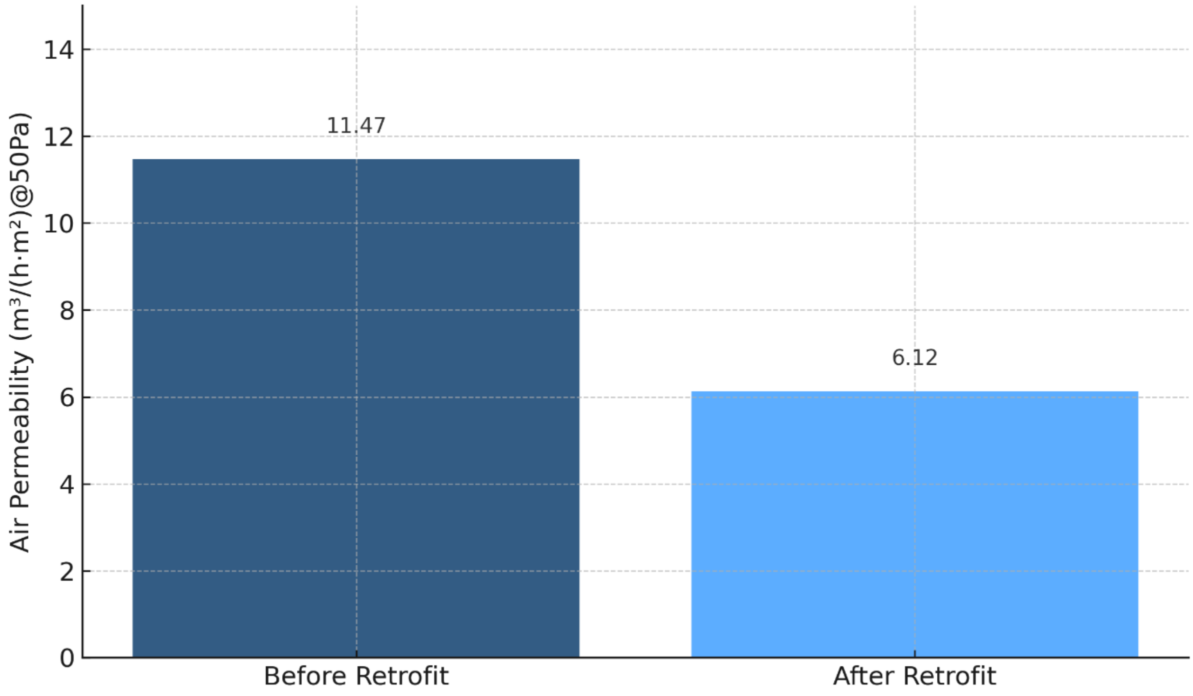


Figure 30. Blower door test results before and after retrofit.

One output from the blower door test is a flow exponent[7], which can indicate what sort of gaps the air is escaping from. In 49RR, an exponent of n=0.607 was measured pre-retrofit. This value indicates that air leakage was dominated by direct paths through open cracks and gaps rather than permeating through materials as values of n<0.65 are generally assumed to represent buildings where direct airpaths dominate throughout the range of airtightness test measurement pressures. It was also noted that airtightness was slightly better under depressurisation than pressurisation, possibly due to the outward opening windows and non-draught-stripped loft hatch being pulled closed under depressurisation. Post-retrofit, the flow exponent had changed to n=0.677. This suggests that a lower proportion of the air leakage was now direct leakage through cracks and gaps in the fabric and a higher proportion permeating through porous materials and more complex leakage pathways.

It is possible to convert a value of air permeability to an approximate value for heat loss attributable to air leakage[8]. On 49RR, this conversion results in a value of approximately 27±3 W/K. However, this conversion relies on several assumptions which, while correct as an average over many measurements, can vary considerably when studying a single home. Therefore, while individual values of heat loss derived from airtightness measurements can be a useful indicator, they should be treated with some caution.

[7] The flow exponent “n” where 0.5<n<1.0; n=0.5 indicates air flow with minimal resistance, n=1 indicates turbulent airflow.
[8] BRE. “The Government’s Standard Assessment Procedure for Energy Rating of Dwellings,” 2012. https://files.bregroup.com/SAP/SAP-2012_9-92.pdf. Page 179.

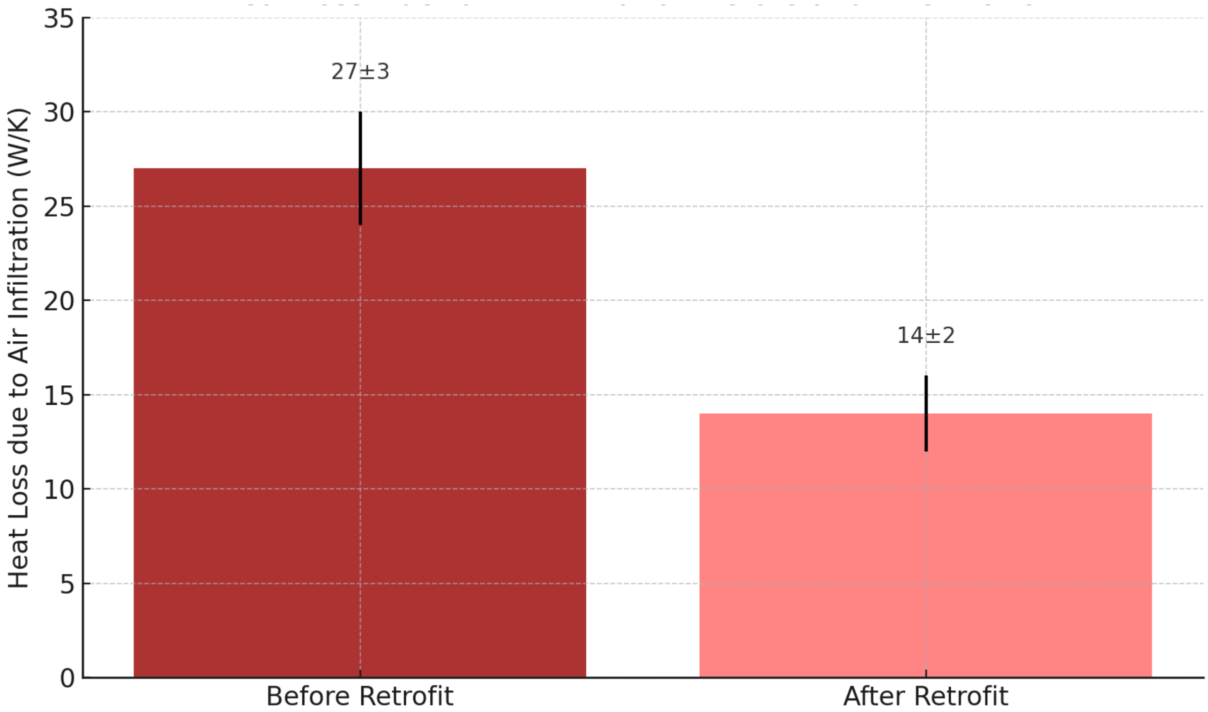


Figure 31. Heat loss due to air infiltration before and after retrofit

2.4.2 Air leakage pathways

Conducting thermal imaging during a blower door test can reveal the primary air leakage pathways. Thermographic leakage detection was therefore undertaken immediately following the depressurisation phase of the blower door tests. The main air leakage pathways identified pre retrofit are described below.

Pre-retrofit, the main direct air leakage paths to outside were detected at penetrations, through and around openings, through the suspended floor void and into the loft void; the main indirect leakage paths identified were through boxed-in services and into the voids behind kitchen units.

Post-retrofit leakage detection revealed that many of the same leakage paths remained but had been significantly reduced either in severity or size of area affected. Significant improvements in direct air leakage were seen around service penetrations particularly the downlighters, and around and through the windows and doors although the trickle ventilators did not appear to close effectively. Also, air movement through the suspended timber ground floor was significantly reduced around the centres of rooms but remained around many room perimeters (see Figure 32) and below the staircase. Indirect air movement had not been addressed, with air movement through the intermediate floor void linking different points of air leakage with gaps in the building envelope some distance removed; one such example being air entering around the air brick above the kitchen window that could be traced under dwelling depressurisation across the bathroom floor to emerge at the landing floor (Figure 33).

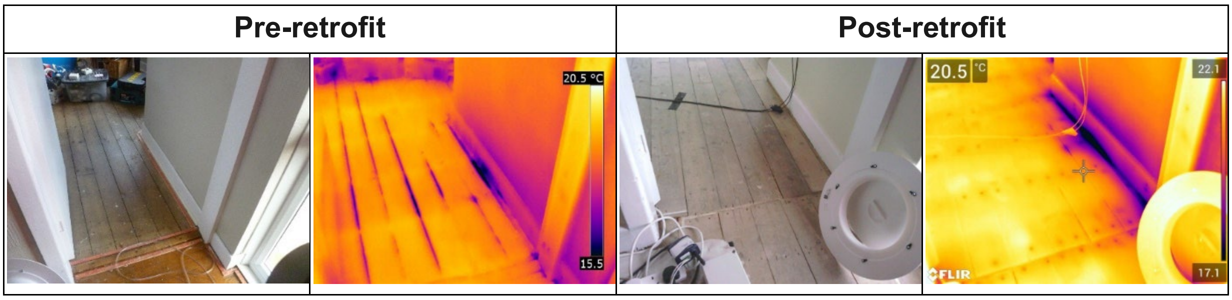


Figure 32. Air infiltration (under dwelling depressurisation) at the lounge floor before and after retrofit.

Figure 33. Air infiltration (under dwelling depressurisation at the post-retrofit stage) passing through the intermediate floor void and emerging on the landing.

2.5 Walls

The external walls of a detached property typically represent the greatest area which is exposed to the outside. Poorly performing walls can therefore contribute a large amount to overall heat loss. To assess the extent at which the walls lose heat, U-values were measured. A U-value is a measure of how easily heat passes through an individual building element. They are described per m^2 of a building material, and therefore take units of W/m^2K, the lower the U-value the better it is at reducing heat loss.

U-values were measured using Heat Flux Plates (HFP). These are small discs which attach to the element under study and measure the amount of heat passing through them. This information, combined with the internal and external temperatures, allows for the calculation of U-values.

Walls are notoriously heterogeneous building elements – one section of wall may have different surface covering, moisture content or air gaps to another section of wall. These differences can manifest in different U-values being measured for different areas. To account for this, thirteen measurements were taken at different locations around the house. The results from twelve of these plates is shown in Table 1. Note that the number following the ± symbol denotes the uncertainty on the figure. This uncertainty describes how precisely we were able to measure the value.

Table 1. U-Values recorded by wall Heat Flux Plates

Element	U-Value Pre-retrofit (W/m^2K)	U-Value Post-retrofit (W/m^2K)
Front room wall	2.0±0.2	0.8±0.1
Front room wall	2.1±0.2	0.6±0.1
Front room wall	1.7±0.2	0.6±0.1
Front room wall	1.6±0.2	0.5±0.1
Front room wall	1.7±0.2	0.6±0.1
Dining room wall	1.7±0.2	0.5±0.1
Dining room wall	1.6±0.1	0.5±0.1
Rear bed wall	1.8±0.2	0.5±0.1
Rear bed wall	1.8±0.2	0.7±0.1
Front small bed wall	1.8±0.3	1.1±1.1
Front small bed wall	1.5±0.4	0.5±0.1
Front small bed wall	1.8±0.2	0.5±0.1
Area weighted average	**1.7±0.1**	**0.6±0.1**

The final line in Table 1 shows the area weighted average of the individual HFP values. The pre-retrofit value of 1.7±0.1 is somewhat high for a cavity construction, though not unheard of. The post-retrofit value of 0.6±0.1 is a good result and is below the threshold in building regulations U-value for retro-filled cavity walls in existing buildings (0.7 W/m^2K).

Multiplying these U-values by their wall areas suggests that the walls contributed around 198±6 W/K of the overall heat loss of the property. After retrofit, this contribution had fallen to 64±6 W/K, representing a considerable decrease in heat loss over the whole surface.

One plate was not included in the average above. This plate was placed on an area of dining room wall which in the past contained a window, as identified from the thermal images (see Figure 34, Figure 5 and Figure 7). The construction materials used when filling in this area have a better thermal performance than the rest of the wall, and a U-value of 0.9±0.1 W/m^2K was therefore recorded in this zone pre-retrofit. Despite being lower, the retrofit works were still able to reduce this U-value, and a figure of 0.3±0.1 W/m^2K was recorded post-retrofit.

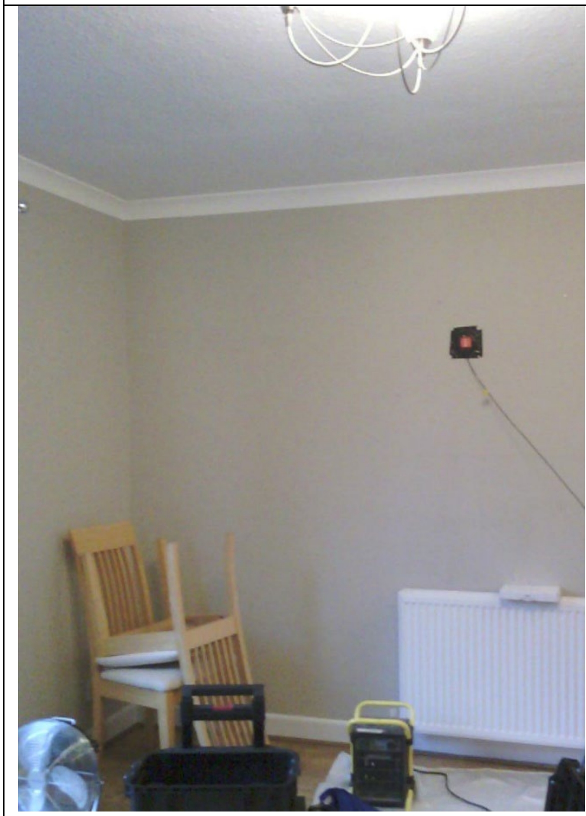
Pre-retrofit	
	

Figure 34 - Thermal image of a window opening in the dining room, now filled in and plastered over (lighter area to the right of the image)

2.6 Floors

Floors are typically one of two constructions in the UK - either a solid concrete slab, or a suspended timber floor with an air void beneath. 49RR is of the latter design. Because suspended timber floors have an air void beneath them, and because this air void is vented to the external environment, they can represent considerable heat loss. For this reason, the floor of 49RR was selected for retrofit, and U-values were measured pre- and post- works to measure the impact.

In the pre-retrofit stage, the carpet had been removed from the lounge, allowing for an assessment of the U-value of the bare floor. One HFP was placed on the “span”, such that directly below the plate and floorboards is the floor void. Another was placed on the “joist” which holds up the floor structure. Floor coverings remained in the dining room, and a further two plates were placed in these areas. However, with the presence of laminate, it was not possible to determine if the plates were on the span or joist.

Post retrofit U-values were measured in these same locations. Post-retrofit, no floor coverings were present in any of the rooms, so the dining room plates were placed with one on the span and the other on the joist.

The individual U-values derived from these plates are listed in Table 2.

Table 2. U-Values recorded by floor Heat Flux Plates

Location	Pre-retrofit U-Value (W/m^2K)	Post-retrofit U-Value (W/m^2K)
Lounge (span)	0.8±0.1	0.15±0.1
Lounge (joist)	0.8±0.1	0.34±0.1
Dining room	0.7±0.1 (laminate)	0.12±0.1 (span)
Dining room	0.6±0.1 (laminate)	0.28±0.1 (joist)
Area weighted average	**0.8±0.1**	**0.14±0.1**

Pre-retrofit, the U-values are relatively high. Interestingly, the U-value for the span and the joist are the same. It also appears as if the laminate has a slight insulative affect, as it displays slightly lower U-values. The average heat loss over the whole floor was calculated as 40±6 W/K.

Post-retrofit, the U-values have reduced considerably. The impact of the floor joists is now apparent, as they show higher U-values than the span. This is a common feature of insulated floors, but as the joists only make up a small proportion of the floor area the overall heat loss through the ground floor is not severely affected. The average heat loss over the whole floor was calculated as 8±1 W/K, suggesting the floor is now responsible for a very small amount of the overall heat loss of 49RR.

2.7 Fenestrations

Measuring window U-values using HFPs provides different results to the U-value provided by window manufacturers. HFPs measure the U-value of the clear centre pane of the glass and do not take the frame into account. Conversely, window manufacturers report the U-value for a window unit, which includes both the glass and the frame. The pre- and post-retrofit results presented here are for the clear centre pane of the glass, not the window as a unit.

Pre-retrofit, the windows and doors in 49RR were all double glazed, though their differing designs suggest they were installed at different times. It was further noted that the seals displayed differing levels of wear. As the fenestrations were to be retrofit, HFPs were placed on these elements to assess their heat loss. However, obtaining U-values from windows is more challenging that from other elements due principally to the sunlight affecting the measurements. It’s often only possible to obtain U-values from windows which are not in direct sunlight and, as such, three HFPs were placed on the centre of the windows deemed to have adequate shading. The U-values measured for these windows pre- and post-retrofit are displayed in Table 3.

Table 3. U-values measured for windows

Location	Pre-retrofit U-Value (W/m^2K)	Post-retrofit U-Value (W/m^2K)
Lounge bay window	1.9±0.1	0.7±0.3
Dining room patio door	2.6±0.2	1.1±0.1
Rear bedroom small window	1.7±0.2	1.03±0.1
Area weighted average	**1.8±0.1**	**1.0±0.2**

Pre-retrofit, some variability is apparent, though the patio door in the Dining room performs noticeably worse than the other two. It is possible that the seals on this window have failed which may have introduced air into the gap between the panes. Assuming that the patio window was unique in its performance, and that other windows have U-values of around 1.8 W/m^2K the windows and doors contribute approximately 46±4 W/K of the overall heat loss of the property.

Post-retrofit, all windows were replaced with triple glazing, with the exception of the dining room patio window, which was replaced with a new double glazed unit. The new windows appear to have reduced the heat loss through the windows in all cases, and indeed the dining room window only performs marginally worse than the triple glazed areas. The retrofit windows contribute approximately 24±8 W/K of the overall heat loss of the property.

2.8 Ceiling

Most lofts in the UK have some level of insulation, though the thickness and homogeneity of this insulation is often sub-standard. The loft was another area to be retrofit in 49RR, and HFPs were therefore applied to the surfaces.

It was noted during the pre-retrofit inspection of 49RR that the loft insulation thickness was 49RR is relatively low. Only ~100mm of insulation was installed between the joists, whereas modern recommendations are to install at least 270mm between and across joists. Furthermore, it was noted that the insulation was compacted in some areas by boards and had been removed in other areas to make way for services. For example, insulation had been moved away from the bathroom downlighters to prevent them overheating, consequently leaving areas of uninsulated ceiling. Additionally, the water tank above the bathroom was covered with insulation quilt, but there appeared to be no insulation beneath it. The heterogeneous nature of this ceiling made obtaining a U-value challenging, but 4 plates were placed to obtain an estimate of the heat loss. 2 plates were placed on the rear bedroom ceiling, and 2 on the small front bedroom ceiling. As per the floor setup, one plate was placed below a ceiling joist, and the other between joists. The U-values obtained from these plates are displayed in Table 4.

Table 4. U-values measured for windows

Location	Pre-retrofit U-Value (W/m^2K)	Post-retrofit U-Value (W/m^2K)
Back Bedroom Ceiling (joist)	0.61±0.01	0.13±0.06
Back Bedroom Ceiling (span)	0.35±0.02	0.11±0.01
Front Small Bedroom Ceiling (joist)	0.50±0.03	0.17±0.02
Front Small Bedroom Ceiling (span)	0.45±0.04	0.10±0.01
Area weighted average	**0.44±0.01**	**0.10±0.02**

The pre-retrofit numbers show considerable variability, which the retrofit appears to have addressed. As was found with the floor, the HFPs on the joists display slightly higher U-values than those in between joists. However, their U-value is still much improved, and they make up a relatively small area of the ceiling (<15%), so their impact on overall heat loss will be less significant.

Pre-retrofit, approximately 24±1 W/K heat loss could be attributed to the ceiling. Post retrofit, this number has reduced to approximately 6±1 W/K.

2.9 Discussion and conclusions

Overall, the building fabric retrofits were extremely successful in improving the energy efficiency of 49RR. The HTC - a measure of the overall heat loss of the home - has been reduced from 322±15 W/K to 147±9 W/K. There are many innovative and more complex insulation retrofits available (such as internal wall insulation or external wall insulation), but compared to these the insulation retrofits installed in 49RR were all fairly simple (cavity wall insulation, new windows, loft insulation top-up, and floor insulation). Given this, the savings achieved are encouraging and suggest considerable savings can be made by installing relatively simplistic measures, to a high standard.

The improvement in overall heat loss was reflected in measurements on the individual heat loss though various elements. These are summarised in Figure 35. The U-values for the floor, ceiling, walls and fenestrations (windows and doors) fell by 80%, 77%, 67% and 45%, respectively. While the improvement varied depending on the element, each element achieved a significant reduction.

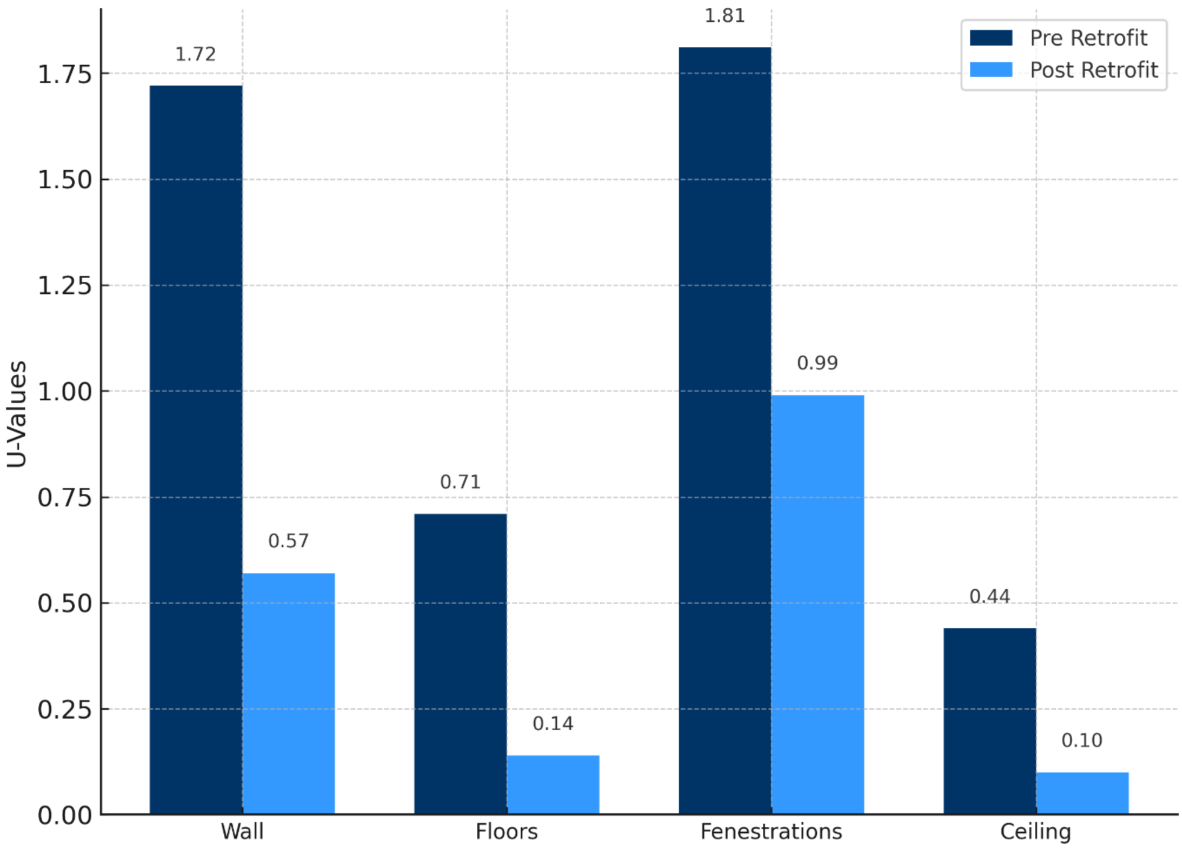


Figure 35. U-value summary

It is also worth noting that these tests measured changes to the building fabric following the retrofit, and cannot be used to evaluate the energy efficiency of 49RR once occupied. This would require different methods to collect in use energy data. As 49RR was not occupied by the same residents pre- and post-retrofit retrofit, it was not possible to accurately assess changes to the property's energy use due to EEMs being installed.

3 Capturing the retrofit experience

3.1 Introduction

This section examines stakeholder experiences of the 49RR retrofit project. Insights span across five project stages:

1. Concept development and scoping;
2. Design, project planning and tendering;
3. Receiving tenders and confirming the project plan;
4. Construction and installation; and
5. Commissioning and post-completion.

The aim is to give Skipton an insight into the challenges faced by stakeholders surveying residential properties then designing, installing and evaluating appropriate retrofit measures. Alongside this, in their paper presented to Skipton's Executive Committee in October 2023, the Skipton Group Sustainability Team identified three key outputs pertinent to this project:

a) Demystifying the cost and financial impact of retrofit for colleagues and customers.
b) Highlight the environmental and social benefits of retrofit.
c) Developing and testing a Group Retrofit Advisory Service.

These objectives relate to customers and to colleagues. Examining them from a supply chain stakeholder perspective, they translate into the following research questions (RQs):

1. What factors affect stakeholder decisions and what are the impacts on this retrofit project?
2. What are the environmental, social and economic benefits of this retrofit identified by stakeholders?
3. What factors are critical to success in developing a Group Retrofit Advisory Service including:

    3.1. What advice should be given?

    3.2. When?

    3.3. In what format?

    3.4. Delivered by whom?

3.2 Research method

3.2.1 Data collection

To answer the research questions, we conducted three waves of eight or nine semi-structured interviews with stakeholders involved in the retrofit process. The research received ethical approval from LBU.

Stakeholders were selected to provide customer, designer, project manager and contractor insights. Participants were selected from a list of contacts provided by Skipton. All were involved in the project at some point during the design, tender or construction stage. Most were interviewed on their own, although some were interviewed in groups of two. We provided the participants with information about taking part in the study. Participants were given the opportunity to ask questions before the interviews and provided informed consent to participate.

Table 6 outlines the details of each of the three data collection waves. Interviews were transcribed using MS Teams and the transcripts were checked manually for accuracy, or the audio files were listened back to and transcribed verbatim.

Table 5. Breakdown of interview specifics

Interview details	Wave 1	Wave 2	Wave 3
Dates conducted	22/05/24 - 14/08/24	02/10/24 - 04/10/24	05/12/24 – 24/01/25
Way conducted	MS Teams	Face to face or MS Teams	MS Teams of face to face
Average duration (mins)	54	46	57
Transcription method	Teams and checked	Verbatim	Verbatim

Table 7 presents the number of participants in each stakeholder group.

Table 6. Breakdown of interview participants

	Stakeholders	**Wave 1**	Wave 2	Wave 3
1)	Skipton Colleague 1	X	X	X
2)	Skipton Colleague 2	X		
3)	Skipton Colleague 3	X	X	X
4)	Skipton Colleague 4		X	X
5)	Wider Group Colleague 1	X	X	X
6)	Wider Group Colleague 2	X	X	X
7)	Wider Group Colleague 3	X		X
8)	External Stakeholder 1	X	X	X
9)	External Stakeholder 2	X	X	X
10)	External Stakeholder 3	X	X	X
11)	External Stakeholder 4	X	X	X
12)	External Stakeholder 5		X	X
13)	External Stakeholder 6			X
	Total No. Interviews	**8**	**8**	**9**
	Total No. Stakeholders interviewed	**10**	**10**	**12**

3.2.2 Analysis

We analysed Wave 1 interview transcripts using template analysis[9] to identify themes[10] in the data. Wave 2 and 3 interview transcripts were coded using the same template, which was refined as more interviews were conducted, transcribed and transcripts analysed. One researcher analysed the data guided by RQ1, "What factors affect stakeholder decisions and what are the impacts on this retrofit project? and a second researcher analysed the data guided by RQ2, "What are the environmental, social and economic benefits of this retrofit identified by stakeholders?" and RQ3, "What factors are critical to success in developing a Group Retrofit Advisory Service " The risks of different findings from parallel analysis were reduced through both researchers meeting regularly throughout the analysis period to discuss the data and emerging findings, validating insights as the analysis proceeded. An inductive approach was taken, where the themes arose from the data rather than by applying a pre-determined framework.

3.3 Findings

3.3.1 Factors affecting stakeholder decisions and subsequent impacts

This section presents data responding to the first research question RQ1, "Which stakeholder decisions change retrofit actions and what are the impacts?" Decisions made by the various stakeholders across organisations either individually or collaboratively influenced the retrofit process and how it unfolded over time across five stages:

1. Concept development and scoping;
2. Design, project planning and tendering;
3. Receiving tenders and confirming project plan;
4. Construction and installation; and
5. Commissioning and post-completion.

The decisions taken are listed alongside the impacts and why the decision was important in Table 8 below.

[9] King, Nigel, and Joanna Michele Brooks. *Template Analysis: For Business and Management Students*. Mastering Business Research Methods. Los Angeles London. SAGE, 2017.

[10] Braun, Virginia, and Victoria Clarke. "Using Thematic Analysis in Psychology." *Qualitative Research in Psychology* 3, no. 2 (January 1, 2006): 77–101. https://doi.org/10.1191/1478088706qp063oa.

Table 7: Key stakeholder decisions made at each stage of the project

	Key decision	Made by	Impact	Why was it important and to who
Stage 1. Concept development and scoping				
1)	**To write a business case for the upgrade and remodelling of 49 Regent Road**	Skipton Building Shared Services Team	• Skipton identified a need to carry out repair and maintenance works to one of their properties.	Skipton - To keep asset in state of good repair and potentially add value.
2)	**To appoint architect to do initial designs based on an "eco-homes of the future" brief**	Skipton Building Shared Services Team	• Skipton explored different options that included a range of energy efficiency measures and layouts for the house.	Skipton – To understand what could be done to the house and how much it would cost
3)	**To change the approach and transfer project responsibility from one team to another**	Skipton Group Sustainability Team	• Decision made against "Grand Design" style renovation. • High costs. • Uncertainty about how environmental benefits and embodied carbon would be measured.	Skipton Group Sustainability Team – Decided to pursue retrofit approach for house Skipton Building Shared Services Team – Change of personnel in team as Skipton colleague who wrote initial business case left organisation
4)	**To talk to wider Skipton Group stakeholders and local universities**	Skipton Group Sustainability Team	• Designs discussed within Skipton, wider partners (WSGO1 and WSGO2) and external stakeholders (LBU and UoL). • Skipton find out about WSGO2's retrofit service and ESRPO's "with you all the way" service. • Project focus shifted from property remodelling to showcasing retrofit challenges to members through education piece. • Project brief changed and narrowed to energy efficiency measures a homeowner might install. • Architect's services were discontinued as they lacked required retrofit qualifications or expertise to satisfy the new brief.	Skipton Group Sustainability Team – To understand relevant skills and services within the Group and what research is happening in the field. To go beyond NatWest's retrofit project[11].

[11] https://www.natwestgroup.com/content/dam/natwestgroup_com/natwestgroup/pdfs/PDFs/BD0598-UK-Natwest-HIWTHI-Outcomes-Report-VR-v8.2.pdf

5)	**To test group-based "with you all the way" option that incorporates PAS 2035 elements and apply WSGO2's retrofit service to the house**	Skipton Group Sustainability Team	• Project team increased in size as WSGO1, ESRPO and WSGO2 joined. • Aim is to follow a "realistic" customer journey as closely as possible.	Skipton Group Sustainability Team and WSGO1 – To pilot a new retrofit service for the private homeowner market.
6)	**To appoint architect recommended by WSGO1**	Skipton Group Sustainability Team	• Had retrofit and sustainable design credentials to avoid risk of poor design. • Able to design extension or loft conversion if Skipton wished to pursue that avenue. • Project team increased in size as RAO joined. • Increase in project budget as new architect's fees were three times more than Skipton originally budgeted for. • Need higher up approval for money. • Aim to claw back costs elsewhere	Skipton Group Sustainability Team - To de-risk project and give Skipton more control over the building work, although expensive.
7)	**To conduct research**	Skipton Group Sustainability Team	• Skipton wanted to work with academic institutions to support their education piece. • Project team increased in size as RAO joined. • Project team increased in size as LBU and UoL became involved.	Skipton Group Sustainability Team - To give voice to retrofit professionals through research and accurately measure change to home's fabric performance following retrofit.
8)	**To run two retrofit delivery processes side by side for the project's duration**	Skipton Group Sustainability Team	• Multiple teams surveyed/generated EPC for house - duplicating work. • Two organisations (RAO and ESRPO) developed their own specification (RAO using PHPP and ESRPO using RdSAP) – duplicating work. • Aim was to use ESRPO's approach to follow the customer journey and use RAO's documentation as a sense check. However, some stakeholders reported a lack of clarity regarding design roles between RAO and ESRPO at this stage.	Skipton Group Sustainability Team – Using two methodologies offered a sense check to Skipton. Skipton Group Sustainability Team - Aimed to benefit from learning by taking this approach ESRPO - Proposed improvements suggested by Skipton improved ESRPO's app interface

9)	**To conduct fabric tests on the home**	Skipton Group Sustainability Team	• LBU carried out pre-retrofit performance tests on the house to determine how much heat was lost through the walls, ground floor, ceiling, windows and doors, plus how leaky the house was. • It was not possible to carry out pre-retrofit monitoring as no one lived in the property.	Skipton Group Sustainability Team – provided baseline metrics which could be compared once the building work was complete.
Stage 2. Design project planning and tendering				
10)	**For one person in Sustainability team to act as the "homeowner or client"**	Skipton Group Sustainability Team	• One person assuming motives of the average person – speeds up decision making but challenging as it's not their own home • Uncertainty from some stakeholders that homeowners would have made the same choices as Skipton	Skipton Group Sustainability Team – Meant Skipton could try to mimic a typical homeowner retrofit journey
11)	**To change Skipton personnel involved in project**	Skipton strategic decision-maker(s)	• New Skipton colleagues join the project team as old ones leave. There is a steep learning curve for new members	Skipton Group Sustainability Team – To manage resources after Skipton restructure
12)	**To refine the scope of works and specification**	Skipton Building Shared Services team, Skipton Group Sustainability Team, RAO, ESRPO, WSGO1	• Skipton decided to install EEMs, carry out general works to the property, and do the work in a single phase. • By discussing RAO's and ESRPO's specifications with external stakeholders, Skipton established the target performance standard sought for the house (between EPC B and AECB Level 2) and EEM's to be incorporated. Through discussions developing multiple options. • Measures discussed and dismissed were: EWI - due to cost and that cavity wall insulation should be enough. Meeting EnerPHit or AECB standards – as these require a high level of airtightness which was deemed too intrusive. So, airtightness was not considered a primary focus. Triple glazing and MVHR - as some stakeholders felt the average homeowner would not select these measures unless they could afford them. • To reduce costs, boarding the loft, dual heating zones and installing underfloor heating were considered and dismissed	Skipton Group Sustainability Team, Skipton Building Shared Services Team - Resulted in an agreed performance target for the house, specification and scope of works to feed into estimated cost plans and tender documentation. WSGO1 – To perform a sounding board role.

			• Divergences between RAO's and ESRPO's revised measures, which were resolved, included: One extra extract fan proposed by ESRPO. LED lighting switch by RAO. Differently sized hot water cylinders. Differently sized heat pumps • Large team and two organisations carrying out same role increased decision-making time for this stage.	
13)	**To prepare cost plans for the EEMs**	WSGO2	• EEMs and general works were separated so EEM costs could be approximated by WSGO2. • WSGO2 provided three cost estimates for slightly different specifications than what was ultimately chosen.	Skipton Group Sustainability Team, Skipton Building Shared Services Team – provide a notion of tender return costs WSGO2 – To have a cost plan that could be compared against construction costs using this approach.
14)	**For ESRPO to lead on contractor selection**	Skipton Group Sustainability Team	• Skipton agreed ESRPO could lead on procurement and contractor selection. • It was difficult to find contractors skilled in both general construction and energy efficiency measures. This meant subcontracting some parts of the work might be needed, which was less than ideal. • Building in this way differed from ESRPO's usual method of using a single contractor.	ESRPO – To pilot their contractor selection process.
15)	**To select a traditional procurement approach with architect and contractor**	Skipton Building Shared Services Team	• Project became more complex, including architect and M&E consultant information • Including general works extends beyond ESRPO's remit – Skipton decided to use a traditional procurement route and tender using documentation prepared by RAO. • Was potentially considered to be a more expensive route but less risky for Skipton.	ESRPO, Skipton Group Sustainability Team **-** This deviated from aim to follow the consumer journey but was done to mitigate risk.

16)	**To use a JCT contract for the work**	Skipton Building Shared Services Team	• Skipton preferred to use a JCT contract (familiar from branch refurbishments) rather than using FMB contract.	Skipton Building Shared Services Team - Less risky than using ESRPO's untested FMB contract.
17)	**To go out to tender**	Skipton Group Sustainability Team, Skipton Building Shared Services Team, ESRPO, RAO	• ESRPO prepared the contractor list using their process. • Four contractors received RAO's tender pack. • Skipton supports ESRPO's aim to approach 5th contractor for comparison as a sideline activity. • ESRPO organizing the tender process added an extra layer of complexity. • Some stakeholders considered the documentation that was prepared for tender to be excessively long and overly detailed. • Some stakeholders felt this approach was complex, time-consuming, and added unnecessary items to the specification. • As a result of the contractual changes, the level of ESRPO's involvement in the construction stage of the project decreased significantly.	ESRPO, Skipton Group Sustainability Team - Skipton unable to follow ESRPO's with you all the way service once the contractor was appointed as incompatible legal framework was in place.
Stage 3. Receiving tenders and confirming project plan				
18)	**To appoint ESCO1 as the preferred contractor**	Skipton Group Sustainability Team, Skipton Building Shared Services Team	• Tenders come in higher than expected. • Successful contractor's bid just over £156,000 • Tender prices varied significantly despite pre-tender cost analysis and descoping of project elements • Commercial approach to Skipton's project was perceived to increase costs, including £4,000-£5,000 in contractor management fees and prelims. • Conversely, some stakeholders said the project costs would have been approximately £50,000 higher for a contractor to do the same job for a homeowner.	Skipton Group Sustainability Team, Skipton Building Shared Services Team - Business status and commercial treatment were perceived by Skipton as significantly increasing retrofit project costs.

19)	**To compare 5th contractor tender return against the other four contractors**	ESRPO, Skipton Group Sustainability team	• 5th contractor comparison was limited to energy efficiency measure items only. • The 5th contractor's costs were within 10% of the three lowest bids, with variations in different measures	ESRPO – To compare a tender return using their process to what the other contractors had returned using a traditional approach.
20)	**To value engineer the preferred tender**	Skipton Group Sustainability Team, Skipton Building Shared Services Team, ESCO1	• Specifying particular brands and proprietary products increased tender prices; using similarly performing alternatives reduced costs. • Original window specification was expensive; switching to alternatives with similar performance values saved thousands of pounds. • uPVC triple-glazed windows were agreed upon, but the choice between double-glazed and triple-glazed uPVC patio doors was debated. • Both options had identical U-values, with triple-glazing costing £3,000 more. Ultimately, Skipton stakeholders selected the double-glazed patio door unit for its cost-effectiveness and comparable performance • The ASHP unit's location was moved from the rear to the side of the house, which stakeholders found less visually intrusive • The ASHP move could save approximately £2,000 by eliminating the need for a trench and concrete plinth. However, this change would incur additional costs for bracketry and core drilling. • Moving internal structural wall to accommodate the boiler. • Fitting equipment in the original space saved £4-5k, though it may have required purchasing smaller equipment at a higher cost. • Omitted exterior and interior decoration from scope of works.	Skipton Group Sustainability Team, Skipton Building Shared Services Team – To reduce the costs as the tender had come in above their budget.

21)	**To confirm architect's services for build stage**	Skipton Group Sustainability Team, Skipton Building Shared Services Team, RAO	• Statutory duties like principal designer were performed by RAO. Contract administration (CA) duties were to be performed by Skipton Building Shared Services Team**.** • Skipton Building Shared Services Team appointed a separate CA at a lower cost. • RAO carried out site inspections and informed the CA of variations and instructions to issue to ESCO1. • Contractor will have to go to more people for answers as architect not CA.	Skipton Building Shared Services Team, RAO – To clarify roles and responsibilities under the building contract for the build stage.
22)	**To update ESRPO's with you all the way model**	ESRPO	• ESRPO modelled the home's performance again based on the revised scope of works and specification	ESRPO – To ensure the design model matched the revised specification after the value engineering exercise.
Stage 4. Construction and installation				
23)	**To address the asbestos found in the bathroom floor**	Skipton Building Shared Services Team, RAO, ESCO1	• Rather than taking the floor up to replace the heating pipework, it was accessed from the kitchen ceiling underneath, leaving the asbestos in situ. • This approach was cost neutral.	Skipton Building Shared Services Team – To comply with H&S legislation.
24)	**To remove the asbestos found under the first-floor bay window soffit**	Skipton Building Shared Services Team, RAO, ESCO1	• Had to be removed. • Removal cost was between £1000-1300.	Skipton Building Shared Services Team – To comply with H&S legislation.
25)	**To change how the telescopic vents are fitted**	Skipton Building Shared Services Team, RAO, ESCO1	• Vents had to come straight through and down the inside wall.	Skipton Building Shared Services Team and ESCO1 – To ensure the vents worked correctly and ventilated the floor void.

26)	**To relocate the ASHP**	Skipton Building Shared Services Team, RAO, ESCO1, ESCO2	• The subcontractor fitting ASHP said it couldn't go next to the external wall. • Still needed a concrete plinth but rerouted pipework through rather than around the house but only a quarter of the external trenchwork was needed. • Money saved by not digging up the path. • There were no changes to the ASHP's efficiency as a result.	ESCO2 – They were unable to install the ASHP in the revised location.
27)	**To reinforce suspended timber floor with concrete lintels**	Skipton Building Shared Services Team, RAO, ESCO1, ESCO2	• Found incomplete sleeper walls under the timber floors that needed reinforcing with concrete lintels. • The cost came out of a contingency budget.	Skipton Building Shared Services Team – To ensure the ground floor was structurally sound.
28)	**To not move the internal wall**	Skipton Building Shared Services Team, RAO, ESCO1, ESCO2	• When the M&E subcontractor provided a 3D model of the equipment to be installed in the space, it was clear it would fit in the ground floor plant room without moving the internal wall. • All that was required was to hang the door, so it swung the other way. • Negated the need to modify the drainage so drainage CCTV was no longer needed, so some money was saved.	ESCO1 – To move the wall would have been difficult, time consuming and labour intensive.
29)	**To replace the kitchen**	Skipton Building Shared Services Team, Skipton Group Sustainability Team	• It made sense to replace the kitchen now while ESCO1 was on site. It would be cheaper than changing it later. • There were conversations about the kitchen colour and specification and price. • The kitchen layout was changed rather than replacing like for like. • Skipton Building Shared Services Team asked for 3 quotes and negotiated costs down. • Skipton Group Sustainability Team felt it would be beneficial to do now as it would need doing at some point in the near future.	ESCO1 – Made it easier for ESCO1 to install the underfloor insulation. Rather than working around the kitchen, they could just take it out and insulate the whole floor.

30)	**To paint the external walls**	Skipton Building Shared Services Team, RAO, ESCO1, ESCO2	• Walls looked patchy from cavity wall insulation. • Painting external render ed walls improved house appearance.	Skipton Group Sustainability Team, Skipton Building Shared Services Team – It is likely that Skipton will want to sell the house at some point, and it would be beneficial to do this now.
31)	**To claim zero rate VAT for renewable technology items**	ESCO1, Skipton Group Sustainability Team, Skipton Building Shared Services Team	• Renewable technology being installed was eligible for zero VAT rate. • Contractor made final decisions on eligible items. • Resulted in £9-10k VAT savings.	Skipton Group Sustainability Team, Skipton Building Shared Services Team – To save money on project as it was over budget.
32)	**To not upgrade the house electrics**	Skipton Building Shared Services Team	• House wiring is out of date despite having a 5-year test done in recent years. • Considered disruptive and not a "must-have". • Factored in property age and whether it added value.	Skipton Building Shared Services Team – The house is currently compliant, and it would have cost around £4k.
33)	**To add mains powered smoke alarm**	ESCO2	• Regulations for battery storage locations changed.	ESCO2, ESCO1, Skipton Building Shared Services Team – To meet the relevant regulations.
34)	**To lower ground floor heating pipework**	ESCO2	• ESCO2 unable to install new pipework with the new insulation depth and heating pipework where it was. • Lowering the pipework meant the insulation depth could be accommodated without extra cost or compromising the heating system performance.	ESCO2, Skipton Group Sustainability Team – Moving pipework meant the insulation was not disturbed.

35)	**To amend and reissue solar schematics**	ESCO2	• PV inverter isolators were built-in which was not anticipated. • A CT clamp was missing from the drawings which was added before installation.	ESCO2, Skipton Building Shared Services Team – To ensure the drawings match what has been installed on site.
36)	**To buy additional PPE for visitors**	Skipton Group Sustainability Team	• Safety equipment had to be purchased for people visiting the house while ESCO1 was on site. • Costs for this weren't considered at the project outset but were sizable.	Skipton Group Sustainability Team – PPE was necessary to show interested parties around the house during construction in line with project aims.
37)	**To ask for extra funds that includes a contingency for hidden extras**	Skipton Group Sustainability Team, Skipton Building Shared Services Team	• Additional internal funding requested for asbestos removal • Contingency not initially included • Skipton Building Shared Services Team and Skipton Sustainability Team questioned budget allocation for specific retrofit parts as maintenance costs could come from a maintenance budget, not the project budget. • Granted £5k as a contingency.	Skipton Group Sustainability Team, Skipton Building Shared Services Team – Meant that any hidden extras could be paid for without having to go back and ask for more money.
38)	**For ESRPO to collect with you all the way scheme documentation**	Skipton Group Sustainability Team, ESRPO	• ESRPO asking contractor for necessary documentation for their service. • Documents collated by Skipton Building Shared Services Team when ESCO1 handed them over to Skipton. • It was hard for Skipton to pay equal attention to ESRPO when they were not on site and their process was not being followed by ESCO1.	ESRPO – To pilot the construction stage of their service.

39)	**To add a hatch in the floor**	Skipton Group Sustainability Team, Skipton Building Shared Services Team	• A member of the Sustainability Team came up with an idea but checked with construction-based stakeholders to ascertain whether it was a viable suggestion. • Floor access hatch added in rear door mat well due to greater floor void space. • Skipton used construction-based stakeholders for ongoing work checks.	Skipton Building Shared Services Team – To gain access to the underfloor void in future without damaging the insulation.
40)	**To film construction work**	Skipton Group Sustainability Team, Skipton Comms Team	• High levels of interaction between Skipton Comms and ESCO1 required synchronization of event timings, which was challenging for both parties. • Skipton made efforts to film key events when ESCO1 changed installation dates to suit sub-contractor availability. • The construction work slowed due to the additional requirements of filming and conducting staff interviews. • The processes of documenting and video filming proved to be more time-consuming than initially anticipated by ESCO1.	Skipton – to capture the retrofit journey as it happened so that members could see what was happening on site.
41)	**To hold the Big Retrofit event**	Skipton Group Sustainability Team, Skipton Comms Team	• Stakeholders invited to attend an event at Skipton HQ. The day consisted of a panel with questions which was live streamed to branches and a forum in which Skipton colleagues could approach stakeholders and talk about various elements of the project and retrofit in general.	Skipton Group Sustainability Team – to communicate to Skipton colleagues what the project is about, why it's important and what had happened to date. Video footage and photographs were used to show the home before, during and after various EEMs were installed.

Stage 5. Commissioning and post-completion				
42)	**To conduct a training session on how to use the new technology**	ESCO1, Skipton Building Shared Services Team, Skipton Group Sustainability Team	• Wider Skipton Building Shared Services Team were able to engage with the technology for the first time and understand how it works. • Skipton Sustainability Team had the technology explained to them first hand without having to read large manuals. • Capturing the session on video means Skipton can refer to it in future.	Skipton Group Sustainability Team – To be able to explain the technology as part of their education piece. Skipton Building Shared Services Team – To understand how the technology works and be able to maintain it going forward.

43)	**To complete the "with you all the way" scheme final checks**	ESRPO, WSGO1, Skipton Building Shared Services Team, Skipton Group Sustainability Team	• Performed post-construction inspection.
			• WSGO1 created a new condition report.
			• Areas requiring attention:
			  ○ Render maintenance.
			  ○ Moisture ingress risk due to render cracks and new cavity fill insulation.
			  ○ Ongoing observation of wet plaster on chimney breast.
			• WSGO1 retrofit coordinator reviewed documents and updated RdSAP data.
			• ESRPO awaiting specifics of energy-efficiency measures before the report is complete.
			• Skipton Building Shared Services Team reluctant to share some contractual information with ESRPO, so there are caveats in the report noting this.
				ESRPO – To continue piloting the service and see whether work had passed set quality checks.

44)	**To complete post-retrofit EPC**	WSGO2, Skipton Building Shared Services Team, Skipton Group Sustainability Team	• Conducted post-retrofit EPC assessment. • Awaiting clarifications on specifications.	Skipton Group Sustainability Team – To see how much the EPC has changes and whether the target of EPC B had been met.
45)	**To carry out post-retrofit building fabric tests.**	Skipton Group Sustainability Team	• It was possible to compare post-retrofit fabric performance of the house to the pre-retrofit fabric test results.	Skipton Group Sustainability Team – To see how effective the retrofit was overall and which EEMs made the most impact on reducing fabric heat loss. ESCO1 – To demonstrate how the measures they installed made a difference in a way that they could show future customers. WSGO2 – To update RdSAP defaults for the post-retrofit EPC so the EPC is more accurate. The potential impact on EPC rating could go from a high B to low A.
46)	**To check internet access and installation**	Skipton Building Shared Services Team	• The house does not have broadband internet as previously assumed. • Absence of internet and Wi-Fi prevents connection of monitoring kit and smart tariff implementation. • Unable to control the technology despite it potentially working.	Skipton Group Sustainability Team, Skipton Building Shared Services Team – To get the technology working correctly .

47)	**To contact ESCO1 about technical queries**	Skipton Building Shared Services Team	• Asking about the technology. • Later than anticipated commissioning of equipment as internet was not present. • MCS certificate cannot be issued until technology is commissioned.	Skipton Building Shared Services Team, Skipton Group Sustainability Team – To get the technology working correctly.
48)	**To compare cost plans with actual costs**	Skipton Group Sustainability Team, ESRPO	• Both ESRPO and WSGO2's cost plans related to the EEMs and not the general works.	ESRPO and WSGO2 – To see how much the cost plans compared to actual costs.
49)	**To put back small items removed for the work and finish off loose ends**	ESCO1, Skipton Building Shared Services Team	• Curtain pole brackets taken down before the work need reinstating. • Work is being done by ESCO1 outside of the contract, which is extra.	Skipton Building Shared Services Team, Skipton Sustainability Team – To get the house ready before the it can be occupied.
50)	**To dress the house**	Skipton Group Sustainability Team	• An interior dresser has been appointed. • Their role is styling the interior design of the house re-using existing furniture where possible, plus choosing floor finishes and carpet colours. • There are extra costs associated with these finishing touches, which are being covered by the contingency money.	Skipton Building Shared Services Team, Skipton Group Sustainability Team – To get the house ready before it can be occupied. To get the home ready for showing people around.

Looking at the decisions made during the project, three points become apparent. First, that if one person makes all the necessary decisions, there are many decisions for them to make over the duration of the project, which could become overwhelming without support. Second, the skills required to make informed decisions change over the five stages. Last, while the ultimate aim of the project was to mimic the customer journey that a homeowner would experience, commercial decisions made by Skipton meant that this was not possible. These points are explored in turn.

3.3.1.1 Volume and speed of decision-making

While Table 8 is not exhaustive, stakeholders described at least 50 key decisions that were made during this retrofit project. Around 45 of the decisions were made over a 13-month period and by a team of individuals that included built environment professionals. Some decisions related to Skipton's protecting their commercial interests; however, many of them constituted decisions that homeowners would make. As one participant discussed, it can be hard for homeowners to make many decisions without sound advice:

> *"It's just analysis paralysis. Sometimes it's so difficult to navigate that… so I could see why it'd be really off-putting for somebody to put themselves in that position, especially when you've financially committed to something, and invested in it. It's even harder to make those decisions, in case it's the wrong one, and especially when the world of retrofit is rife with horror stories, as well, so you'd just be worried. So that advice role is really critical, that helping hand." Interview 3.2*

Timing wise, the decisions were not evenly spaced. Stage 1 comprised nine key decisions over more than a year. During Stage 2, six crucial decisions were made in as many months, often with the result of one decision impacting others, i.e., by selecting one EEM, others were no longer feasible. Stakeholders also focused on creating their ultimate shopping list of measures without taking costs into account. While stakeholders had calculated costs, there was uncertainty about how closely they would match the amount a contractor quoted. Throughout Stage 3, time was of the essence, meaning decisions were made to reduce costs and clarify stakeholder roles as quickly as possible so that ESCO1 could start promptly on site. The bulk of decision-making was done on site during Stage 4, as plans became reality. Over a 12-week period, many decisions were made at a rapid rate, as unexpected events occurred and were addressed. More maintenance was also done while ESCO1 was on site as it was cost effective to do the work then. Decisions made during the last stage centred around understanding how to use the house, ironing out teething problems and finishing off the final bits and piece, which were taking place at a slower place.

3.3.1.2 Skills required to make informed decisions

Many decisions during Stages 1,2,3 and 5 were led by the Group Sustainability Team. However, during Stage 4, responsibility for making decisions appeared to shift to the Building Shared Services Team based on their construction expertise.

“I think when we were in the build stage it was definitely [the Building Shared Services Team] … [They] know what we should and shouldn’t be doing… with [the Sustainability Team] definitely being involved in those discussions but ultimately [the Building Shared Services Team] making build decisions. I think now as we’ve moved off build stage and into actually what are we doing, how are we sharing this learning… That’s become more [the Sustainability Team’s] decision making.” Interview 3.7a

Some stakeholders described how they did not feel comfortable making those kinds of onsite decisions and, had it been left to them, they would have made a different choice. In those circumstances, they felt grateful to have access to in-house construction experts.

“The word I would use is lucky because if I was a homeowner and I had to make all these decisions alone I would probably feel like I was second guessing myself a lot.” Interview 3.2

To illustrate this, Decision 39 - to add the ground floor hatch so it was easy to access services in future - was suggested by a member of the Group Sustainability Team. While they thought it a sensible addition, they sought reassurance from construction-based stakeholders first to make sure it was not an outlandish suggestion.

3.3.1.3 Skipton vs a homeowner’s retrofit journey

Stakeholders referred to five key decisions that were made where they felt homeowners might have made different decisions.

Choosing to use an architect and having extra professional help (6)

Stakeholders discussed how projects sit on a scale that ranges from simple to complex and that this project could have been achieved without architectural input, saving a homeowner money. However, they understood why Skipton appointed an architect to de-risk the project.

“It’s been really interesting to look at how an architect approaches a project… But I also believe that that’s taken it out of the realms of realism… [an architect] on an energy upgrade project just adds so much cost to a project that I think it stops making financial sense for the average homeowner.” Interview 3.3

Deciding on specification items (12)

During the design stage, a Skipton Sustainability Team member assumed the role of “homeowner”. Stakeholders described this as a challenging role to fill because it was not their house so there was not the same emotional attachment to shape decisions. Examples given included whether to board the loft, replace the roof and install underfloor heating.

“I think just because [Skipton is] not actually a homeowner, I would say there's been an impact to the measures potentially… Underfloor heating is very much seen as a comfort thing. So, they took that out, which totally makes sense. But a homeowner might not.” Interview 1.1

Choosing to complete the work in one phase (12)

Stakeholders talked about how the average homeowner would find installing underfloor insulation too disruptive to stay in the property and would need to move out. As the property was not occupied, Skipton did not experience the same level of disruption a homeowner would. Similarly, given the extent of the works, stakeholders felt homeowners would probably phase the work to when they could accommodate some disruption and were able to pay for it. However, phasing it in this way could cost homeowners more over time.

> *"The way that [Skipton] have approached the works – floors up… is probably not the way it would happen in an occupied property... I suspect most homeowners would maybe do it bit-by-bit or as and when budgets allowed… that would potentially have an impact in cost… if you're doing it in small dribs and drabs, you're not necessarily getting the economies of scale." Interview 3.4*

Choosing to use a JCT minor works contract (16)

This decision was the point at which the project pathway diverged from one of Skipton's main project aims – to pilot ESRPO's "with you all the way service". ESRPO's service uses a Federation of Master Builders contract, which had just been launched. However, Skipton Building Shared Services Team preferred to use a JCT Minor Works contract as they were more familiar with it. Stakeholders described how the average homeowner carrying out a retrofit was unlikely to use either type of contract. Some stakeholders were familiar with simple commercial agreements that just set payment terms; however, these carried a degree of risk. Using more complex contracts meant employing consultants or contractors assuming design responsibilities, which carried more onerous liabilities.

> *"I would have said [the average agreement for a retrofit project] was just a commercial agreement between a homeowner and a builder. But then again, that then opens a can of worms for the homeowner in the sense of, the contractor has no contractual obligations to the client, other than a piece of paper with a signature on and a value … But the issue with [a JCT Minor Works contract] is, you've then got contractor's design portions of this as well. So, unless you've got a consultant involved, a [JCT] Standard [contract] is the way to go with contractor's design, which is a bigger contract still." Interview 3.8a*

Choosing to appoint a large contractor with extensive commercial experience (18)

As Skipton decided on a JCT contractual pathway, the project followed a more traditional route, with an architect taking design responsibility and a contract administrator administering the contract. ESCO1 had also appointed a commercial arm of their workforce to manage the project. External stakeholders commented that working in these conditions was very different to working with a homeowner, as most people involved were experienced construction professionals and could make informed decisions far quicker than the average homeowner.

> *"It's so different than with a domestic customer… with Skipton, you're talking about very knowledgeable people who've employed very knowledgeable builders to do the project on their behalf. So, it's a lot simpler." Interview 3.9*

3.3.2 Perceived benefits (and risks) of retrofit

This section responds to RQ2, “What are the social benefits of retrofit for supply chain stakeholders?” As well as presenting data on what stakeholders believe the benefits of retrofit in general could be, the perceived benefits of retrofit for customers and homeowners specifically are also discussed here, together with the challenges of realising those benefits.

For the group of stakeholders interviewed, a significant co-benefit is the creation of new (profitable) business, revenue streams and enterprise. Beyond the commercial opportunity for individual firms, there is a local / regional / national opportunity to support new jobs and skill development (‘upskilling’) of the existing workforce.

While the bespoke nature of working on individual owner-occupied properties currently presents financial challenges in terms of paying for the design and professional fees that are needed to ensure a successful retrofit project, if retrofit take place at scale, potentially concentrated in specific areas where there is support to get local supply chains involved, there is a strong economic argument for spreading design and project management costs between projects, while also delivering local economic benefit.

For Skipton the opportunity to enhance brand and reputation was suggested by several stakeholders, with different aspects. The opportunity to facilitate the kind of local or area-based approach which deliver local benefits, through employment in the supply chain as well as improving housing quality, was suggested as a way for Skipton to demonstrate corporate citizenship, with improvements to housing which could be part of ESG performance. The need to decarbonise the loan book was also noted as a challenge across the finance industry, although this was only mentioned by one or two stakeholders. Supporting area-based co-ordination and delivery of retrofit programmes would also increase the evidence that Skipton was able to offer to national programmes for policy advocacy and development, in effect creating a ‘blueprint for UK action’.

Focussing more on practical benefits for Skipton, stakeholders identified that fully engaging with retrofit could lead to the development of new products and acquiring new customers. The characteristics of such products if they are to be successful is explored in section 4.3 below. There may be an emerging potential opportunity to reduce the costs of investment, for Skipton to then pass on to its members, through using carbon credits created by successful retrofit projects as a new source of funding.

Amongst the stakeholders interviewed, Skipton staff felt that the most important benefit was in supporting customers (members) to have more comfortable or healthier homes. No stakeholder suggested that more affordable homes was something that Skipton could help support, although the need to improve affordability in terms of running costs for homes was repeatedly mentioned as a core customer motivation.

This concern for members in turn linked to wider benefits where retrofit offered broader public good. Stakeholders indicated it was important, especially in a time of housing shortage, to avoid demolition of homes because they don’t meet required energy performance. Skipton’s role was seem as being part of a massive improvement in owner occupied housing energy efficiency that *“won’t happen without private sector involvement” Interview 1.4.*

Turning to the benefits that retrofit is perceived to offer Skipton customers and homeowners more generally, the first thing to note is that customers' primary interest is perceived to be in reducing energy bills, although the data collected here does not prove this empirically. However, retrofit alone cannot be certain of delivering a reduction in bills and any reduction is near impossible to predict with confidence. The electricity tariff makes a huge difference, together with changes in lifestyle, and behaviour that affect energy consumption, such as increasing room temperature to improve comfort or health.

> *"The other things that you would definitely need to think about, and I would say would need to think about upfront, which I didn't at all, was your energy tariff and provider." Interview 3.2*

This is not to suggest that there is no value to homeowners in carrying out retrofit activity as a way of reducing energy consumption, and there are additional potential benefits such as providing a more comfortable, warmer and healthier home. Other benefits to the owner-occupier were improvements in aesthetics, or an increase in useful space. The improvement in soundproofing was a surprise to several stakeholders. There is some suggestion that in the long run retrofit will increase home value, although that cannot be evaluated from this project and is unlikely to rest on the implementation of EEMs alone.

However, to achieve these potential benefits, there are a number of challenges and perceived risks that need to be overcome. Principal among these is the need for the customer to understand, and accept, the entire costs of the project, which are greater than the costs of the EEMs. Four areas of work which offer value to successful retrofit delivery, which are seen as additional or optional costs by customers were identified. First, the costs of professional advice and design input are vital to get the best solution for the home and to avoid costly rework or scope changes later in a project, but professional fees are not part of the capital costs of technology which customers typically have in mind when they think about investing in their homes. The scale of fees associated with design will rise with the complexity of the works being undertaken, and they might be very small for installation of a single EEM but they cannot be ignored.

Second and third are two types of consequential costs. There are consequential costs which are required, associated with the EEMs themselves, with the example for 49RR being checking whether there is a sufficient power source to run the new technologies. A separate area of optional consequential costs come from the broader, non-energy, opportunities for home improvement because of the nature of retrofit work, with floorboards lifted or plaster removed (items such as decoration or storage). The benefit to the customer from these optional consequential activities can be high, but they appear to be an additional cost if the project is framed as energy retrofit rather than home improvement.

Finally, the costs of effective commissioning and post-completion assistance are rarely factored into the overall project costs, but they are vital to supporting the customer in living comfortably, and affordably, in their home in the future. This is explored further in section 3.3.3 below.

There are also risks to project success associated with deploying unfamiliar technologies, or technologies perceived as risky. Heat pumps are the prime current example of an unfamiliar technology since they are always on, with radiators at lower temperatures, achieving efficient warmth in a very different way to the rapid response and high temperatures that customers are often used to from gas or oil central heating. This emphasises the need for post-completion support and communicating essential maintenance routines to help homeowners "operate" their homes effectively.

One stakeholder also referred to risks associated with External Wall Insulation (EWI) installation, a risk that was made visible by a report to Parliament in January 2025[12].

3.3.3 Perceived characteristics of successful retrofit projects

This section responds to the third research question RQ3, "What critical success factors inform a Group Retrofit Advisory Service?"

A retrofit advisory service will only be used if it recognises and reflects **customer motivations**. Customer motivations may be primarily reducing bills, as the stakeholders interviewed believe, or increasing property value, but both of these are very difficult to measure or to expect simple payback from, although this may be changing, slowly:

> *"Return on investment, if coupled with the time of use tariff, is starting to look far more attractive than it once was." Interview 3.1*

> *"There has been a substantial increase in the value [at 49RR], but not close to the value of the works, which is an old severe adage of, a pound spend doesn't equal a pound of value, which is quite often a challenge when people do work of any type." Interview 3.4*

Staying within an agreed and affordable budget becomes the proxy for this kind of financial payback. Stakeholders felt that carbon reduction per se was not a motivating force for most customers contemplating retrofit, although they recognised the importance of carbon reduction as a motivation for action by Skipton and other lenders.

Therefore, being able to characterise co-benefits such as having a warmer home, with health benefits for the household, while the living in the home stays – or becomes – affordable is important. The phenomenon of 'comfort taking' where a household takes advantage of increased energy efficiency by heating their home to a higher temperature, will also limit the reductions in bills that a household might otherwise see[13].

Interviewees, particularly when reflecting at the end of the project, suggested that supporting retrofit as part of ongoing home maintenance and improvement, with a whole life plan, or as a series of incremental measures which complement each other, might be more aligned with what is manageable and the approach that customers may take reflecting their desired goals from home improvement. This means that the design of a retrofit service will need to consider how to frame retrofit as a broader plan of home improvement, which might align with stronger customer motivations than carbon reduction provides.

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[12] https://www.gov.uk/government/news/action-taken-to-protect-households-with-poor-quality-insulation
[13] Page 19 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1008681/need-report-2021.pdf

Overall, the data gives a strong sense that it would be very easy for a customer to get information overload, especially if they are not familiar with construction or renovation work, and/or were not primarily driven by carbon concerns, which seems likely. An effective retrofit advisory service must therefore address **what customers need to know**, while recognising what they are interested in, which might be rather different.

Analysis identified four areas where customers need information, although the specifics of the information needed in each area does change as the project moves from design through implementation to completion. The four, linked, areas are:

- Project scope,
- Costs,
- Risks and trade-offs,
- Roles / responsibilities.

The relative importance of these areas changes over the project stages, summarised in Table 9. This table shows that the customer's information needs are greatest at the concept development and scoping stage, and that iterating around cost information remains very important all the way through to the construction and installation stage, after which the scope for variation is much smaller, although the customer still needs to understand why costs might still change. Understanding who is responsible for doing what, and who to contact becomes increasingly important once scope is reasonably well fixed at the stage of receiving tenders and confirming the project plan.

Table 8. Indicative profile of how information needs change throughout a retrofit project

	Project scope	Costs	Risks and trade offs	Roles and responsibilities
Concept development and scoping	Essential to address	Essential to address	Essential to address	Useful to address
Design, project planning and tendering	Moderately important to address	Essential to address	Essential to address	Useful to address
Receiving tenders and confirming project plan	Moderately important to address	Essential to address	Moderately important to address	Moderately important to address
Construction and installation	Useful to address	Moderately important to address	Moderately important to address	Essential to address
Commissioning and post-completion	Useful to address	Useful to address	Useful to address	Essential to address

Project Scope and Costs

The first issue to tackle is establishing whether the householder needs support with the retrofit project given the approach they take. Will it be a big, comprehensive project, potentially starting at the point of property purchase, or will a more incremental approach, a retrofit programme, get the homeowner, eventually, to the same position? From this flows the framing of retrofit as a measure-by-measure, room-by-room, or whole house. A further consideration in scoping is enabling a project scope that improves aspects of home improvement and renovation which are not directly related to energy efficiency, but which make sense, in construction terms, to do at the same time as installing EEMs. Stakeholders noted the challenges of finding contractors who were able to price and carry out both EEM and more general renovation work.

One starting point for deciding on scope is establishing whether the customer is willing to leave the home for a period of the project.

"I think it's the fabric stuff that gives people the most heebie-jeebies the most really isn't it because it's turfing you out of your house, making a mess with all the dust, basically completely gutting it in a way and putting all the insulation and piping and stuff in." Interview 3.2

Consistent with Decision 12 outlined in Table 8, described in section 3.3.1.2, stakeholders who were knowledgeable about energy efficiency and renewable energy included the costs of design, and permitting / planning, through to delivery and commissioning in their description of complete project costs, not only the costs of the energy efficiency or electrification measures. Considering the project solely in terms of improving energy efficiency might suggest that the best results are achieved by tackling a whole house retrofit[14] all at once. However, householder motivations are more likely to be addressed by recognising a project scope larger than the costs of installing EEMs. That larger scope will include costs from dismantling existing features and repairing elements or reconfiguring space all the way through to redecoration and flooring/carpets. These costs are real project costs for the householder that need to be budgeted for and needed to be included in the project scoping that drives costing, and financial support. Thus, while a whole house, all-at-once project might appear to offer best value when judged on energy performance alone, the broader project that delivers more value to the householder might be better delivered as a series of linked phases. As the following quote indicates, including more aesthetic measures in a retrofit project can help with the perceived value of the project:

"Everyone can look at, and admire a new kitchen, and that's their payback, right? But they can't look at and admire a piece of cavity wall insulation, so they need to know what it's going to pay back." Interview 3.1.

Similarly, homeowners need to be aware that retrofit will not solve all home maintenance challenges. There may still be damp problems, even once energy efficiency measures are implemented, depending on other fabric condition challenges, and in 49RR there was some discussion about whether woodworm was still a current maintenance concern, something that retrofit would not change per se.

Communicating the implications of a complete scope goes beyond ensuring that the customer understands project costs, it also needs to be reflected in the customer's understanding of the project schedule, particularly in terms of disruption and limitations on living in the home while the project is underway. Often design activities are quite technical and technology focussed, whereas the customer needs need to know the answers to questions such as: When is the roof off? When is the bathroom / kitchen unavailable? When is the heating off? When does redecoration / making good happen?

In the first two stages through to issue a tender, or a schedule to price against, and in developing the tender response, stakeholders designing and preparing costs want to know everything about a house's condition to improve accuracy and reduce risk, to both costs and energy outcomes.

[14] Fawcett, T. (2013). "Exploring the time dimension of low carbon retrofit: owner-occupied housing." Building Research & Information **42**(4): 477-488.

"We definitely need the capability of a property being properly assessed before work's done to it. So, you understand the condition of it and any specific impediments to retrofit." Interview 3.4

Given that such certainty is impossible, the discovery of asbestos is the obvious example for 49RR, as changes to both the specification and costs must be expected, and the strategies – or procedures – to deal with changes need to be agreed in advance.

As scope of work details translate into tender responses, there remains a need to keep information flowing between customer, designer or project manager, and contractor. For 49RR, an example of this is the selection of PV panels to sit flush with the roof, rather than positioning the panels on top of the existing roof, which was explained and justified as follows.

"…primarily aesthetics, but it would also have the other benefit. The more PV panels you have sitting flush, you don't actually need tiles behind it or slates behind it, the amount of slates was reduced as well." Interview 2.6

49RR illustrated that there are technology-specific requirements that customers may not necessarily be aware of, but that have an impact on the costs of the project overall. If a heat pump is being installed, discussing which radiators need to change and what this means for how the customers will use space in their home is potentially as important to the customer as identifying if any small-bore pipework needs to be replaced to enable greater flow around the heating system. New radiators needed for efficient heat pump operation is an example of where one technology requires additional project items; other examples could be appreciating the need for internet and Wi-Fi to be able to monitor and operate technology, and the potential requirement for a power supply sufficient to support electrification.

"If you're a consumer that information should really be upfront to you. You need Wi-Fi if you want this data available." Interview 3.2

Another specific information need lies in financial aspects of the project. This is separate to cost information, but rather focuses on where financing will come from. The grant or incentive funding landscape is complicated and changes regularly. The debate in this project about which elements of the contractors' costs and EEMs were liable to VAT and where VAT was not payable, illustrates that even amongst experts it can be difficult to understand the situation. In this case, the contractor took the decisions about where in their invoices to apply VAT, reducing invoices by several thousand pounds, but as stakeholders affected by these decisions observed, not all domestic building firms, particularly the SMEs that dominate work on existing properties will be confident in making such decisions.

Risks and trade-offs

Stakeholders on the design and delivery side of the project felt that customers want more certainty about costs than can realistically be provided. It was agreed that risk could be reduced, and understanding of potential impact could be increased by more testing than, for example, an EPC allows, but:

"Our challenge … is, when you introduce additional testing requirements and hardware requirements and those sort of things, it increases the upfront costs significantly for customers." Interview 3.3

If carrying out an initial comprehensive assessment of the home is considered too costly or invasive then assumptions must be made in order to design the project and to allow contractors to tender effectively. What is important is updating the design as those assumptions are shown to be inaccurate. Uncertainty is inherent in working on existing homes, so initial costs will change as the practicalities of the project are revealed, often literally, as happened with the discovery of asbestos in 49RR. It was suggested that customer needs to have a contingency fund available, rather than accepting compromises because an uncovered issue forces changes in the design, and therefore in the project outcomes.

Stakeholders report a clear trade-off between reducing risk (to financial exposure, or scope of work amendments) and initial scoping/assessment costs i.e. they believe that spending more up front will reduce later risks. However, not all risks can be avoided. There are intrinsic risks in retrofit so design and cost of detailing will vary as work progresses. However, any such changes need to be understood in the context of which elements matter for the customer's priority outcomes; which trade-offs are acceptable, and which are not? Stakeholders involved in design and assessment felt that trying to design out risks is likely to lead to a lower carbon/energy reduction as conservative assumptions will miss property-specific opportunities to improve energy efficiency.

The challenges for the customer in deciding which changes and trade-offs are acceptable is also clear when tenders are returned. Stakeholders with construction experience recognised that quotes are rarely directly / exactly comparable, and this was the case for the 49RR tenders. For 49RR, different combinations of double or triple glazing for different windows made a big price difference but the overall effect on energy efficiency, or thermal comfort, is more difficult to assess for a householder who does not have full information on the difference in performance of different price proposals.

Roles and responsibilities

Specific risks also arise when roles and responsibilities are unclear. At the 'Design, project planning and tendering stage' more voices and areas of expertise enter the discussion

> *"There's a real risk that people doing [retrofit] in that piecemeal way, with people that aren't speaking to each other won't be able to optimise it and there'll be some mistakes." Interview 3.2*

Who takes on the design risk and overall design responsibility and liability should something go wrong? Whose insurance might need to be called upon at different project stages? Who ensures that energy performance is not overlooked in any design changes? One stakeholder described this as a:

> *"…quarterback role, to say to everyone, "This is why we're doing this, and I appreciate you don't understand, from bill of quantities point of view, but this is why we're doing this thing." Interview 2.4*

Beyond these design risks, it is also at this stage that a range of regulatory and technical requirements start to emerge. Planning permission may be required, or at the very least someone will need to determine if the scope of the project is permitted development in the local context. Building regulations will almost certainly apply. Installing renewable energy equipment will involve applying for grid connection permissions as well as ensuring that installation complies with Microgeneration Certification Scheme (MCS) requirements. Any project will require clarity about who is responsible for managing these, and giving the customer reassurance that all relevant regulatory issues have been attended to so that the project achieves more than the sum of all the individual EEMs. Clearly, the need for such support will vary with project complexity, but the consistent point is that competent and qualified contractor selection is vitally important for project success.

> *"If you're choosing a contractor, you need to make sure it's somebody who's got that expertise and experience. Making sure they've got a track record of doing installations or they're backed by somebody who does." Interview 3.9*

It is at the 'Construction and installation stage", once a tender has been accepted and project implementation gets underway that the customer needs to know who their primary adviser is. There are lots of different elements with specialist knowledge in any home improvement, and energy efficiency just adds more information into the mix. How does the customer understand and navigate the many small decisions that need to be made as a project progresses? The management and co-ordination of contractors and subcontractors is vital but will go beyond the capacity of most homeowners. Co-ordinating a range of small contractors may reduce overheads and mobilisation costs, but it will require more co-ordination time, which needs to be paid for.

As already outlined, any construction work on an existing building means that the scope and detail of work will change once work starts on site. At the most basic level, stakeholders across the board emphasises that the customer needs to know how to access someone who can help and inform them both during and after the project.

> *"The key thing that customers need to know at this point in time is, again, what to do if they find something unknown." Interview 2.5*

It is worth noting that this group of stakeholders did not present an 'us and them' situation where the needs of the customer and the contractor were in tension. There was a sense of shared responsibility to achieve a successful project.

> *"You have a responsibility, a little bit, as a contractor, to help them out along the way." Interview 3.9*

Responsibilities continue into the "Commissioning and post-completion" stage although they are easy to forget in the relief of final invoices being issued and paid. Not all stakeholders have a clear understanding of what the post-completion processes might be, covering commissioning, snagging, handover and maintenance. Client-side stakeholders valued the careful handover process for 49RR, including operational videos and a 'cheat sheet' of instructions alongside the voluminous O&M documentation. The handover enabled different building users to understand that lower flow temperatures do not lead to colder rooms, and to know not to turn the heating on or off.

On a more technical front, customers need to be aware that proprietary products may have warranty requirements. For example, an annual service is needed to maintain warranty validity, then some way of prompting or scheduling this would be useful. What warranties are there, what do they cover, and how does the customer use them, if they need to?

Finally, there is the need to monitor and evaluate the impact of the retrofit and its objectives, especially if a preferential loan product or grant has been used. Evaluation needs to involve checking the quality of the works done, and potentially validating the installation, if that has not been achieved through other regulatory measures like building control or MCS accreditation. 49RR stakeholders held a financial retainer, as is common practice in commercial construction projects and there was some suggestion that this could be useful in smaller domestic projects, if the issue of who was able to certify completion and release the retainer could be resolved.

Stakeholders expressed a desire to gather data which would enable them to look beyond financial metrics to establish the “business case” – and the success – of the project.

3.3.4 Developing a Retrofit Advisory Service

This section looks across all the characteristics that stakeholders identified as part of a successful retrofit project (section 3.3.3) to reflect on what **customers’ needs** are, so that these can be reflected in scoping a retrofit advisory service, and the actions of Skipton in broader support of their customers and members.

The interviews with stakeholders all, in different ways, asserted that a householder, or single property retrofit customer, needed ‘handholding’ through the many decisions that needed to be made over the entire project lifecycle. While some of the support can be delivered online or via an app which included information, guidance and a project route map, there was usually an expectation that a client would be able to talk to someone who knew their property and their project if they had queries.

Clearly, the need for such support, and who is well placed to provide that support, will vary with project complexity. Following the five distinct stages of stakeholder activity for the 49RR project, helpful customer support activities to improve the likelihood of a successful retrofit project include

Concept development and scoping

1. Understanding current situation in terms of building energy performance, building fabric and in terms of how customers would like to improve their homes.
2. Eliciting customer priorities for any home improvements.
3. Eliciting customer constraints e.g. are they willing to move out of the property for a period? do they have specific access needs?
4. Developing realistic budget, informed by any grant, finance or incentives available, and establishing an expectation that the budget should include a contingency element.
5. Ensuring the project scope is the entire project scope from the customer’s perspective, not only the cost of installing EEMs
6. Deploying a consistent methodology for working out whether a single project or a programme of an incremental measures is the best option for this householder and what that means for the budget/finance, and benefits that the householder will feel.
7. Providing plain English explanations of what the project or programme might be, expressed in ways that align with the customer’s stated priorities.

Design, project planning and tendering

8. Enabling customers to understand the detail of an entire project in their home, potentially through use of a checklist.
9. Explaining common risks, the things that have to remain uncertain until a project gets under way, and some ways of dealing with those risks if they arise.
10. Clarifying and documenting known risks and who is responsible for risk mitigation, or is liable if things go wrong.

Receiving tenders and confirming project plan

11. Homeowners are more likely to get quotes from contractors as opposed to going out to tender. Therefore, support customers with quote evaluation, particularly if there are multiple quotes, because even with the same specification, contractors will include different products and assumptions in their quotes, so that the customer understands the impact on energy and comfort and other priorities, as well as budget.
12. Support in sizing a contingency budget, using a set of known risks.
13. Enabling the customer to be assured that regulatory and permitting requirements and compliance are covered, potentially through use of a checklist.
14. Developing project plan timings to fit around customer constraints.
15. Agreeing invoicing and payment schedules and any requirements to be met.
16. Identifying specific roles, responsibilities and potential liabilities.
17. Providing a single point of contact if the customer has queries about the project plan and quote costs, and having an agreed and consistent way of communicating and sharing information.

Construction and installation

18. Project management and co-ordination of contractors; lots of different trades are connected or even dependent.
19. Continuing to provide a single point of contact if the customer has queries about the project delivery, and using an agreed and consistent way of communicating and sharing information
20. Given that improvisation is inevitable, and changes to the project will occur, helping the customer agree what is ‘acceptable’ improvisation and what impact that might have on the customer priorities, including energy performance.
21. Support in managing contingency funds.
22. Ensuring warranty requirements are met.
23. Validating invoices for payment., confirming that work has been completed to agreed standard (and checking if VAT is being applied correctly).

Commissioning and post-completion.

24. Ensuring careful commissioning, clean up and handover. This includes the post construction checks that give the householder, and the potentially the funder, that what was specified has been completed.
25. Ensuring ongoing monitoring and evaluation, fed back to customer as part of ongoing support.
26. Helping the customer set up planned maintenance, including ensuring that warranty requirements are met.

27. Supporting the customer in any learning they need to be able to use their home in an energy efficient but also comfortable and enjoyable way.

Looking beyond the individual customer's needs, stakeholders also identified several **possibilities for Skipton to play a role in influencing the financial landscape of retrofit** (on behalf of customer interests).

Picking up on the very first item of support that customers need as listed above, the need to understand the existing home performance and function, stakeholders felt there would be value in something that extended beyond the EPC to be more like a HomeBuyer report, a standard cost at the time of home purchase, to include recommendations for a programme of work, reflecting realities of the property. If generated at the time of purchase, which stakeholders recognised as a key window of opportunity for decisions to make changes to a property, such an additional report is a tiny fraction of the overall transaction cost, but it could be available at precisely the point where a new owner might be more willing to contemplate disruption. Such a plan or list of actions, created to a standard template but reflecting the property specifics, could also be helpful in getting quotes from contractors, should the homeowner want to proceed with general home improvement, with retrofit a useful by-product of work that the homeowner wants to undertake anyway.

Mortgage providers such as Skipton are present in homeowners' lives at the specific window of opportunity provided by moving home. This window of opportunity might provide a different lens on retrofit depending on whether the purchaser is thinking about a "forever home" or some other lifestyle change such as having children, or downsizing. Stakeholders noted that mortgage brokers are a key actor on Skipton's behalf, and that this group is currently not engaged. Linked to this is how properties are valued. Stakeholders noted current surveyor property valuation practices rarely consider retrofit, as value is determined relative to neighbouring properties, and few have EEMs for comparison. They felt these practices required modification at the industry level to capture value added through retrofit.

Reflecting further on the opportunity for the finance sector to influence the landscape that accelerates retrofit and broad improvements in the UK's housing stock, there could be scope for the finance sector to provide demand for design templates or pattern books which enable 'mass customisation'[15]. An architect's expertise - and fee - can be highly valuable work for derisking projects and ensuring quality outcomes, especially in more complex properties so bundling up projects is essential to achieve some economies of scale on these fees. Of course, every home is different once it is occupied, but for a major proportion of property types on the loan book "*the average Terry and June 1970 semi*" or other large categories, there ought to be some standard measures and details which could be attached to the condition report and extended home improvement plan. This would allow other technical property professionals, with surveyor-type skills, to help the homeowner move from plan to action in a more affordable way. Stakeholders noted that it is important that this is an advisor, not a sales, role, although this leaves open the question of who carries the risk – and liability – for design decisions, if the standard designs and specifications are not effective.

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[15] Barlow, J. (1999). "From Craft Production to Mass Customisation. Innovation Requirements for the UK Housebuilding Industry." Housing Studies **14**(1): 23-42.

These comments address the needs of single dwelling owner-occupier retrofit clients. Stakeholders also identified that there were different needs in social housing and in the private rented sector. Social housing has had specific financing opportunities through public funding, e.g. the Social Housing Decarbonisation Fund, and is also able to operate across multiple users in a way more familiar to commercial construction, albeit with a distinct and sometimes vulnerable set of residents.

Stakeholders talked predominately about the private homeowners. However, some discussed rental properties and what motivates landlords to improve the energy performance of their homes. The private rented sector has specific needs, and different regulatory drivers as the expectation that all rented properties will meet EPC band levels takes hold. For example, all privately rented homes in England and Wales needing to achieve a minimum EPC rating of C by 2030. This sector also has a distinct mortgage provision, sometimes through buy to let loan products, and will therefore need different support to improve energy efficiency. The situation is complicated by the fact that any reductions in bills, which are assumed to be the main motivation to implement EEMs, do not reduce the landlords' costs although, as described above, the cost incentive of bill reduction is not clear cut in homes of other tenure either.

4 Conclusions and recommendations

4.1 Impact of retrofit on energy performance

Pre-retrofit, the energy performance certificate (EPC) score for 49RR was 58 (D rated), slightly below the national average of 60, making the house a fitting case study to investigate potential improvements from EEMs. However, EPCs only give a rough estimate of a building's thermal performance. For this project, LBU conducted several detailed tests to determine the impact of installed EEMs on the building fabric. Tests determined the overall heat loss, airtightness testing for air leakage, U-value measurements for heat loss of individual elements, and thermal imaging to identify areas of unusual heat loss at both the pre- and post-retrofit stages. Pre retrofit tests were conducted between November and December 2023, and post-retrofit tests were conducted between November and December 2024.

The HTC describes the overall heat loss of a property. The lower the HTC, the less heat is being lost from the inside of the property to the outside. The pre-retrofit HTC of 322±15 W/K measured at 49RR is typical for a property of this age and size. The EEMs have reduced overall heat loss by 175±17 W/K, amounting to approximately a 54% reduction. The retrofits have reduced air permeability by 5.4±1.3 $m^3/(h.m^2)$@50Pa, amounting to approximately a 47% reduction and drastically reducing the amount of heat lost through air leakage. All elements achieved considerable reductions in U-values. The U-values for the floor, ceiling, walls and fenestrations (windows and doors) fell by 80%, 77%, 67% and 45% respectively. The post-retrofit EPC score for 49RR was 87 (B rated) which is higher than the median EPC score for a newly built home.

The project was highly successful in improving the energy efficiency of 49RR. While many innovative and complex insulation retrofits exist, the building fabric EEMs installed here were simple. The energy savings achieved are encouraging and suggest significant savings can be made by installing basic measures to a high standard. The area where retrofit activity needs to be strengthened therefore, is not in the debate over technologies and materials, but in how to ensure quality installations, carried out in a way that meets specific property and household requirements.   The success of the 49RR project provides evidence that retrofit, alongside renovation, does provide the opportunity to decarbonise Skipton' and other providers' loan books.

4.2 Themes from qualitative research – stakeholder perceptions

Over the project's duration, stakeholders described the impacts of around 50 key decisions. We have divided the project into five stages of Concept development and scoping; Design, project planning and tendering; Receiving tenders and confirming project plan; Construction and installation; and Commissioning and post-completion. Notably, Skipton as the "homeowner" had to make a high volume of decisions often at speed during the project, which was challenging at times. Decisions before and after the 'Construction and installation' stage were made by Skipton's Group Sustainability Team. During construction, Skipton's Building Shared Services Team assumed greater responsibility in influencing decisions based on their expertise. This suggests that diverse competencies are required at specific stages of a retrofit project to facilitate the numerous decisions that need to be made. While one of the project's objectives was to trial ESRPO's "with you all the way" service, Skipton as a business entity could not replicate a homeowner's journey, resulting in discernible differences emerging between the two pathways.

Six distinct themes were identified from interviews with stakeholders encompassing, client, design, project management and delivery perspectives. These themes have different questions associated with them, and different priorities to be addressed, at different stages of the project. The themes are:

- **All retrofit projects will entail risks and uncertainties** which are inevitable in undertaking work that changes an existing building; a project working on an existing property cannot be fully understood and accurately detailed until the interventions are under way. Uncertainties arise from gaps in data and also being unsure who is responsible for taking decisions, and who carries the risks of cost, time or performance that come with taking those decisions. Additional investment in time to assess a property initially is helpful in reducing uncertainty, but this uncertainty cannot be fully removed. The initial investment to reduce uncertainty appears to be an upfront cost to the customer, with little clear signalling of the value and payback of this initial investment.

- **While achieving a reduction in bills is perceived to be the primary customer concern, retrofit projects cannot clearly guarantee this saving.** Energy bills are affected by tariffs and energy costs as much as by improving energy efficiency. ‘Comfort taking’ will also limit reductions in energy bills, as increased energy efficiency can increase energy demand by allowing a household to be able to afford heating their home to a higher temperature. There therefore needs to be a convincing description of the value of the project in terms of comfort, quality of the home, aesthetics, usable space, noise reduction or, potentially, property value. Therefore, co-benefits such as having a warmer home, with health benefits for the household, while staying – or becoming – affordable is important[16]. It is also worth noting that this research gathered stakeholders’ opinions and has involved no empirical testing of the assumption that bill reduction is customers’ primary concerns. Further customer research which explored motivations for retrofit, and for renovation more broadly, particularly where financial support would be needed, would be helpful in ranking different possible values and returns, while also relating these to customer characteristics in terms of life stage, demography, etc.
  This in turn relates to **the need to position retrofit work as part of a programme of home improvement and repair,** where the value might also be achieved in terms of increasing usable space or dealing with other challenges in the property, such as damp. It is currently very difficult for a homeowner to see the value in big, one-off programmes of change, beyond the windows of opportunity provided by moving house[17], so there needs to be a way of putting retrofit into a broader programme of work. An additional, related challenge arises from the difficulty of making retrofit visible, and therefore valuable, to a household. If retrofit activities were positioned as part of a broader programme of home improvement, this could help make retrofit more aligned with customer priorities. For 49RR, this might have meant remodelling and more visible elements of design activities, such as expanding into the loft, or creating an ensuite bathroom etc. If design fees are incurred, as they should be, it can be helpful if there is more evident ‘design’ in what is achieved.

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[16] Mills, E. and A. Rosenfeld (1996). "Consumer non-energy benefits as a motivation for making energy-efficiency improvements." Energy **21**(7–8): 707-720.
[17] Schäfer, M., et al. (2012). "Life Events as Windows of Opportunity for Changing Towards Sustainable Consumption Patterns?" Journal of Consumer Policy **35**(1): 65-84.

- There are many people involved in a retrofit project or programme, from the multiple inputs to design, through to the variety of installation and fabric/buildings skills being deployed in project delivery, through to supporting homeowners to live comfortably in their homes. Mapping **who does what, and who knows what** at any given time will be slightly different for each project, but having a general pattern of who is advising the homeowner and who is managing the risks of different stages is essential.

- Connected to this is the need to pay careful attention **to comprehensive, and comprehensible, communications** throughout the project or programme. Setting expectations about disruption, what activities happen when, with what result, and how any inevitable changes to the programme will be decided upon and managed is also essential.

  Finally, and easily overlooked**, project handover and post-completion support for customers** in getting the most value and comfort from their retrofitted homes is vital[18], not least in being reassured that the work has been done well. Retrofit improvements do not end when the contractors' vans leave. While accessible materials such as videos of the specific changes made in that home are very helpful, research suggests there is also a largely unmet need for ongoing help when aspects of lifestyles change or when customers are simply overwhelmed and need a simple refresher on any actions they need to take.

[18] Owen A, Mitchell G, Gouldson A. (2014). Unseen influence-The role of low carbon retrofit advisers and installers in the adoption and use of domestic energy technology. *Energy Policy.* 169-179 **73**

4.3 Where Skipton and the wider Group can make a difference

Based on these evidence-driven insights, the final section of the report offers suggestions for further action that Skipton Building Society and the wider Group could take to support customers in taking retrofit action and thereby reducing the carbon intensity of Skipton's loan book. These include:

4.3.1 Customer support

Customers need guidance they can trust in developing a full retrofit plan, and then need support in deciding if this is most achievable measure by measure, room by room or as a whole house retrofit. As identified in section 3.3.4, the need for support will vary with project complexity, as will the range of people who are involved.

Once a plan is in place, customers then need help in navigating the many complexities of their specific project. A checklist that enables the customer, supported by professional/technical expertise as appropriate, to appreciate the complexities of the project and the kind of things that could go wrong, as well as strategies for dealing with those issues should they arise, would be valuable. During the project, customers would also benefit from access to a platform or app which acts as the single source of information and reference point for decisions (and implications of those decisions) rather than a proliferation across multiple platforms of design details, supply details, project schedule, photos, amendments etc. A map of "who does what" (and why) in renovation/retrofit to make roles clear would also be a very helpful addition to the information given to customers to help them understand who is involved in the project. A further checklist for handover and post-completion maintenance, to help with evaluation and also provide reminders of how to work the technology and live comfortably, together with anything the customers need to do, like annual servicing, to keep warranties valid would make it easier for customers to be confident that the project had been worthwhile.

These checklists and tools might be most effective if developed as part of sector-wide agreements and standards, although there may be a distinctive proposition that Skipton could offer its customers, building on WSGO2's retrofit service or ESRPO's "with you all the way" approach. If acting alone is not the preferred route, then it may be feasible to work with other lenders or to spearhead a working group in a cross-sector organisation such as the Green Finance Institute or the Building Societies Association.

An action that has most value as a cross-sector initiative, ideally co-ordinated with government departments, would be an accessible portal for homeowners to get advice on current funding grants and incentives, searchable by location as well as technology type and property type, and tenure.

One further action is suggested for consideration. Having commissioned this research, Skipton is in a strong position to be straight with customers when there are so many confusing messages. Skipton can state with confidence that retrofit does improve energy performance of homes, if it's done with attention to detail and quality. However, financial payback cannot always be assured as there are too many other variables which affect energy bills. Energy efficiency could be positioned as a side benefit from going about home improvement in a way that makes the home more comfortable, usable or valuable, reflecting homeowner priorities. Focussing on bill reduction is likely to require partnership with an energy retailer[19] which brings many additional complications.

4.3.2 (Financial) Product development

This research identified two specific considerations to make loan finance for retrofit function effectively, in addition to the existing lending assessment criteria of credit rating and affordability. First, reflecting the uncertainties of retrofit – or renovation – loan products could automatically include a contingency, while still adhering to affordability guidelines, based on checklists of known risks that can arise once a project is on site. The checklist would include guidance on how to decide if a scope change is acceptable, given the implications for costs and project outcomes. Second, loan products and associated repayments could include professional fees for effective scoping, design, project management and evaluation into the overall project cost and loan product offering, as using professional expertise reduces the risk in achieving the intended project outcomes in terms of energy efficiency and quality.

In terms of developing products which unlock a greater scale of retrofit and carbon reduction activity, it could be possible to look for opportunities to group[20] together properties which could benefit from retrofit and work with designers/contractors to package these up into more cost-effective projects with a connected programme of financial support. Such packages of activity might be area-based, and developed in collaboration with local or combined authorities, taking the learning from social housing decarbonisation into the private owner-occupier market. Given that architects and designers need volume to make designing retrofits financially feasible for their practices, there is a potential role for loan providers role in grouping together assets and then financing the design across a set, either of the same archetype or in the same location.

A bespoke product offer for landlords is also worth evaluating. Private rented landlords will have different financing requirements, but also have specific pressures, deadlines and standards to meet too.

4.3.3 Work with policymakers

The need to find mechanisms to position retrofit as part of a programme of home improvement work has been a repeated theme in this research. While not explored in this research, supporting the next stages of the Green Finance Institute's work on "building renovation passports"[21] could be one such mechanism helping to finance planned programmes of work rather than big one-off projects. A complementary approach, which was discussed by

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[19] *such as Lloyds TSB working with Octopus on Leeds Local Low Carbon Accelerator*
[20] https://www.greenfinanceinstitute.com/wp-content/uploads/2024/06/GREEN-FINANCE-BUILDING-RENOVATION-final.pdf
[21] A Building Renovation Passport has many similarities to a car log book, staying with the asset rather than the owner. It contains both a record of what has been previously done to the house, and also a plan or suggestions for further improvements that could be made – see footnote 20.

stakeholders, is to explore how a retrofit plan might become part of the property sale process, expanding on the EPC into a more meaningful list of actions, opportunities and possible benefits, as a standard part of purchasing a property, similar in cost to the HomeBuyer Report. Making the case for incentives and grant support to cover total retrofit project cost, meaning that incentives are associated with energy performance, rather than specific technologies or equipment. This would then allow the ancillary costs of installation, pipework and changes to fabric to be scoped as part of a retrofit project and reduce the additional costs that householders have to find, and potentially enabling those householders to use the savings they had allocated to home improvement such as a new kitchen or a change to room layout as match funding for retrofit work.

A trickier issue might be whether the finance sector, including insurance, could come together to explore the issue of liability and insurance for design risk? The intrinsic unknowns in undertaking quality retrofit work mean that it is entirely possible to come across issues which require a project to decide between expensive design changes or losing the full energy reduction potential. Are there sector wide standards and insurance cover that might spread this risk wider than individual homeowners or architects?

Uncertainty about where VAT is incurred remains a major issue in understanding costs. Where does energy efficiency work end and ancillary work begin? Support from the finance sector could help trade organisations (e.g. Builders Merchants Federation, Federation of Master Builders) communicate widely and keep guidance to their members updated. In addition, *c*urrent VAT relief on EEMs is only confirmed until 2027.

5 Glossary

Air Permeability	The air movement into or out of a building at a defined pressure (in this case 50 Pascals) per square meter of building envelope area. Mean air permeability is the average of both pressurisation and depressurisation tests.
AECB	Association for Environment Conscious Building, an organization promoting sustainable building practices.
Air Source Heat Pump (ASHP)	A heating system that extracts heat from the outside air to heat a building.
Blower Door or Airtightness Test	A test used to measure the airtightness of a building by pressurising or depressurising the interior.
Coheating Test	A method used to measure the overall heat loss (HTC) of a building by heating the interior to a constant temperature and monitoring energy consumption.
Energy Efficiency Measures (EEMs)	Modifications or improvements made to a building to reduce energy consumption and increase energy efficiency.
Energy Performance Certificate (EPC)	A document that rates the energy efficiency of a building on a scale from A (most efficient) to G (least efficient).
EnerPHit	A certification standard for refurbished homes using Passivhaus components.
Heat Transfer Coefficient (HTC)	A measure of the overall heat loss of a property, typically measured in watts per kelvin (W/K).
PAS 2035	A publicly available specification for the energy retrofit of domestic buildings.
Passivhaus	A rigorous, voluntary standard for energy efficiency in new homes.
PHPP	Passive House Planning Package, a design tool and software package for energy-efficient buildings to reach Passivhaus and EnerPHit standards.
RdSAP	Reduced data Standard Assessment Procedure, a method for assessing the energy performance of existing dwellings.

Retrofit	The process of adding new technology or features to an existing building to improve its energy efficiency and performance.
Thermal Imaging	A technique using infrared cameras to visualize and identify areas of heat loss in a building.
U-value	A measure of the rate of heat transfer through a building element, such as walls, floors, or windows, expressed in watts per square meter per kelvin (W/m^2K). Lower U-values indicate better insulation.

Annex 1: Stakeholder key learning and 'top tips'

As part of the interview protocol. At the end of every interview, all stakeholders were asked what they felt their key learning from the project was, at the point at which the interview took place, and what "top tips" they would pass on to other actors considering undertaking a domestic retrofit project.

The themes and ideas from these responses all appear in section 3.3. However, it might be useful to see the ideas as stakeholders presented them to the researchers, therefore this Annex presents them as learning and "top tips", as they were offered.

Responses are summarised, grouped by whether people identified them before, during or after the project, in the first, second of third waves of interviews.

Wave 1: Key Learning and Top tips

- Get clarity about the project goals – be sure of what you want out of a project (what's essential, what's nice to have) to aid decision making throughout project life.
- At the beginning – determine the customer budget and are they willing to leave the property – that shapes what the feasible project might be.
- It's helpful to understand retrofit (or renovation) as an upgrade / improvement project rather than a single intervention. There are different pathways to the same outcome – one big project or measure by measure, room by room. Could retrofit be made a routine, planned, part of maintenance and improvement?
- RIBA Stage 4 (or equivalent) is where client discussion / understanding / value-add can happen.
- The focus on (expensive) technology should not always be the starting point. While "fabric first is a mantra in retrofit, interviewees also made the point:

  > *" If you don't have 15 millimetre pipes and you don't have up-to-scratch radiators, then you don't really know how good your boiler is." Interview 3.9*

  although also acknowledging that this would not improve environmental performance.
- Recognise the complexity of the home as system and retrofit as a project (like renovation!).
- Detailing, and learning by doing, both lead to uncertainty and risks – acknowledge them as that's better than avoiding them.
- Think ahead to what could go wrong so that you make the right decisions about warrantied products, contractors etc.
- There is always uncertainty in costs and designs until a job starts and the contractors start [asbestos illustrates this]. This is why it's important to have a contingency fund
- Projects / plans needs to be scoped in their entirety, including consequential works – not just identifying a heat pump but identifying if the power source is sufficient to run the heat pump.
- Look beyond financial metrics for the "business case"
- Need to establish clear roles from the outset.
- Customers need to be asked to take decisions at a time that they are able to make them.

- Do research (and prior assessment!), but also share information with trusted / accredited networks. Working with people that can give recommendations leads to social propagation of idea by neighbours or from colleagues.
- Understand what's going on from the contractor's point of view when they are costing your job – who they are approaching and how many levels of subcontracting and the design work needed.

Wave 2: Key Learning and Top tips

- Identify a single mode for information sharing between designer, installer(s), project manager and client/homeowner.
- An area where personal contact and on-site help is essential is in project delivery. Information flow between main contractor and subcontractor, so that measures are integrated across the home/project, is essential. The supply chain for smaller projects, where Skipton is not the customer, can be fragmented, variable in quality and difficult to manage. This is another area where customers need help and support so they can be confident of what they're investing in.
- There is a highly valued personal element to this, which is removed if a process is entirely remote and virtual.
- It's worth taking time over decisions to avoid rework – but that also means the contractors have to be patient – and how can this be achieved when extending elapsed time incurs additional labour costs.?
- One stakeholder suggested that it's best to work with contractors who have their own labour, as subcontracting introduces risks and uncertainties due to competing priorities and challenging information flows.
- Unforeseen issues are bound to arise – like access to the EV charger, or the need for internet access and Wi-Fi to control the renewable technology.
- Extra work comes up from doing the job – cracked paving tiles that need to be replaced, for example.

Wave 3: Key Learning and Top tips

- Look beyond financial metrics for the "business case" – and for monitoring success.
- Homeowners are not all the same!

Interview 3.1 "you can never underestimate, I think, the just differing levels of knowledge out there in the market with homeowners,"

- Have a contingency – you can't really know the extent and detail of a project until you've "opened up" the house (good advice for any home improvement!)
- Heating a house with a heat pump is different (and easier) than what homeowners with GCH are used to

"The most important thing when you're changing from gas central heating to an air source is sort of changing your mentality over how your thermostat works." Interview 3.9.

- The homeowner needs help "*upskilling*" to both manage the technology and live comfortably in their home!
- When selecting a contractor, think about what they offer in terms of support, as well as their price. Will there be someone to call directly if you have queries?

- Quality of technologies does vary depending on specific supply chains. This isn't visible to most householders, so how does quality get embedded? The specific example was about the quality and installed risks of inverters and batteries.
- Make the before and after visible – either through an EPC or some other measures of experience.
- Cheat sheets and videos are good practice for commissioning and handover.
- Even with this project, there were some follow up issues to keep an eye on (residual damp, woodworm, render clearance being perhaps a little tight and meriting monitoring).
- Retrofit is not (yet) seen as investing in property. It's seen as a cost.
- One stakeholder suggested two vital elements (a) incentives – financial – to invest in things that can't be seen and (b) a one stop shop to hold the customer's hand through the entire journey, including navigating the finances of loans, grants (national and local), and VAT!

Annex 2: Pre-retrofit airtightness report

Skipton Building Society

Airtightness & Thermography Report

Address: 49 Regent Road, Skipton

Date: 17th November 2023

Testers: Felix Thomas, Adam Hardy, Dominic Miles-Shenton

Airtightness Result:

Date	Details	Depressurisation Only			Pressurisation Only			Mean	
		Permeability	Air Change Rate	r^2	Permeability	Air Change Rate	r^2	Permeability	Air Change Rate
		$m^3/(h.m^2)$ @ 50Pa	h^{-1} @ 50Pa		$m^3/(h.m^2)$ @ 50Pa	h^{-1} @ 50Pa		$m^3/(h.m^2)$ @ 50Pa	h^{-1} @ 50Pa
17-11-2023	Pre-retrofit	11.16	10.43	1.000	11.79	11.02	0.999	11.47	10.73

Conditions:

External Temperature 11.0 °C Internal Temperature 20.1 °C

External RH 68.2 % Internal RH 50.5 %

External Pressure 999.3 mbar Internal Pressure 999.3 mbar

Wind Speed <0.2 ms^{-1}, no gusts.

Dry, broken cloud, possible rain in previous 24hrs.

Observations:

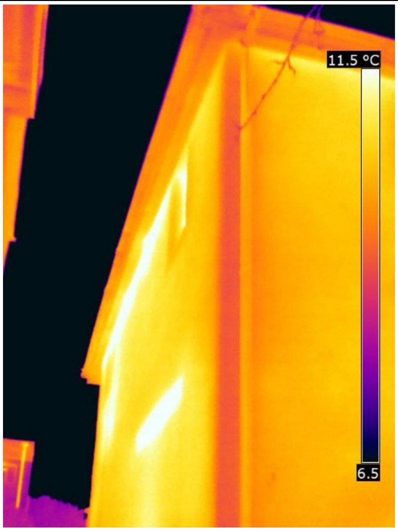
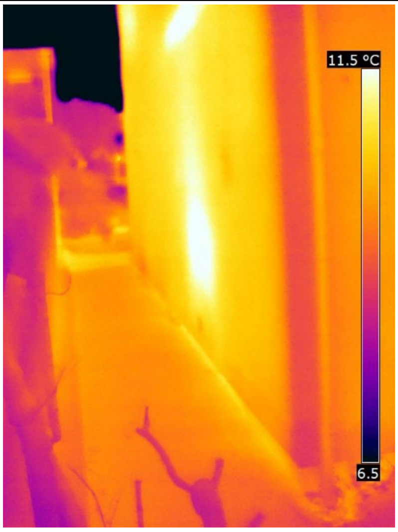
A pressurisation test was undertaken on the dwelling prior to retrofit. The blower door test was conducted under both depressurisation and pressurisation, the measured mean air permeability was 11.47 $m^3/(h.m^2)$@50Pa and the air change rate 10.43 h^{-1}@50Pa. Airtightness was slightly better under depressurisation than pressurisation, possibly due to the outward opening windows and non-draught-stripped loft hatch being pulled closed under depressurisation. Flow exponents of n=0.607 and n=0.610 were recorded for depressurisation and pressurisation respectively, indicating air leakage was mainly due to airflow through cracks and gaps rather than permeating through materials (0.5<n<1, lower values of n imply less turbulent airflow through gaps and holes, higher values represent more turbulent flow).

Following the depressurisation phase of the test, 2 vents on the chimney breast were discovered which had not been sealed. These were temporarily sealed for the duration of the test. Spot 50Pa measurements were conducted and showed that sealing these vents only reduced the air permeability by <1%, negating the need to repeat the depressurisation phase of the test.

A ΔT=9.1K was sufficient for a brief thermographic survey to be carried out prior to the test and some thermographic leakage detection to be undertaken immediately following the depressurisation phase of the blower door test at an average -50.2 Pa. Some internal and external thermal images were captured prior to depressurisation and are included for context and comparison. Neither thermal survey was comprehensive, but were quick surveys performed to indicate the more severe and easily accessible issues which may impact on the coheating test being set up.

The main direct air leakage paths to outside were detected at penetrations and openings, direct leakage paths into the suspended floor void and loft void were also observed. The main indirect leakage paths identified were through boxed in services and into the voids behind kitchen units.

External Thermal Images:

		Direct sun on the front and south side of the house prevented thermographic imaging. On the north side a warm strip was visible at the eaves. Also, where a window had been filled in at the dining room warmer areas were visible at the lintel and where a radiator was positioned on the external wall beneath it.
		
		The rear elevation showed a warmer area in the bathroom, which had a higher internal temperature than the rest of the house, and at the patio doors in the dining room.
		Again, a warmer strip was observed at the eaves and potential thermal bridging at the lintel.

<table>
<tr>
<td></td>
<td>
</td>
<td rowspan="2">The patio door frame appeared to perform particularly poorly from a thermal perspective.</td>
</tr>
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<tr>
<td></td>
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</td>
<td rowspan="2">Even with recent solar on the front of the house, warmer areas were visible around the radiator in bedroom 3 and above the front door where pipework for that radiator ran through the intermediate floor void and through the area exposed by the recessed front door.</td>
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Loft Thermal Images:

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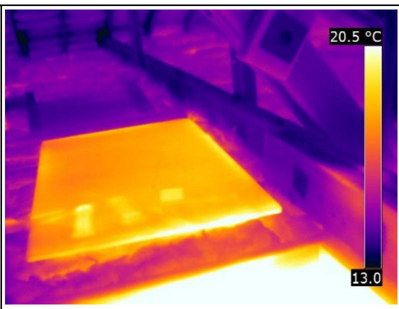
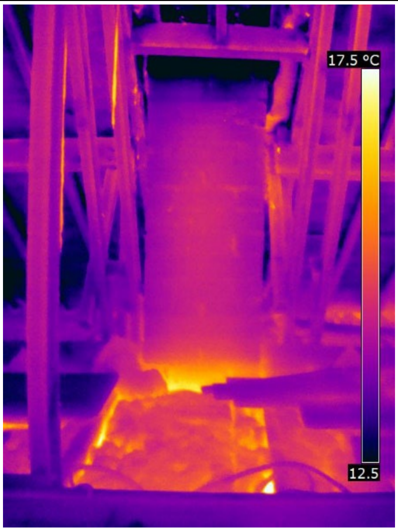
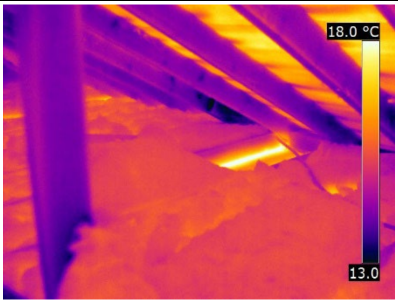
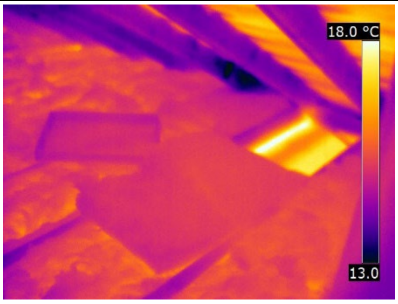
<td>
</td>
<td>The loft hatch was uninsulated and unsealed, appearing to consist of just a sheet of MDF.</td>
</tr>
</table>

		Images were captured from the loft hatch looking towards the front of the house and then moving anti-clockwise around the loft.
		Loft insulation was present between the joist with an approximate thickness of 100mm. This insulation was compressed in many areas by boards lying on the surface. Breaks in insulation occurred where deeper joists ran and where the blockwork for internal partition walls extended through it.
		
		The chimney was positioned between bedrooms 1 & 2, thermal bridging was observed where the chimney penetrated the ceilings. A potential thermal bypass heat loss mechanism may exist, where air within the chimney is being heated within the building envelope, and that heated air id moving up the chimney and exiting at the top.
		

<table>
<tr><td></td><td></td><td rowspan="2">The water tank above the bathroom was covered with a polythene covered insulation quilt, but there appeared to be no insulation beneath it. Insulation had been moved away from the bathroom downlighters to prevent them overheating, consequently leaving areas of uninsulated ceiling.</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td><td rowspan="3">Above the WC and bedroom 3 cupboard there were missing areas of insulation around the downlighters and where a roll of loft insulation appeared to have been rolled back to expose the plaster ceiling beneath.</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
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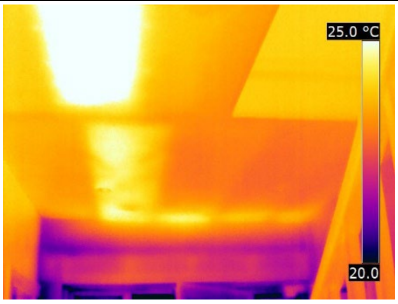
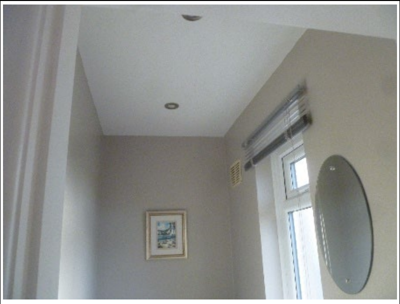
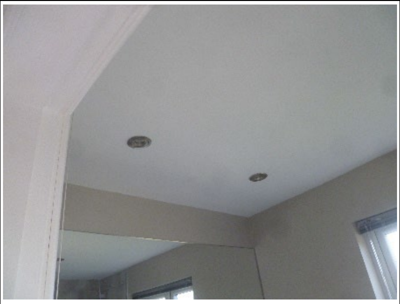
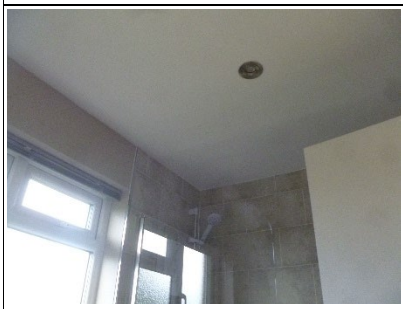
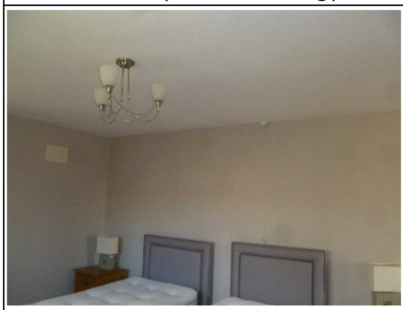
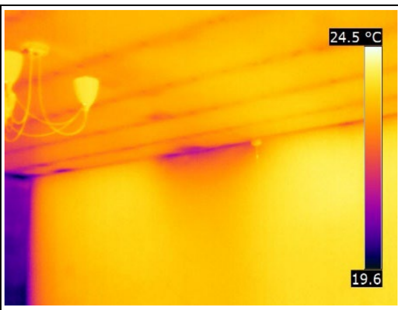
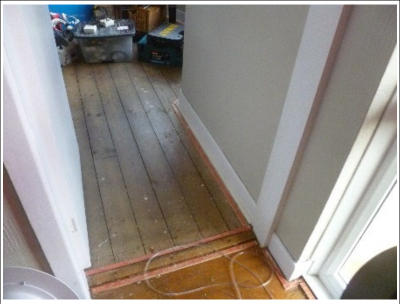
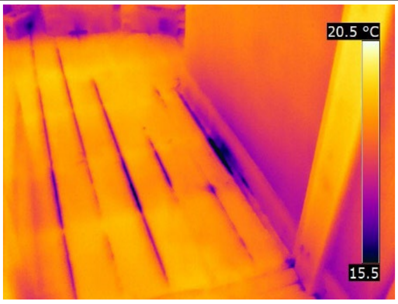
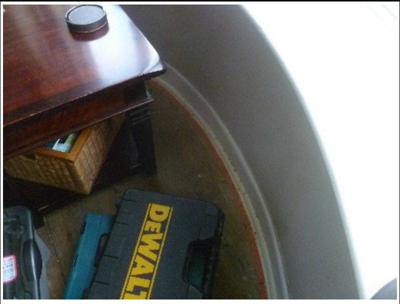
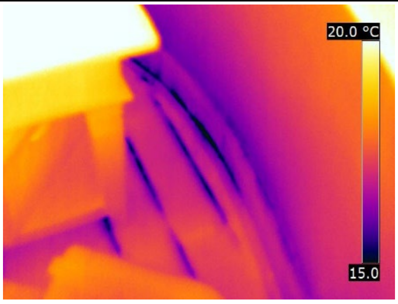
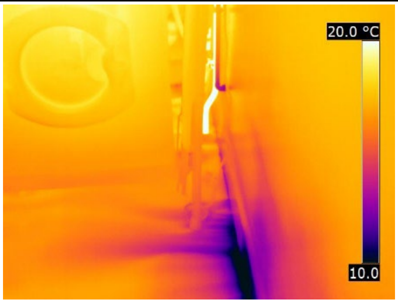
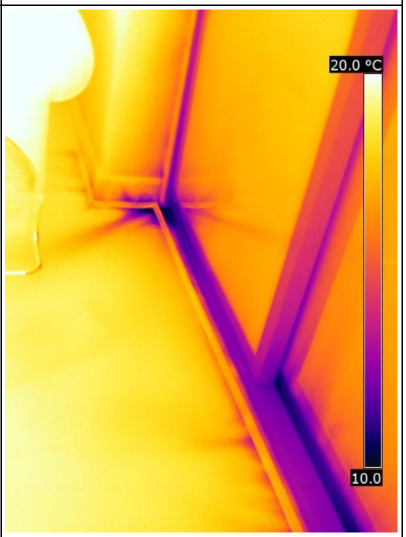
Internal Thermographic Observations (no induced pressure differential):

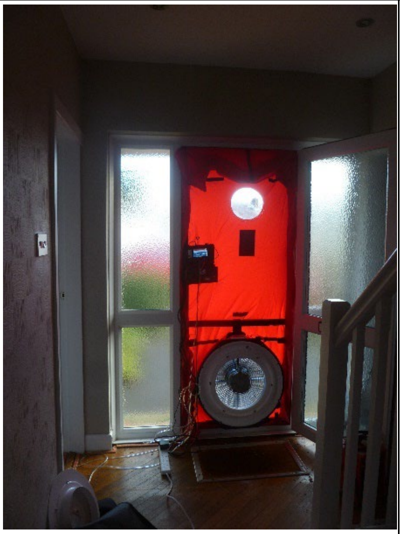
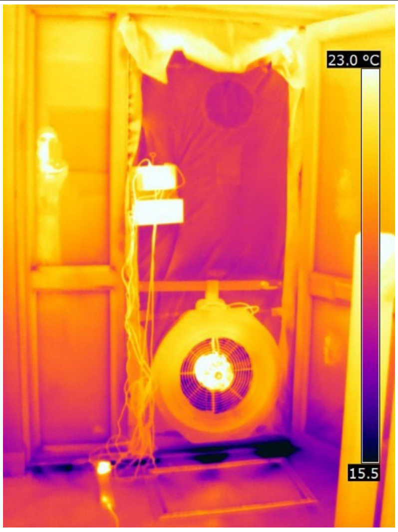
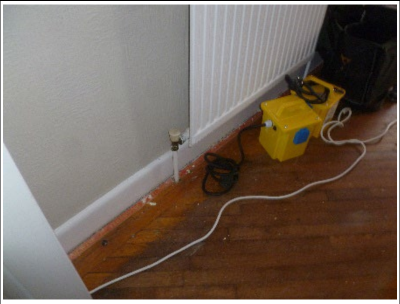
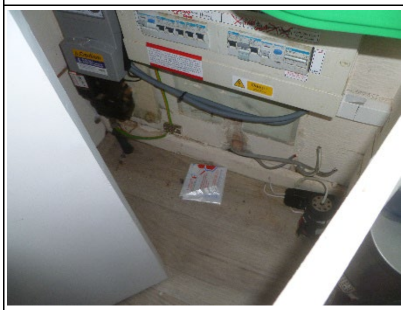
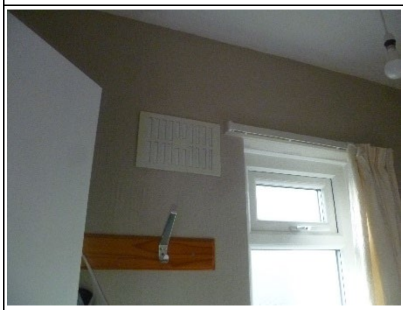
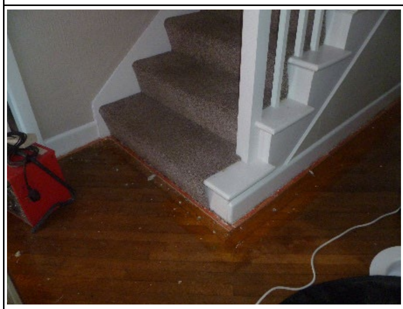
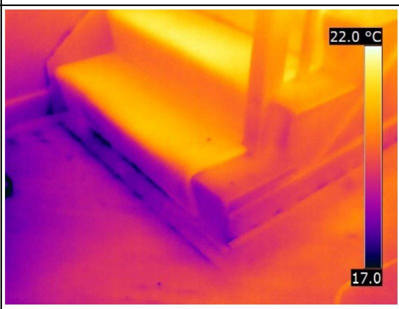
Hall, Stairs & Landing		
		The hall ceiling, showing the central heating pipework for the radiator in bedroom.
		The WC ceiling, showing uninsulated area around the downlighters and where the piece of insulation in the loft had been rolled back.
Bathroom		
		Gaps in loft insulation around the downlighters and underneath the water tank in the loft.
		
Bedroom 1 (Rear-Facing)		
		Thermal bridging at the ceiling perimeter in bedroom 1 where the chimney extends into the loft space, and potential thermal bypass beneath.

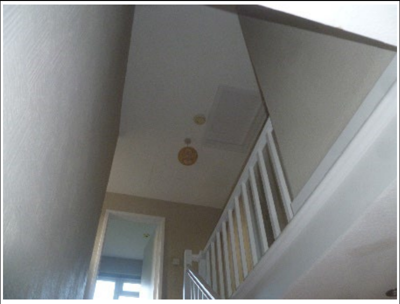
Bedroom 2 (Front-Facing)		
		Colder strip observed at the ceiling perimeter along the bay roof junction,

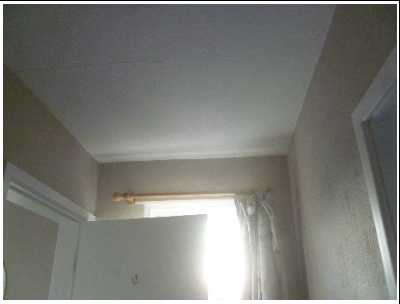
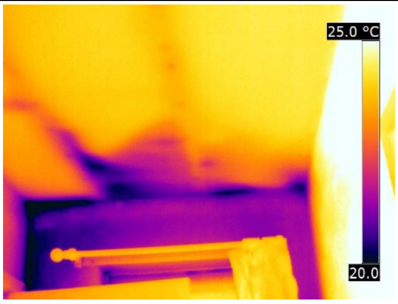
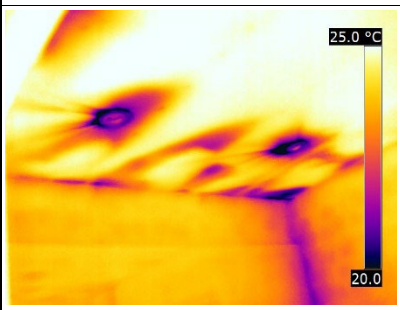
Thermographic Leakage Detection (-50.2 Pa):

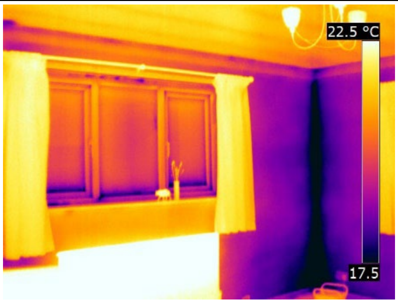
Lounge		
		Direct sunlight on the bay window prevented thermal imaging, but air movement around the frames under depressurisation could be detected by hand. Thermal imaging did show significant air movement from the floor void, between floorboards and around the entire floor perimeter.
		
Kitchen		
		Air leakage was detected around the kitchen door frame and between the door and frame.

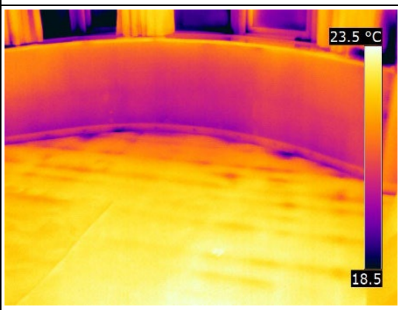
		Under depressurisation, there was significant air movement emerging from behind/beneath the kitchen units, further investigation would be necessary to determine where this air was entering the building envelope.
		In the kitchen cupboard there was a section of the junctions between the floor and external wall showing a major infiltration pathway, with air emerging under the skirting and could be observed flowing underneath the lino floor covering.
Dining Room		
		More minor air leakage was observed around the floor perimeter and through the downlighters in the fireplace, but by far the most significant air leakage paths in the dining room existed around the patio doors. Under depressurisation air was emerging all around the frame but particularly at the threshold, and at numerous areas between and around the sliding doors.
		
		

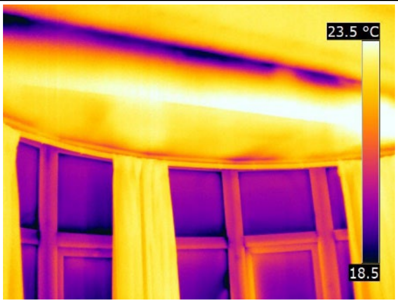
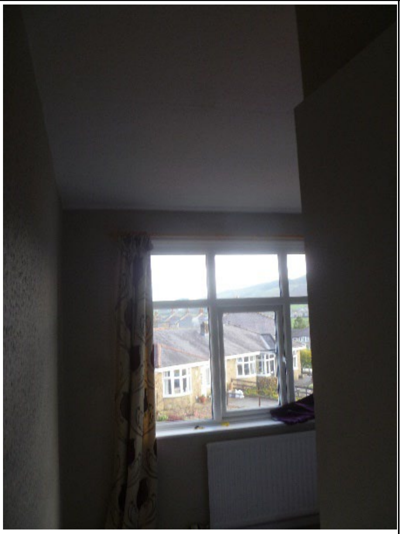
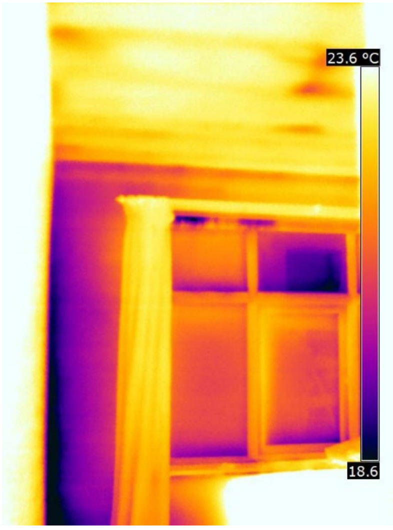
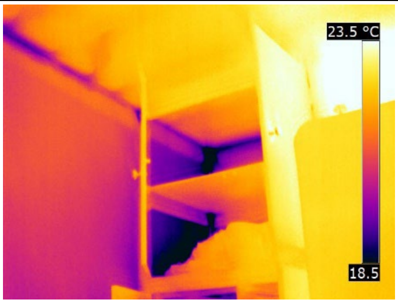
Hall, Stairs & Landing		
		Around the front door the most severe air leakage was observed at the threshold. With the blower door frame positioned in the front door it was not possible to assess the airtightness of the front door and letterbox.
		Although the floor itself appeared airtight there was air entering around the floor perimeter and old radiator pipework holes which remained unfilled.
		Althpough affected by direct sunlight through the window, the hall cupboard displayed air leakage around penetrations for the electric meter through the floor and through/around the closed wall vent.
		
		Significant air movement was detected emerging around the bottom riser of the stairs.

<table>
<tr><td></td><td></td><td rowspan="2">Under depressurisation there was notable infiltration between the loft door and surround, lesser air leakage through ceiling penetrations are barely visible in this thermal image due to the severity of air movement at the loft hatch.

The cooler area of ceiling above the landing window appeared to have worsened under depressurisation, but this would require further investigation to confirm.</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="3">WC & Bathroom</td></tr>
<tr><td></td><td></td><td rowspan="2">Air movement around the downlighters was detected, but the more severe air leakage paths appeared to be at the wall vent (as in the hall cupboard) and into the boxed-in service services for the toilet and basin.</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td><td>As in the WC airflow around the downlighters was observed, it appeared more severe as the ambient temperature in the bathroom was higher (emerging air temperature and airflow were similar for both rooms).</td></tr>
</table>

<table>
<tr><td colspan="3">Bedroom 1 (Rear-Facing)</td></tr>
<tr><td></td><td>
</td><td rowspan="2">Again the closed wall vent allowed significant infiltration. Air leakage around the window was again present, but minor in comparison.</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="3">Bedroom 2 (Front-Facing)</td></tr>
<tr><td></td><td>
</td><td rowspan="2">Air movement was observed around the central light rose, around the bay window and up through the intermediate floor.

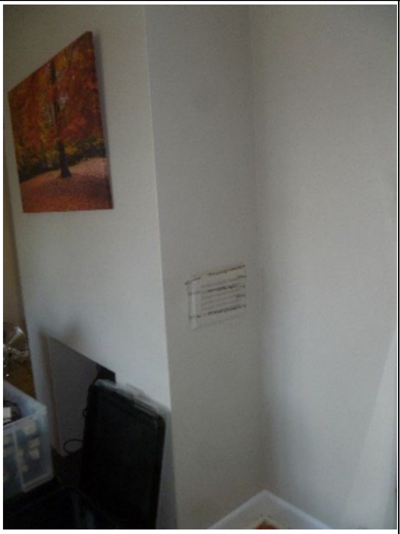
Leakage around the bay window frames and casements appeared similar to the bay in the lounge, with less direct sunlight it was possible to see some of this in the thermal image.</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td></td><td>
</td><td>Air emerging from the floor appeared coolest in the actual bay, getting warmer toward the centre of the house.</td></tr>
</table>

<table>
<tr>
<td></td>
<td>
</td>
<td rowspan="2">The thermal bridge at the ceiling junction with the external front wall did not appear to alter noticeably during depressurisation, indicating that the excessive heat loss causing the cold strip is more likely to be due to thermal bridging than air movement related issues.</td>
</tr>
<tr>
<td></td>
<td>
</td>
</tr>
<tr>
<td colspan="3">Bedroom 3 (Front-Facing)</td>
</tr>
<tr>
<td></td>
<td>
</td>
<td>Again, the airtight performance of the window was reasonable and fairly typical with the rest of the house.</td>
</tr>
<tr>
<td></td>
<td>
</td>
<td>Some minor air leakage around shrinkage cracks at the loft perimeter.
The external wall in the cupboard was cooler than expected, but the doors had been closed previous preventing warmed air from entering.</td>
</tr>
<tr>
<td></td>
<td>
</td>
<td>As in bedroom 2 the coolest air coming up from the intermediate floor was nearer the edges of the house, particularly in the external corner above the front porch where the intermediate floor was exposed beneath.</td>
</tr>
</table>

Additional Images:

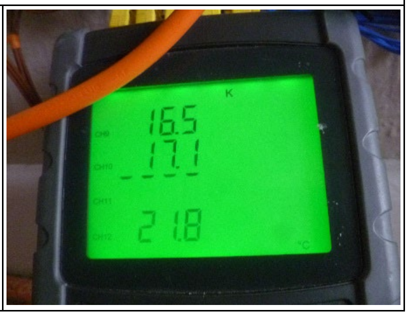
Gas meter reading on arrival

Electric meter reading on arrival



Chimney breast vents sealed following depressurisation phase of test

Shrinkage of glazing seals

<table>
<tr><td></td><td></td><td rowspan="2">Numerous different types of spacers observed in glazing panels</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="3">Probe inserted through a hole in the suspended timber floor to show the temperature of the sub-floor void; 15.0°C at 450mm below the surface, increasing to 17.1°C 100mm below floor level and 21.8°C above floor level.</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

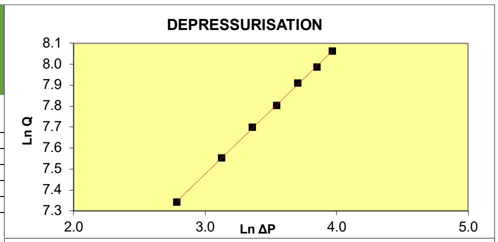
Airtightness Spreadsheet:

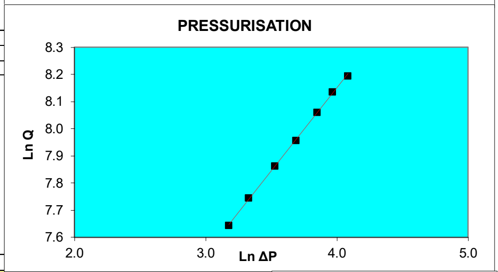
LEEDS BECKETT UNIVERSITY

Leeds Sustainability Institute

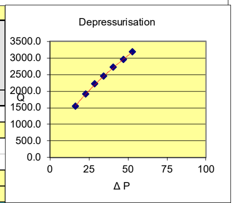
MINNEAPOLIS BLOWER DOOR DATA INPUT AND CALCULATION

date:	17/11/2023		Version 16e	##################
test house address:	49 Regent Road			
company:	SBS			
house type:	detached			
tester:	FT, AH, DMS			
test reference number:			Blower Door & Gauge Used	Model 3 with DG700
outdoor temp (°C)	11	°C	Note: ENSURE THAT FLOW SETTINGS ARE IN m3/h - When using the DG700 gauge run baseline pressure adjustment for minimum 60s with fan switched on but not rotating	
indoor temp (°C)	20.1	°C		
outdoor humidity (%rh)	68.2	%RH		
indoor humidity (%rh)	50.5	%RH		
outdoor barometric pressure	999.3	mbar or hPa	Calculated Outdoor Air Density	1.22 kg/m^3
indoor barometric pressure	999.3	mbar or hPa	Calculated Indoor Air Density	1.18 kg/m^3
temperature corr. fact. depress.	0.969		description of main construction details:	
temperature corr. fact. press.	1.032		3 bed, masonry, pre-refurbishment	
wind speed (m/s):	0			
baseline pressure diff (Pa) (+/-)		Pa		
house width:	7.3	m		
house depth:	8	m		
house height:	5.3	m		
floor area:	55.2	m^2		
volume:	296.6	m^3		
envelope area including floor:	277.3	m^2		
Pressure Difference for ELA	10	Pa		
RESULTS:				
Q50 Mean Flow at 50Pa =	3181.71	m^3/h		
Mean Air Leakage at 50Pa =	10.73	h^{-1}		
Mean Air Permeability at 50 Pa =	11.47	m/h or m^3h/m^2		
Equivalent Leakage Area =	0.133	m^2 at	10	Pa

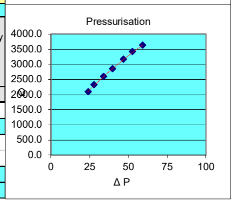




DEPRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Depressurisation Only ($m^3/(h.m^2)$)	Air Leakage Depressurisation Only (h^{-1})
Approx 65 Pa	A	52.7	3279	3173.7	OK	52.7	3.965	8.063	3093.82	11.16	10.43
Approx 57 Pa	A	47	3037	2939.5	OK	47	3.850	7.986	r^2	1.000	
Approx 49 Pa	A	40.6	2812	2721.7	OK	40.6	3.704	7.909	C_{env}	285.458	$m^3/h.Pa^n$
Approx 41 Pa	A	34.5	2527	2445.9	OK	34.5	3.541	7.802	n	0.607	
Approx 33 Pa	A	28.7	2283	2209.7	OK	28.7	3.357	7.701			
Approx 25 Pa	A	22.8	1970	1906.7	OK	22.8	3.127	7.553	C_L (corrected)	287.407	$m^3/h.Pa^n$
Approx 20 Pa	A	16.2	1596	1544.8	OK	16.2	2.785	7.343			



PRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Pressurisation Only ($m^3/(h.m^2)$)	Air Leakage Pressurisation Only (h^{-1})
Approx 65 Pa	A	59.3	3508	3624.4	OK	59.3	4.083	8.195	3269.60	11.79	11.02
Approx 57 Pa	A	52.6	3308	3417.7	OK	52.6	3.963	8.137	r^2	0.999	
Approx 49 Pa	A	46.9	3065	3166.7	OK	46.9	3.848	8.060	C_{env}	303.065	$m^3/h.Pa^n$
Approx 41 Pa	A	39.8	2763	2854.7	OK	39.8	3.684	7.957	n	0.610	
Approx 33 Pa	A	33.9	2516	2599.5	OK	33.9	3.523	7.863			
Approx 25 Pa	A	27.8	2234	2308.1	OK	27.8	3.325	7.744	C_L (corrected)	301.259	$m^3/h.Pa^n$
Approx 20 Pa	A	23.9	2022	2089.1	OK	23.9	3.174	7.644			



Spot 50Pa measurements

Pressure or Depress? Input D or P	RING (O=open or A,B,C)	FAN PRESSURE (Pa)	FLOW (m3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Air Density Corrected Flow at 50Pa (m3/h)	ACH (ach)	Air Permeability (m/h)	Comment
d	a	51.9	3166	OK	51.9	3067.70	10.34	11.06	sealed chimney vents in lounge
d	a	51.7	3180	OK	51.7	3081.27	10.39	11.11	sealed chimney vents in lounge

Annex 3: Post-retrofit airtightness report

Skipton Building Society

Airtightness & Thermography Report

Address: 49 Regent Road, Skipton

Date: 6th December 2024

Testers: Felix Thomas, Adam Hardy, Dominic Miles-Shenton, Martin Fletcher

Pre-retrofit:

Post-retrofit:

Airtightness Results:

Date	Details	Depressurisation Only			Pressurisation Only			Mean	
		Permeability	Air Change Rate	r^2	Permeability	Air Change Rate	r^2	Permeability	Air Change Rate
		$m^3/(h.m^2)$ @ 50Pa	h^{-1} @ 50Pa		$m^3/(h.m^2)$ @ 50Pa	h^{-1} @ 50Pa		$m^3/(h.m^2)$ @ 50Pa	h^{-1} @ 50Pa
20-12-2024*	Post-retrofit, post-coheating	5.88	5.50	0.998	6.36	5.94	0.998	6.12	5.72
06-12-2024	Post-retrofit	5.74	5.36	0.999					
18-12-2023*	Pre-retrofit, post-coheating	10.75	10.05	0.995	12.00	11.22	0.995	11.38	10.64
17-11-2023	Pre-retrofit	11.16	10.43	1.000	11.79	11.02	0.999	11.47	10.73

*Gusty conditions

Conditions 20-Dec-2024:

External Temperature 5.3 °C Internal Temperature 17.9 °C

External RH 83.3 % Internal RH 49.3 %

External Pressure 1013.4 mbar Internal Pressure 1013.4 mbar

Wind Speed 2.2 ms^{-1}, gusts >4.4 ms^{-1}.

Dry, overcast, rain in previous 24hrs.

Conditions 06-Dec-2024:

External Temperature 8.1 °C Internal Temperature 21.4 °C

External RH 69.8 % Internal RH 50.1 %

External Pressure 1004.1 mbar Internal Pressure 1004.1 mbar

Wind Speed 0.4 ms^{-1}, no gusts.

Dry, broken cloud, rain in previous 24hrs.

Observations:

Pressurisation tests were undertaken on the dwelling post retrofit. The pre-coheating blower door test was conducted under depressurisation only, the measured air permeability under depressurisation had reduced from 11.16 to 5.74 $m^3/(h.m^2)$@50Pa and the air change rate under depressurisation from 10.43 to 5.36 h^{-1}@50Pa. The flow exponent under depressurisation had increased from n=0.607 to n=0.677 indicating air leakage flow had increased in turbulence, suggesting that a lower proportion of the air leakage was now direct leakage through cracks and gaps in the fabric and a higher proportion permeating through porous materials and more complex pathways. The post-coheating test was performed under both pressurisation and depressurisation, the mean air permeability under depressurisation had reduced from 11.38 to 6.12 $m^3/(h.m^2)$@50Pa and the air change rate under depressurisation from 10.64 to 5.72 h^{-1}@50Pa. The flow exponent under depressurisation had increased from n=0.609 to n=0.653, again indicating air leakage flow had increased in turbulence; however under pressurisation there was no change (n=0.655 to n=0.654) suggesting that air leakage under pressurisation was impacted by the elevated pressures on the outward opening windows.

With ΔT=13.3K pre-coheating and ΔT=12.6K post-coheating, the internal/external temperature differentials were sufficient for a brief thermographic surveys to be carried out prior to both tests, also thermographic leakage detection was performed under depressurisation during the post-coheating test. Some internal and external thermal images that were captured during the pre-retrofit blower door test on 17-Nov-2023 are also included for context and comparison. Where possible thermal images have been adjusted to a 5K temperature span to aid comparisons, this was not always possible where much larger temperature ranges were observed in certain images (particularly where much colder external air was being drawn into the building), variations in temperature spans must be taken into account when comparing thermal images.

Pre-retrofit the main direct air leakage paths to outside were detected at penetrations, through and around openings, through the suspended floor void and into the loft void; the main indirect leakage paths identified were through boxed in services and into the voids behind kitchen units. Post-retrofit leakage detection revealed that many of the same leakage paths remained, but had been significantly reduced either in severity or size of area affected. Significant improvements in direct air leakage were seen around service penetrations particularly the downlighters, and around and through the windows and doors although the trickle ventilators did not appear to close effectively. Also air movement through the suspended timber ground floor was significantly reduced around the centres of rooms, but remained around the room perimeters and possible below the staircase. Indirect air movement had not been addressed, with air movement through the intermediate floor void linking different points of air leakage with gaps in the building envelope some distance removed; one such example being air entering around the air brick above the kitchen window that could be traced across the bathroom floor to emerge at the landing floor under dwelling depressurisation.

Observations from post-retrofit tests, 06-Dec-2024 & 20-Dec-2024

External Thermal Images:

<table>
<tr>
<td></td>
<td></td>
<td rowspan="4">The warm strips previously visible at the eaves were significantly reduced post-retrofit.

On the North side façade at the eaves junction 2 warmer spots remain, possibly the sites of old air bricks. These are only now visible as the rest of the eaves junction has improved significantly, previously the whole junction showed up as warmer.

Some issues were noticeable around the bay windows. Warmer strips at the jambs are potential thermal bridges, with the edge frame units positioned in line with the outer leaf rather than with the cavity and insulation layer. The mullions appear warmer than the actual window frames. The bay wall appear warmer than other external wall surfaces at intermediate floor level, but not at the ground floor level.</td>
</tr>
<tr>
<td></td>
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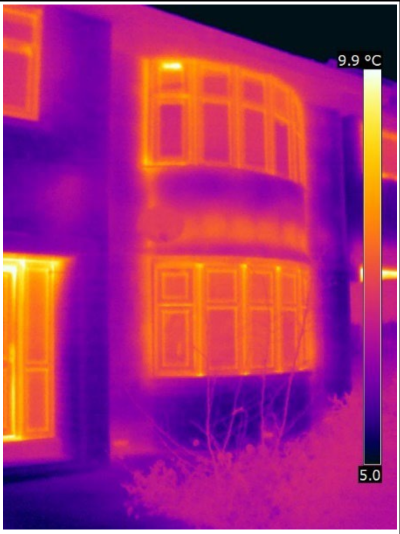
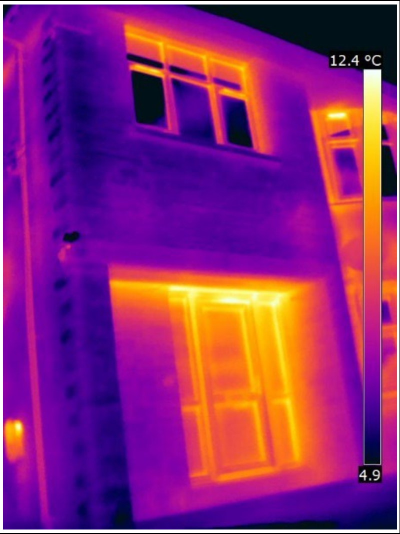
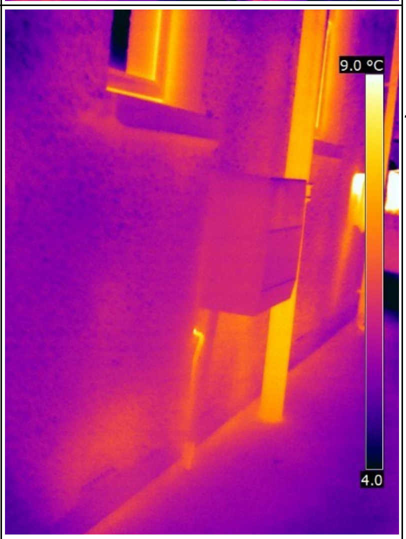
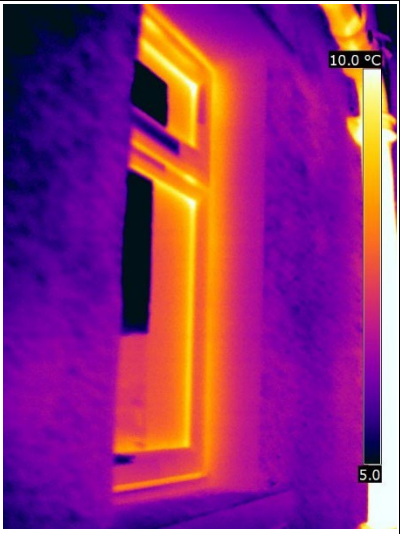
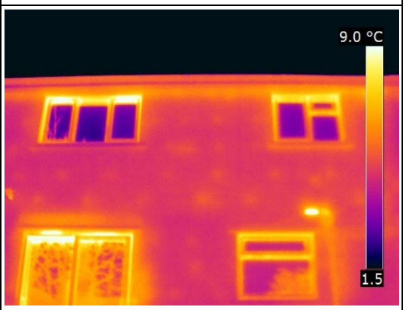
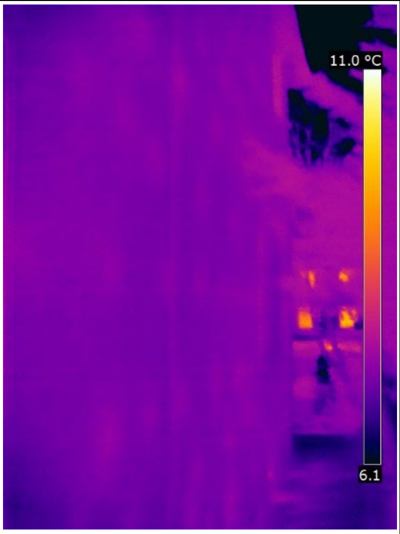
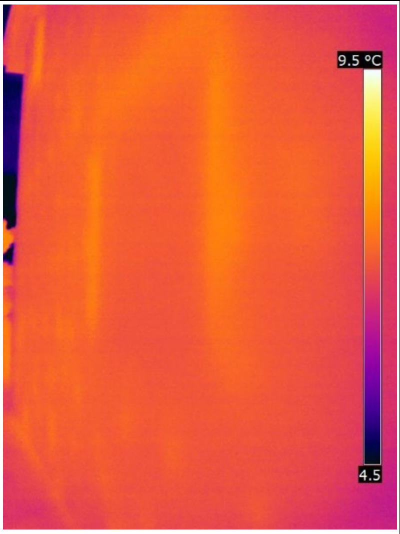
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>The warm strip above the recessed front door displayed the warmest surface temperatures visible on the front elevation (besides warm air exiting through the trickle vent in the upstairs bay window), and is most likely</td>
</tr>
</table>

		due to a thermal bridge at the lintel.
		The South side displayed less uniform surface temperatures, possibly unsurprising given the number of service and openings in the wall.
		In contrast to the bay window jambs, the windows and door on this elevation were positioned much deeper within the external wall. Thermal bridging around the frames was still observable, but did not appear to be excessive

		
		The rear elevation showed some slightly warmer areas at the first floor window heads and at the patio doors in the dining room, but this was only visible by reducing the temperature range on the thermal image (effectively exaggerating the heat loss compared to other facades).
		At the time of the survey this was the leaward side of the house, warm air could be observed being drawn out of the air brick above the kitchen window.
		The previous patio door frame appeared to perform particularly poorly from a thermal perspective, the replacement performed markedly better. Some thermal bridging was observed around the ground floor perimeter, but again this did not appear excessive.
		

<table>
<tr>
<td></td>
<td>
</td>
<td>A warmer area was visible on the rear elevation, where a doorway appeared to have previously been but was now filled in.</td>
</tr>
<tr>
<td></td>
<td>
</td>
<td rowspan="2">On the north wall where a window had been filled in at the dining room, there were previously warmer areas clearly visible at the lintel and jambs. These were now only visible by manipulating the thermal image to highlight the slight difference in surface temperatures.

(17-Nov-2023)</td>
</tr>
<tr>
<td></td>
<td>
</td>
</tr>
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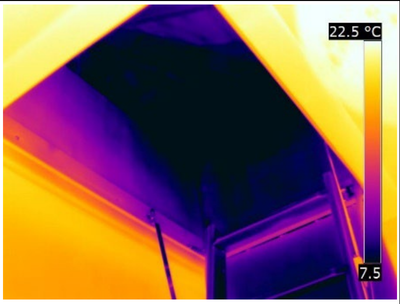
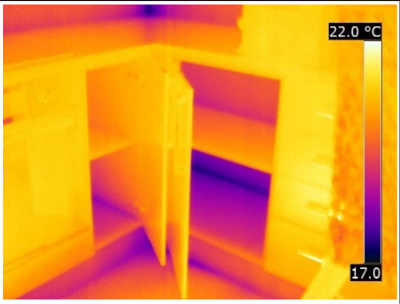
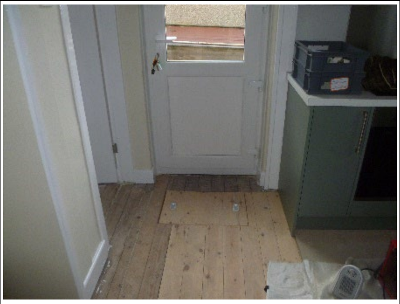
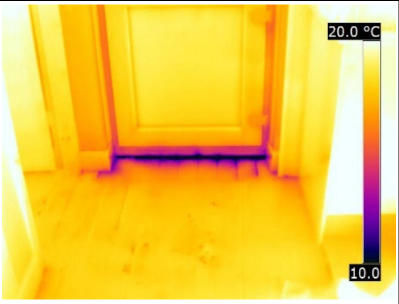
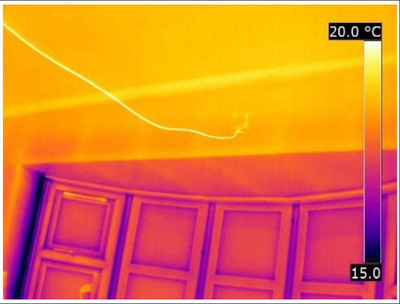
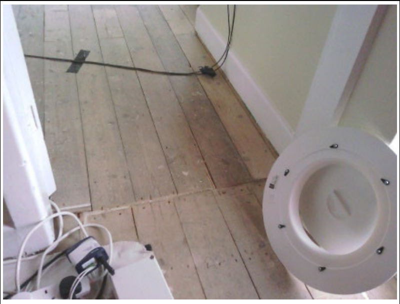
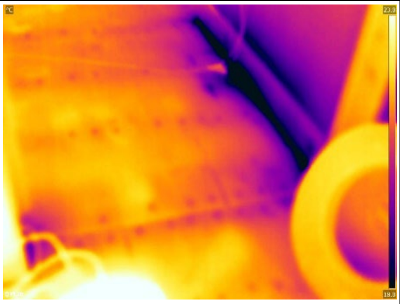
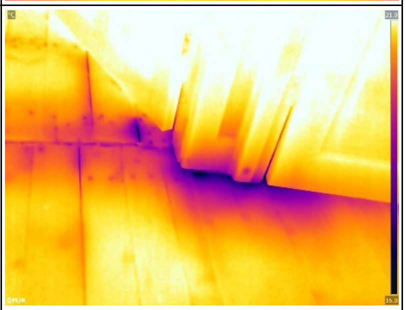
Loft Thermal Images:

<table>
<tr><td></td><td>
</td><td rowspan="2">The loft hatch was now a proprietary insulated rather than just a sheet of MDF, with boxing fitted to allow insulation to be properly fitted.

With the water tank now removed and new decking covering the downlighters there was little to observe in the loft. The insulation appeared even and fitted right up to the eaves, with just a few warmer areas around the ceiling junctions with trusses.</td></tr>
<tr><td></td><td>
</td></tr>
</table>

Internal Thermographic Observations (no induced pressure differential):

<table>
<tr><td colspan="3">Kitchen</td></tr>
<tr><td></td><td>
</td><td>Where the warmer area of rear wall was observed the back of the kitchen unit was not noticeable cooler than elsewhere, although this does not necessarily reflect the wall surface temperature behind it.</td></tr>
<tr><td></td><td>
</td><td>The rear threshold displayed the lowest surface temperatures in the kitchen, potentially low enough to be a condensation risk without adequate ventilation.</td></tr>
<tr><td></td><td></td><td>The external floor/wall junction in the utility room appeared noticeably cooler.</td></tr>
</table>

<table>
<tr><td colspan="3">Lounge</td></tr>
<tr><td></td><td></td><td rowspan="2">The bay ceiling appeared slightly cooler than the rest of the front façade, but with this being the windward side of the house this may be due to infiltration (as observed here at point along the floor/wall junction).
The bay mullions which appeared warmer from outside appear cooler from inside, as does the thermal bridging at the jambs. With these being the coolest surfaces, should any condensation occur it is likely to be on these surfaces first.</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td><td>Under natural conditions (not under dwelling depressurisation) air was detected entering at the floor/wall junction on the windward front wall.</td></tr>
<tr><td colspan="3">Dining Room</td></tr>
<tr><td></td><td></td><td rowspan="2">Under natural conditions some cooler air was observed being drawn up from the sub-floor void, this was only observed at the room perimeter and not through the main expanse of floor.</td></tr>
<tr><td></td><td></td></tr>
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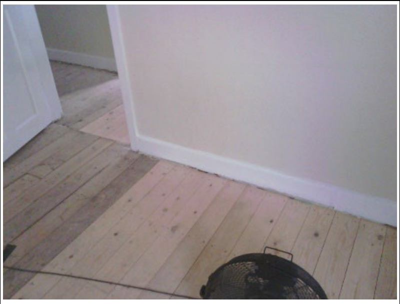
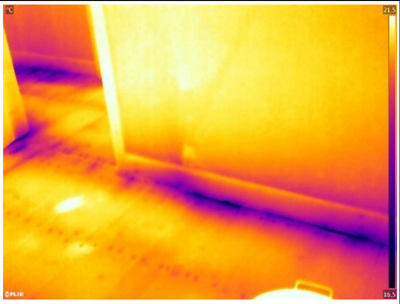
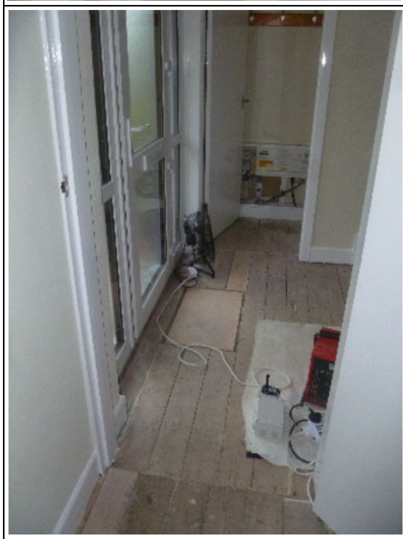
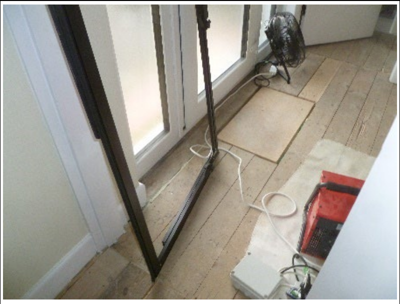
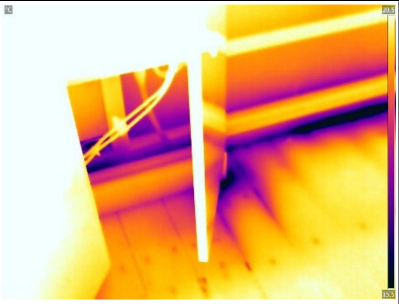
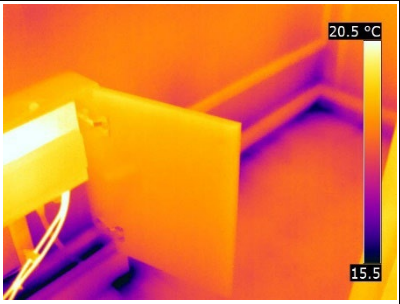
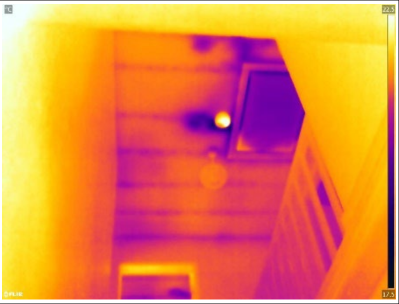
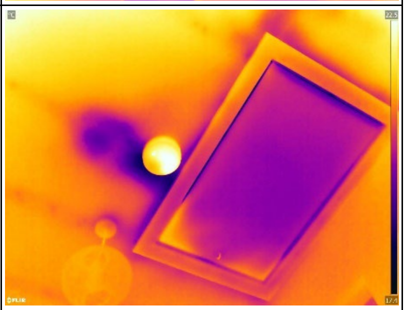
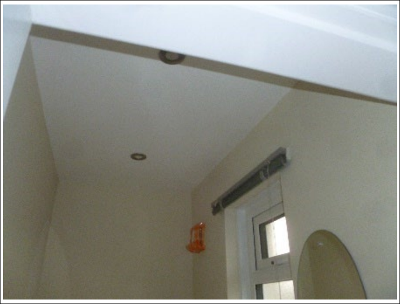
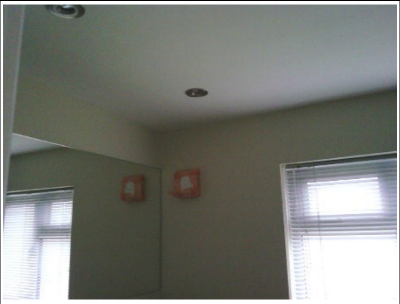
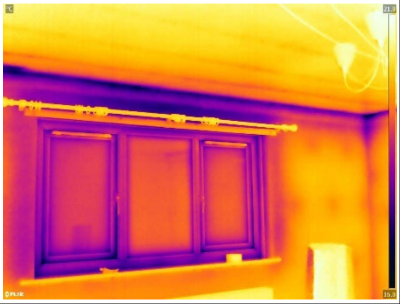
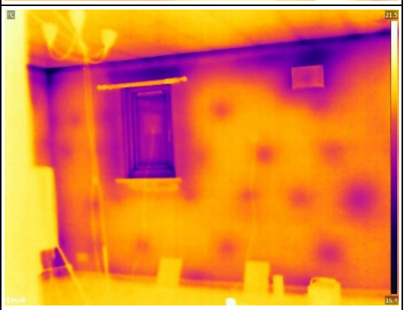
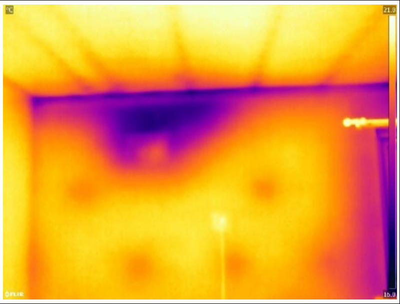
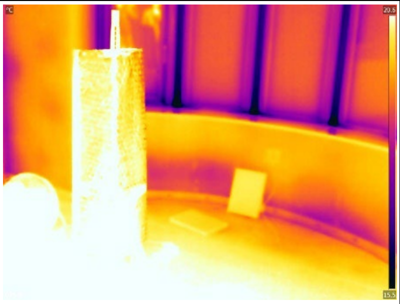
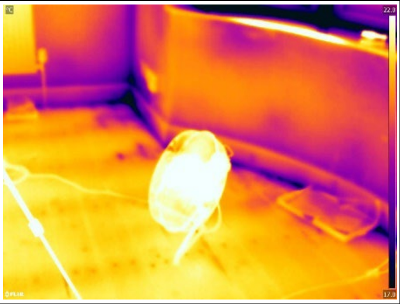
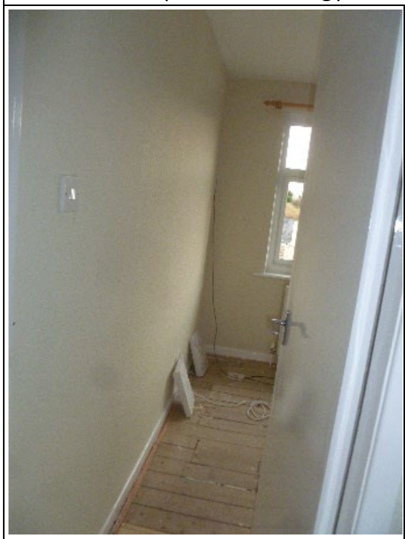
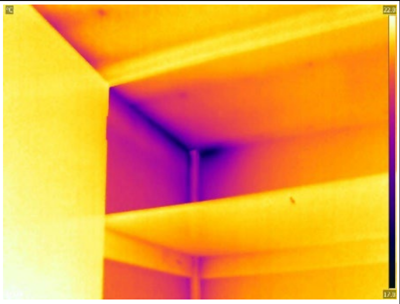
		
		The patio doors appeared to be a marked improvement over the old ones, but as they were placed in line with the outer surface of the wall there was noticeable thermal bridging around the opening. This was most apparent at the threshold where the floor extending into the threshold is clearly not as well insulated as the main floor and (as the rear entrance threshold) may constitute a condensation risk under adverse environmental conditions.
		
Hall, Stairs & Landing		
		The coolest surfaces observed in the Hall were at the front door threshold. As with both the other entrances, this door was again sited on the outer edge of the external wall leaving the threshold less insulated that the adjacent floor. Once again, as the door and side lights are a much better standard thermally than before, the threshold is again significantly cooler and may constitute a condensation risk.
		

		
		In the meter cupboard (as seen in the adjacent utility room), the junction of the ground floor and external wall is noticeably cooler.
		
		The loft hatch appeared to be a significant improvement over the previous uninsulated one. There were a few areas around ceiling service penetrations where the loft insulation may have been misplaced or dislodged
		

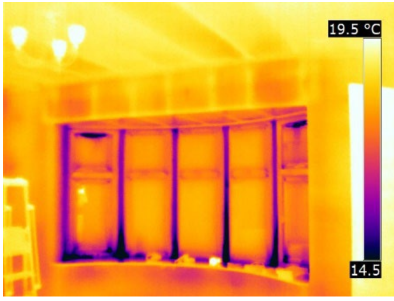
WC and Bathroom		
	 	The WC ceiling showed cooler areas at the eaves suggesting misplaced loft insulation, but much improved over the pre-retrofit: (17-Nov-2023)
	 	Gaps in loft insulation around the downlighters and underneath the water tank in the loft had been resolved, with the external corner the coolest surface area not visible in the bathroom.
		
Bedroom 1 (Rear-Facing)		
		Some cooler areas were visible at the ceiling perimeter in bedroom 1 around the lintels and at the wall vent on the north elevation.
		

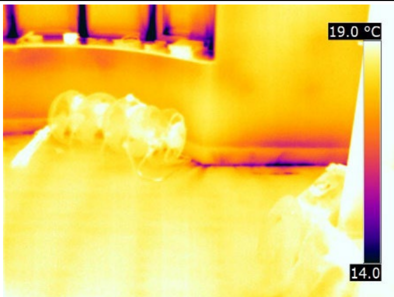
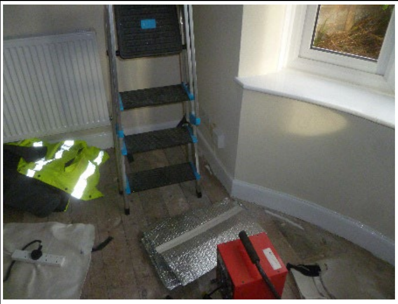
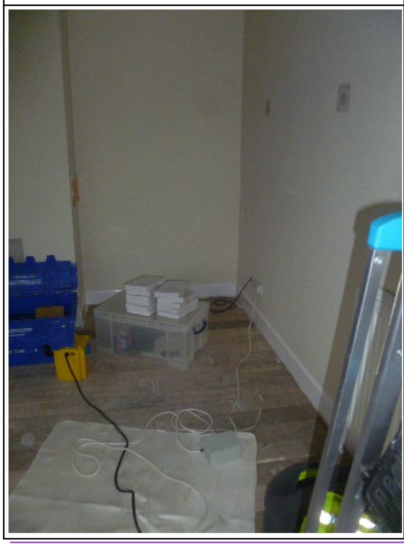
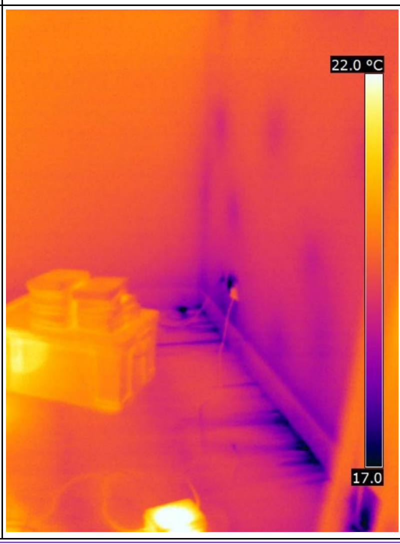
<table>
<tr><td colspan="3">Bedroom 2 (Front-Facing)</td></tr>
<tr><td></td><td></td><td>As with bedroom 1, a wall vent on the north wall displayed cooler surface temperatures, although the vent here had been plastered over.</td></tr>
<tr><td></td><td></td><td rowspan="3">The colder strip previously observed at the ceiling perimeter along the bay roof junction was still visible, but the bridge appeared to be reduced even though the plane element performance of the walls had improved:


(17-Nov-2023)
As with the downstairs bay window, the mullions again appeared to display the coolest surface temperatures.
Cooler areas of floor with thermal gradient, suggest that air might be entering at the windward front elevation and moving through the intermediate floor void.</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="3">Bedroom 3 (Front-Facing)</td></tr>
<tr><td></td><td>
</td><td>The floor surface directly above the front porch was not noticeably cooler than the floor above the hallway.</td></tr>
</table>

<table>
<tr><td></td><td></td><td>The penetration inside the bedroom 3 cupboard over the stairs appeared the same as it had pre-retrofit.</td></tr>
</table>

Thermographic Leakage Detection 20-Dec-2024 (-55.7 Pa):

<table>
<tr><td colspan="3">Lounge</td></tr>
<tr><td></td><td></td><td rowspan="4">Under dwelling depressurisation the wall above the bay, the bay ceiling and the ceiling showed cooler sections between joists suggesting external air entering these voids.
The window casements showed an improvement over the old windows, but under depressurisation the mullions appeared even cooler and air was entering through the closed trickle vents.

Cooler air was observed entering through the suspended timber ground floor, this was most noticeable around the room perimeter with the infiltrating air being slightly cooler at the floor junctions with external walls.</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
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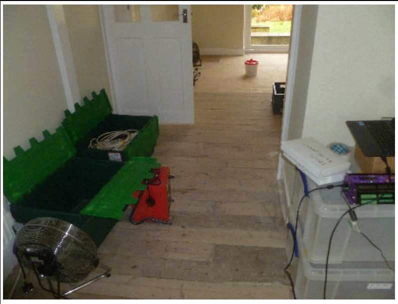
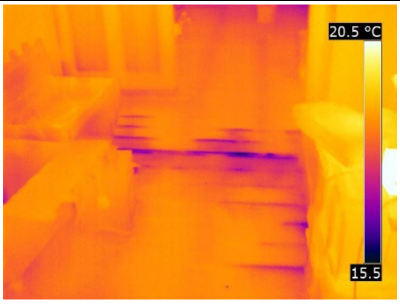
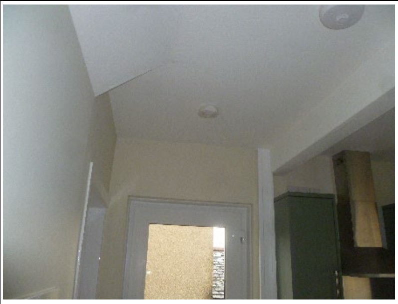
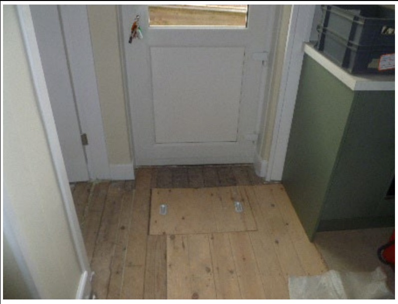
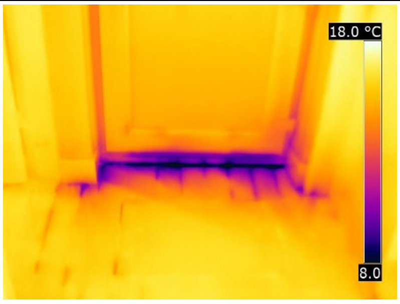
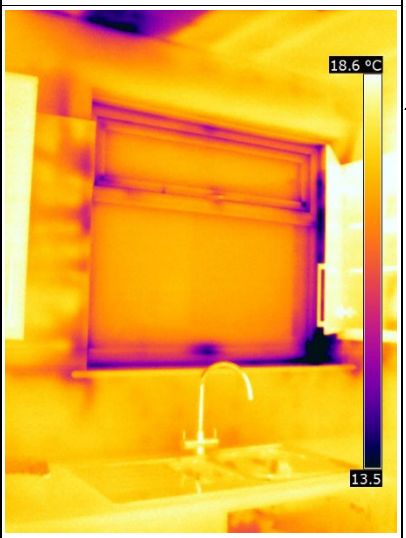
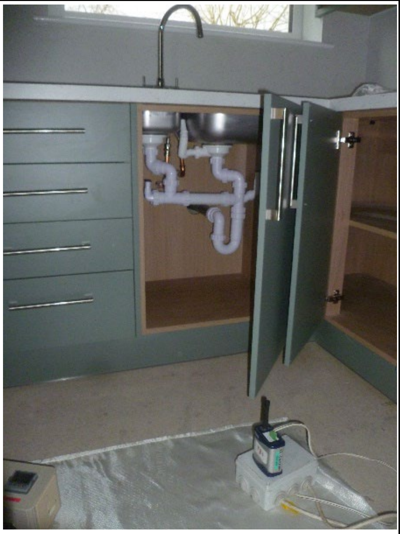
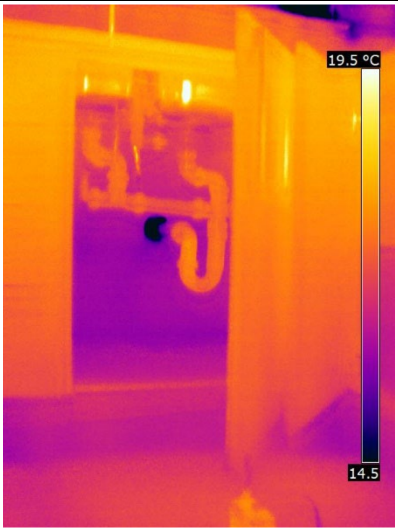
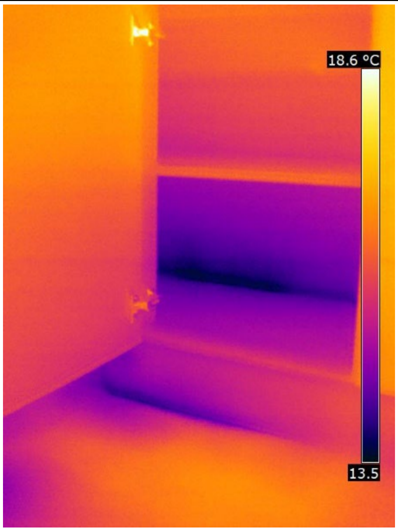
<tr><td></td><td>
</td><td></td></tr>
<tr><td colspan="3">Kitchen</td></tr>
<tr><td></td><td>
</td><td rowspan="2">Air leakage previously detected around the kitchen door frame was significantly reduced with the new door, although there was still some air leakage observed at the threshold.</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td></td><td>
</td><td>Under depressurisation, air was being drawn in from the air brick above the kitchen window all across the kitchen ceiling and emerging around the intermittent extract fan.</td></tr>
<tr><td></td><td>
</td><td>Some air movement could be seen around the window jambs entering the void behind the surface boarding rather than directly into the habitable space.</td></tr>
</table>

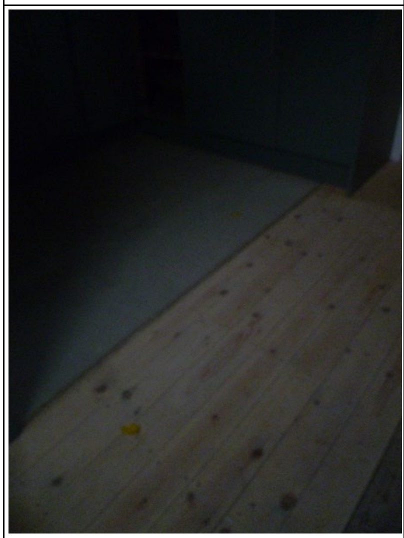


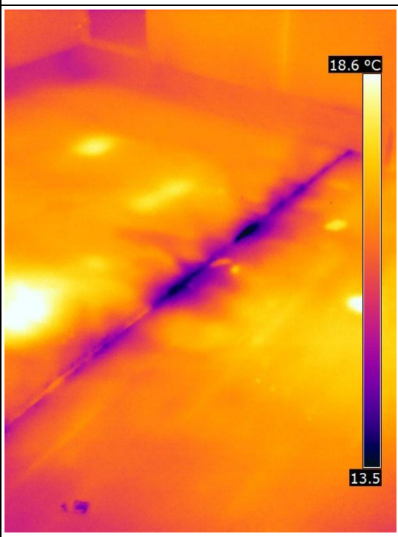


Cooler air behind the kitchen cupboards was observed emerging around the kitchen sink waste pipe but not significantly around the cupboards or plinths.

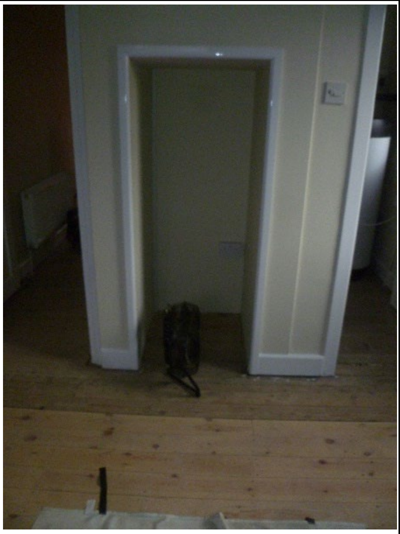
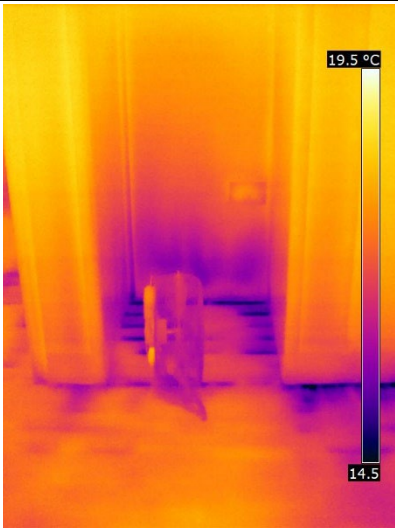


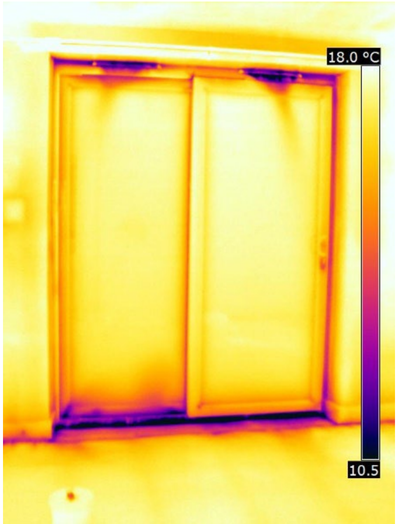
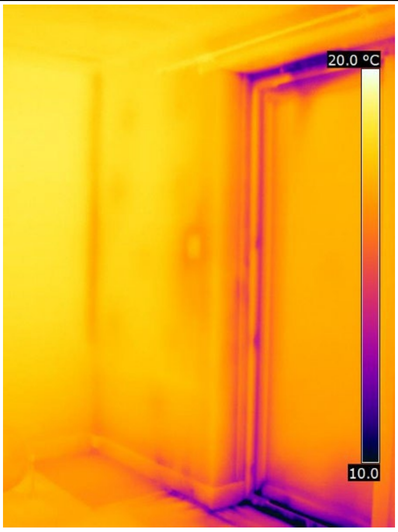
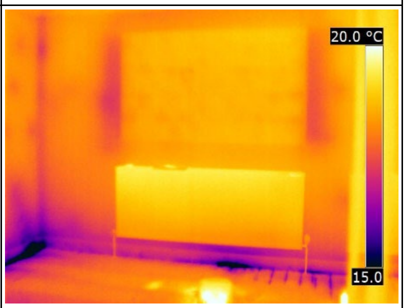
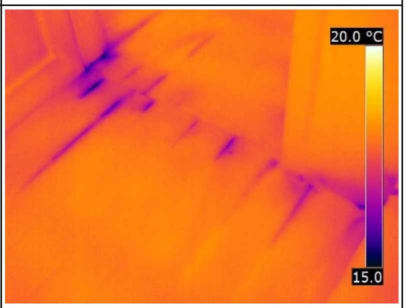
At the external corner where a warmer area of external wall was observed from outside, the temperature of air being drawn in was cooler, but only by a degree or so.

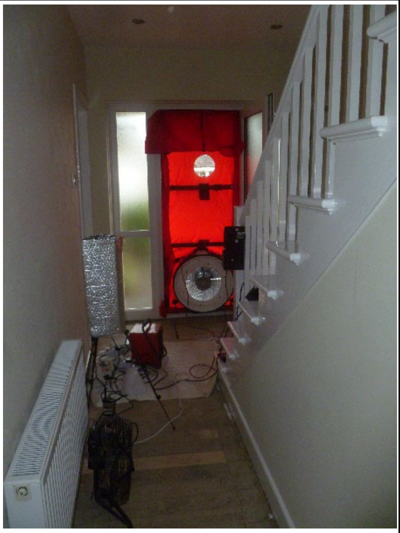
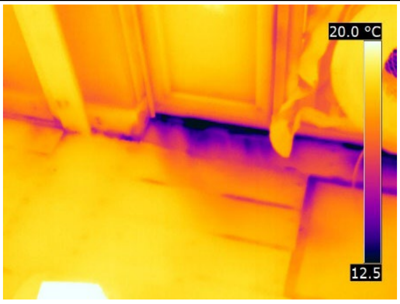
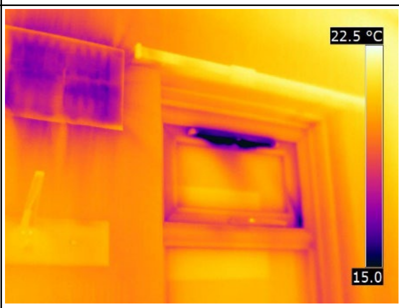
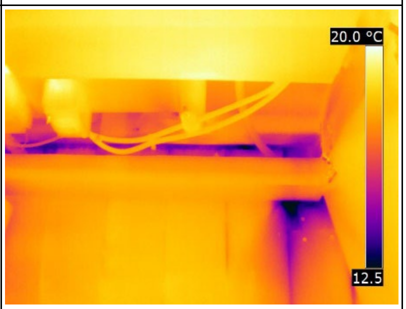
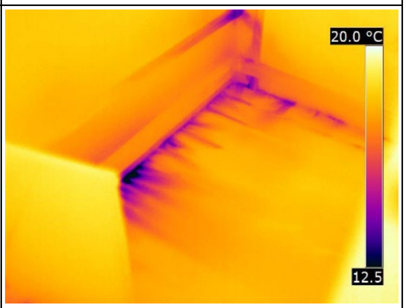


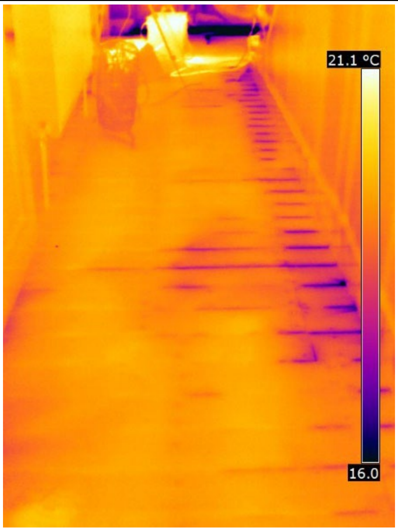
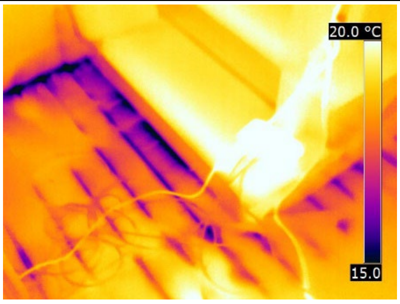
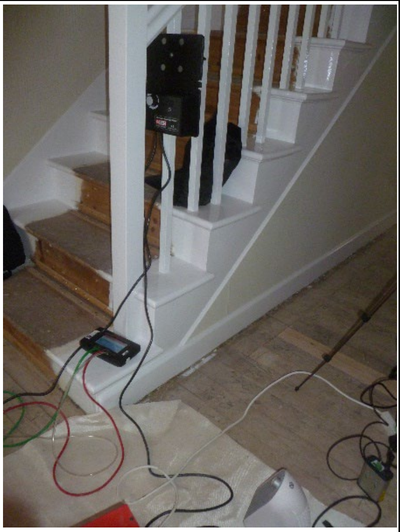
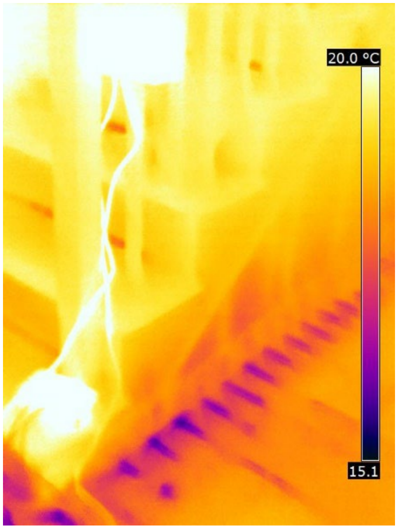


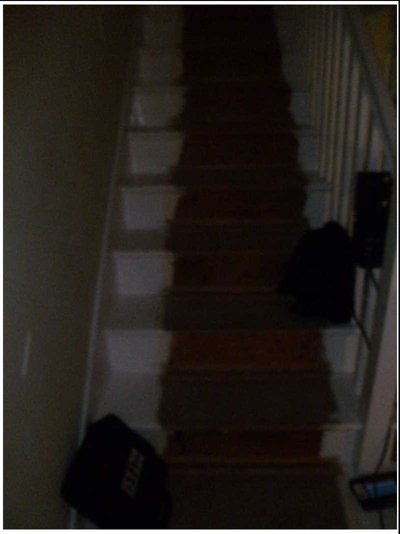
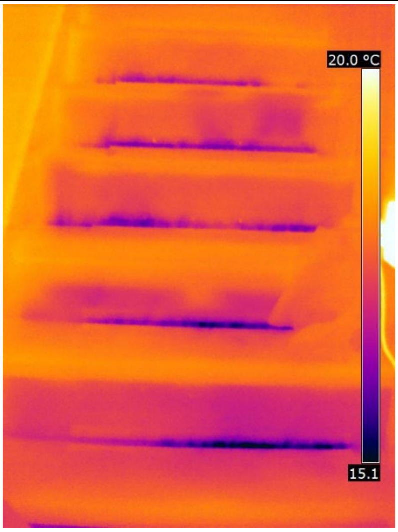
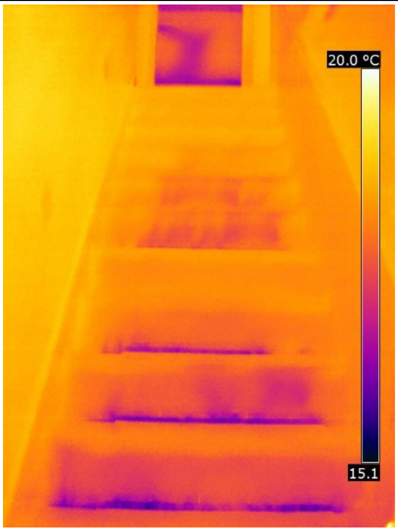
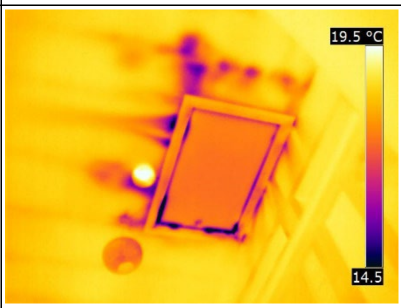
The junction in the kitchen floor between traditional floorboards and flooring chipboard had not been sealed and allowed some noticeable air leakage under depressurisation.

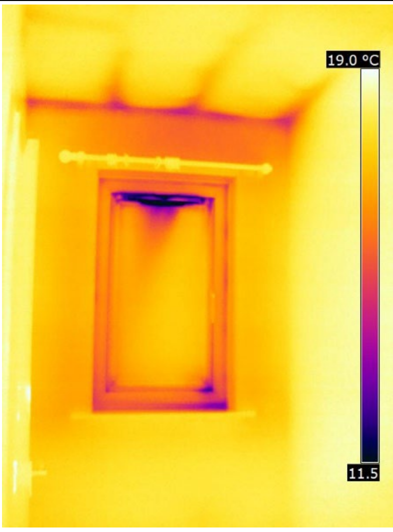
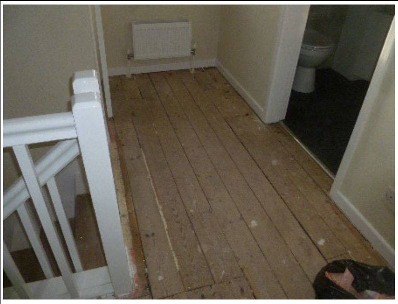
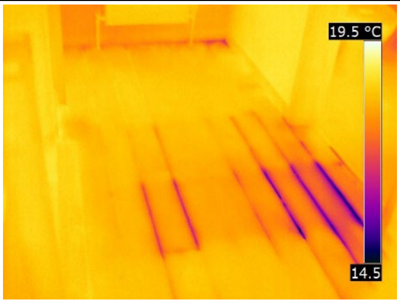
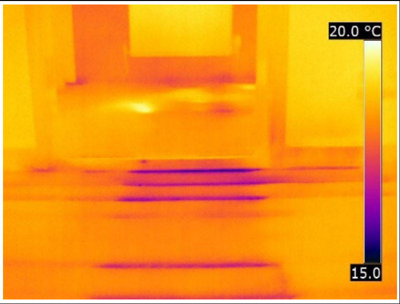
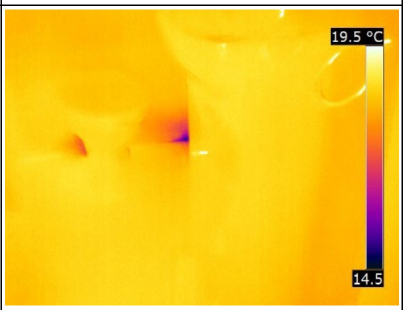
		Similarly, the alcove in the kitchen backing onto the staircase allowed infiltration through the floor. The thermal gradient on the wall backing onto the void beneath the stairs suggests that air is also entering this void from below.
		Unlike other wall vents, the one in the utility room appeared not to allow air leakage.
		The floor junction with the external wall in the utility room did allow air to enter under depressurisation.

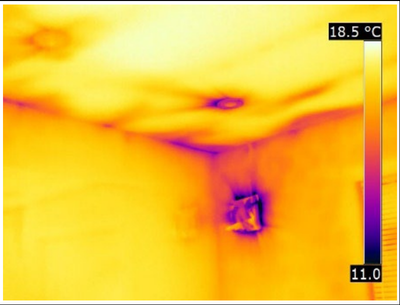
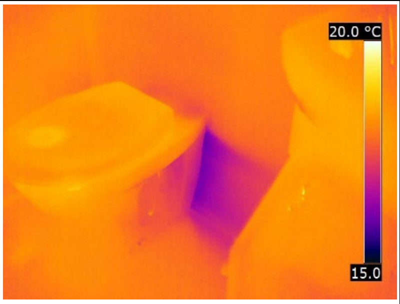
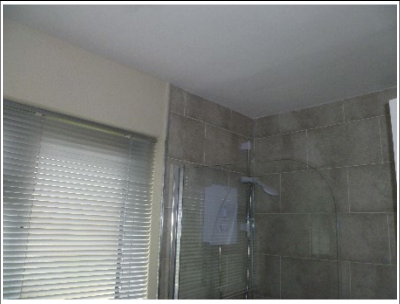
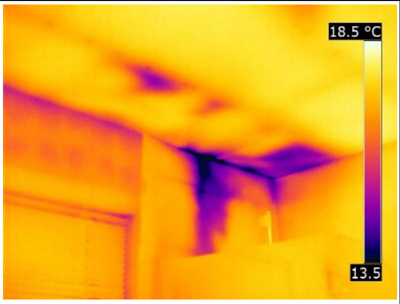
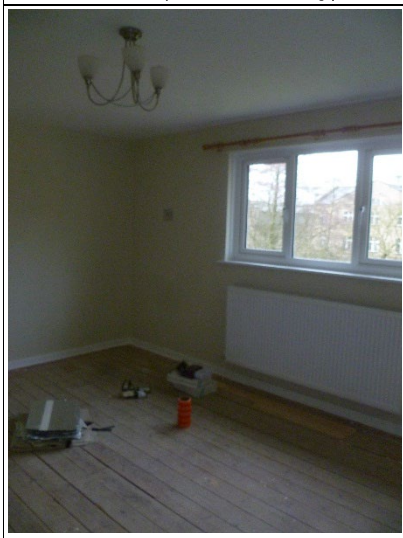
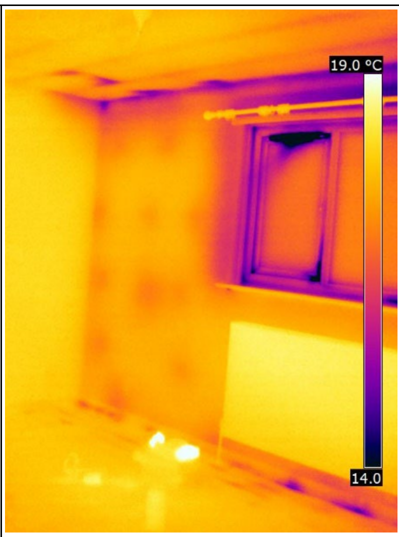
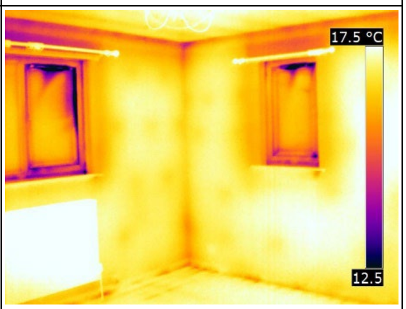
<table>
<tr><td colspan="3">Dining Room</td></tr>
<tr><td></td><td>
</td><td>Under depressurisation, air was detected emerging around the patio doors at the threshold and through the closed trickle vents, but generally they performed well and vastly superior to the patio doors they replaced.</td></tr>
<tr><td></td><td>
</td><td>More air leakage was observed around the floor perimeter, with the temperature of the emerging air significantly higher than at the threshold where it emerged at near external temperature.</td></tr>
<tr><td></td><td>
</td><td></td></tr>
<tr><td></td><td>
</td><td></td></tr>
</table>

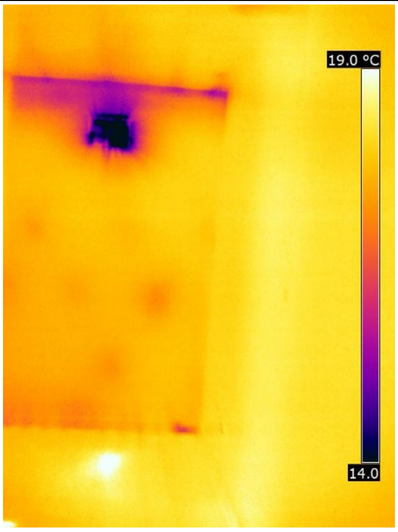
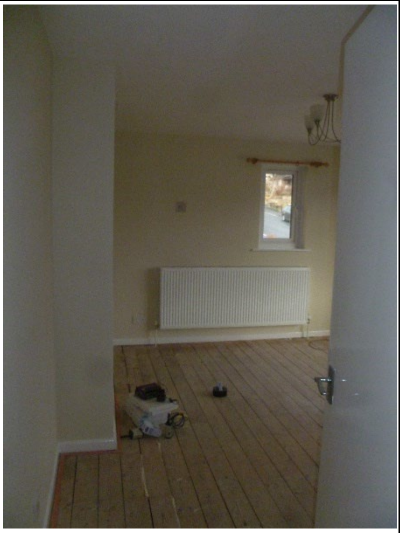
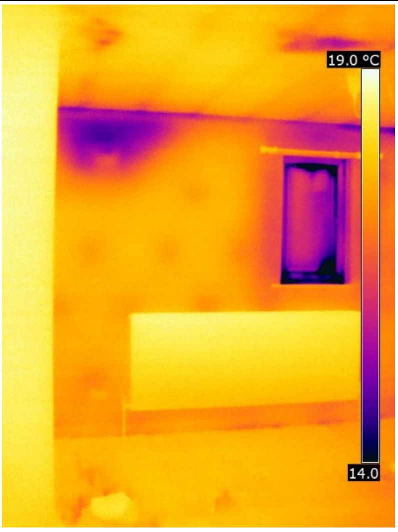
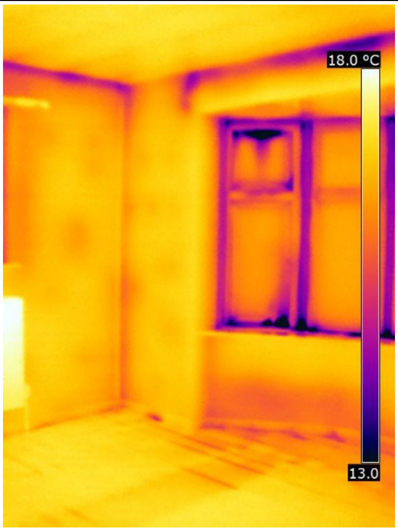
Hall, Stairs & Landing		
		As with the pre-retrofit test, the blower door frame positioned in the front door it was not possible to assess the airtightness of the front door and letterbox. Around the front door the most severe air leakage detected was again observed at the threshold. This was the most severe airflow and the coolest infiltrating air as it was entering directly from outside.
		
		The trickle vent in the hall cupboard window displayed cooler air entering than at the wall vent as the infiltration path is more direct. There was also a small amount of air leakage at a corner of the window casement. Air leakage around penetrations for the electric meter through the floor and at the floor/wall junction was also detected.
		
		

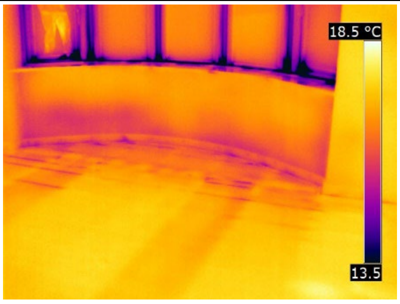
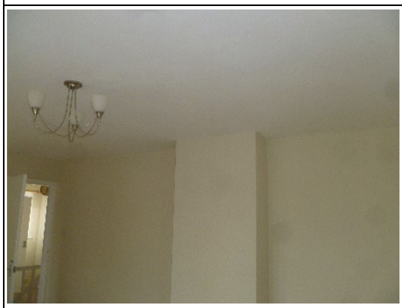
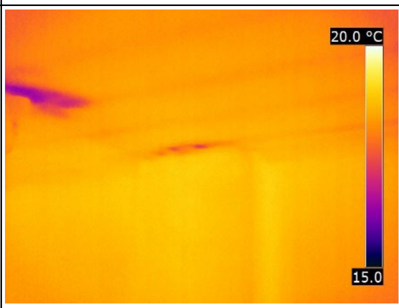
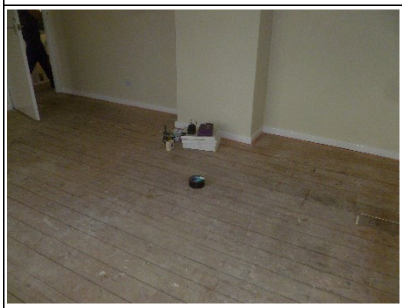
		Air movement up through the hall floor was detected all along the side of the hallway next to the staircase and around the base of the stairs.
		
		

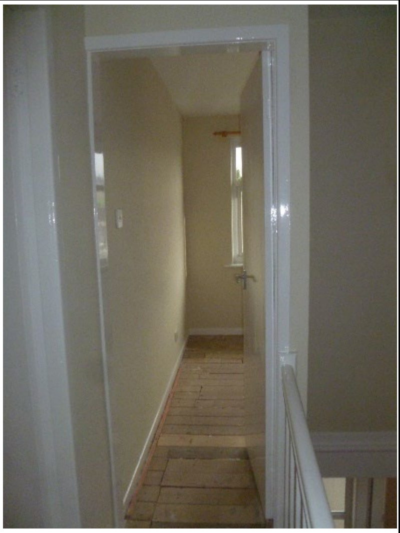
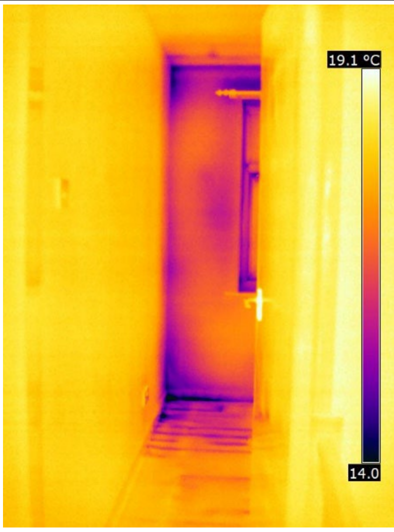
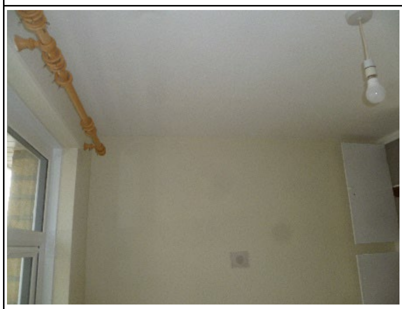
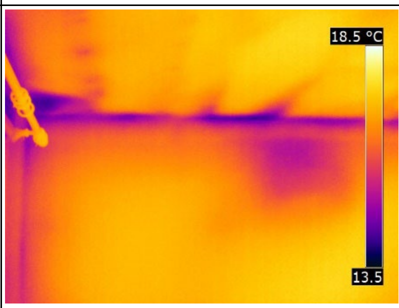
		On the staircase air emerged from the base of each riser, with coolest temperatures emerging from the void beneath the stairs.
		Further up the stairs the emerging air was either at room temperature, or just below, so not as apparent in the thermal images.
		Under depressurisation there was infiltration between the loft door and surround at the opening end and at some points around the hatch surround.

		The landing window thermal image was dominated by the cold external air entering through the closed trickle vent.
		The cooler strip of kitchen ceiling was also visible from above, as a cooler area of landing and bathroom floor. Cold external air entering at the airbrick above the kitchen window could be tracked moving through the bathroom floor and emerging through gaps between the floorboards on the landing floor.
		
WC & Bathroom		
		Air movement previously detected around the downlighters and the boxed-in services for the toilet was significantly reduced and barely detectable. The more severe air leakage path at the wall vent remained.
		

		As in the WC airflow around the downlighters and boxed-in services for the toilet and basin in the bathroom was reduced, with more noticeable air leakage around the wall vent.
		
		However, the service penetration for the shower appeared to let significant amounts of air movement to be drawn into the wall void from above.
Bedroom 1 (Rear-Facing)		
		Again, the closed trickle vents appeared to be the most severe air leakage paths along with the the sealed closed wall ven. Air leakage was detected at the intermediate floor junctions with the external walls, but this was minor in comparison.
		

		
Bedroom 2 (Front-Facing)		
		A cooler area was still visible around the sealed vent on the north wall, with some air leakage detected around the adjacent window.
		Leakage around the bay window appeared similar to the bay in the lounge, with direct leakage worst through the closed trickle vents and the coolest areas of the windows being the mullions. Some additional air leakage was observed around the sill, this was not particularly severe but appears worse on the thermal image due to the coldness of the emerging air.

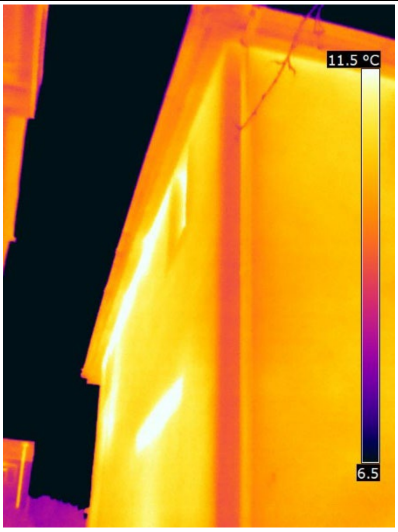
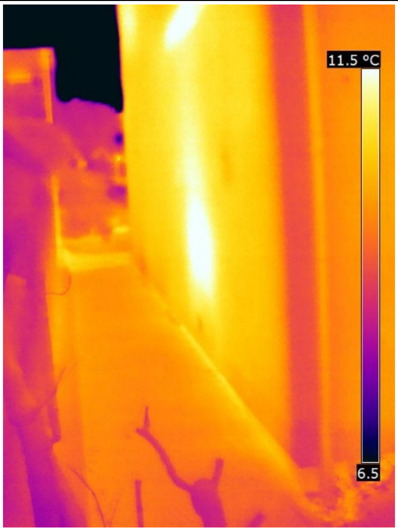
		Air emerging from the intermediate floor appeared coolest in the actual bay, getting warmer toward the centre of the house, indicating direction of travel of the infiltrating air entering at the bay and moving across the floor. The bay wall appeared cooler, but not the bay ceiling.
		
		
		The chimney breast on the internal wall between bedrooms 1 & 2 did not appear to show any significant bypassing or air movement under dwelling depressurisation.
		

<table>
<tr><td colspan="3">Bedroom 3 (Front-Facing)</td></tr>
<tr><td></td><td>
</td><td rowspan="3">Under depressurisation the area of floor above the front porch was distinguishable from the area directly above the hall by the temperature of air emerging from the intermediate floor.</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td></td><td>
</td><td>Again. The window performed well for airtightness apart from the closed trickle vents.</td></tr>
<tr><td></td><td>
</td><td>Another cooler area was visible on the wall where an old vent had been covered over.</td></tr>
</table>

		The penetration through the ceiling in the bedroom cupboard remained, with cool air being drawn down and through the conduit under depressurisation.

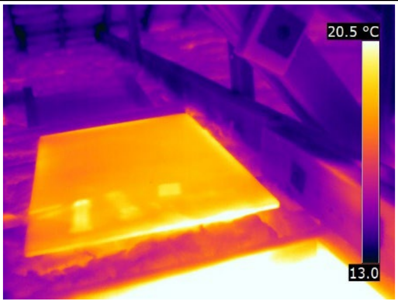
Observations from pre-retrofit test, 17-Nov-2023

External Thermal Images 17-Nov-2023:

		Direct sun on the front and south side of the house prevented thermographic imaging. On the north side a warm strip was visible at the eaves. Also, where a window had been filled in at the dining room warmer areas were visible at the lintel and where a radiator was positioned on the external wall beneath it.
		
		The rear elevation showed a warmer area in the bathroom, which had a higher internal temperature than the rest of the house, and at the patio doors in the dining room.
		Again, a warmer strip was observed at the eaves and potential thermal bridging at the lintel.

		The patio door frame appeared to perform particularly poorly from a thermal perspective.
		
		Even with recent solar on the front of the house, warmer areas were visible around the radiator in bedroom 3 and above the front door where pipework for that radiator ran through the intermediate floor void and through the area exposed by the recessed front door.
		

Loft Thermal Images 17-Nov-2023:

<table>
<tr>
<td></td>
<td>
</td>
<td>The loft hatch was uninsulated and unsealed, appearing to consist of just a sheet of MDF.</td>
</tr>
<tr>
<td></td>
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<td>Images were captured from the loft hatch looking towards the front of the house and then moving anti-clockwise around the loft.</td>
</tr>
<tr>
<td></td>
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</td>
<td rowspan="2">Loft insulation was present between the joist with an approximate thickness of 100mm.
This insulation was compressed in many areas by boards lying on the surface.
Breaks in insulation occurred where deeper joists ran and where the blockwork for internal partition walls extended through it.</td>
</tr>
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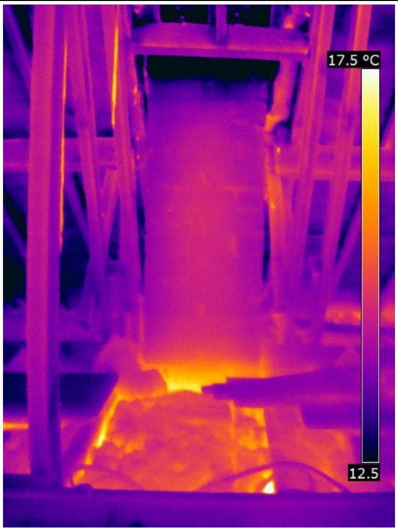
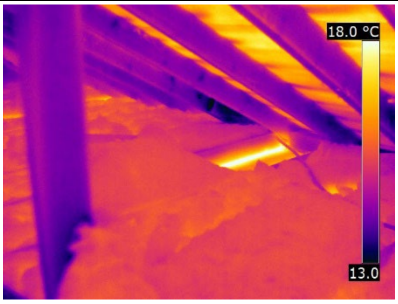
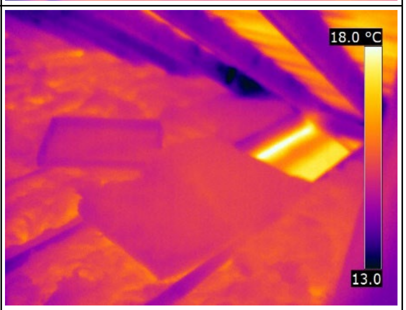
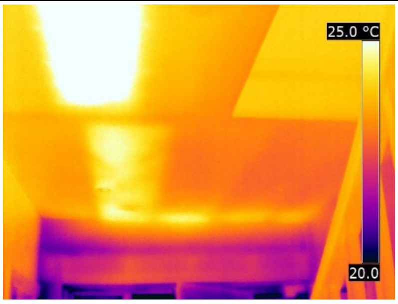
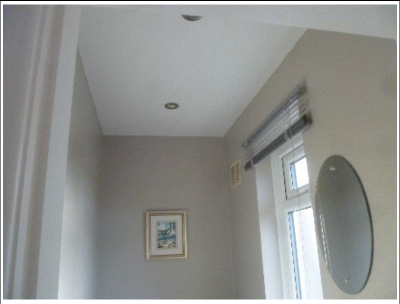
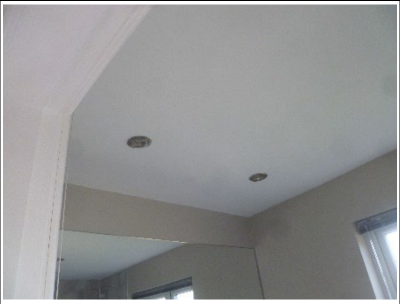
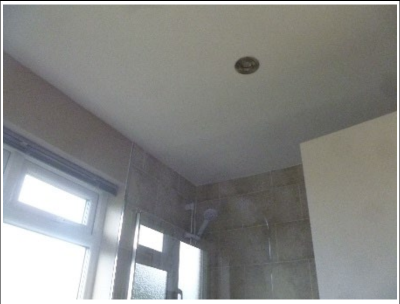
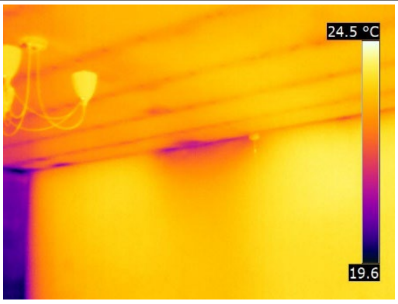
<td></td>
<td>
</td>
<td>The chimney was positioned between bedrooms 1 & 2, thermal bridging was observed where the chimney penetrated the ceilings.
A potential thermal bypass heat loss mechanism may exist, where air within the chimney is being heated within the building envelope, and that heated air id moving up the chimney and exiting at the top.</td>
</tr>
</table>

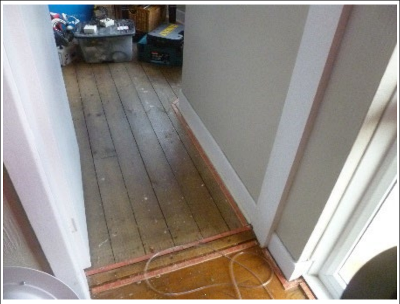
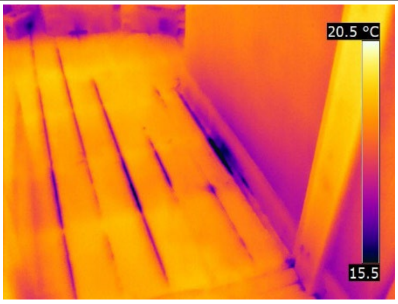
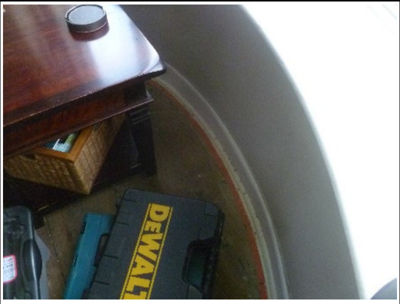
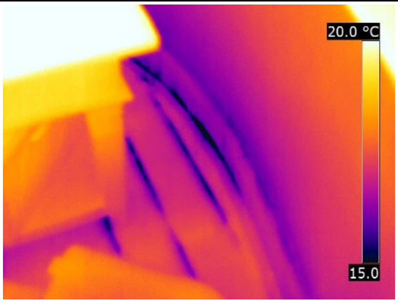
		
		The water tank above the bathroom was covered with a polythene covered insulation quilt, but there appeared to be no insulation beneath it. Insulation had been moved away from the bathroom downlighters to prevent them overheating, consequently leaving areas of uninsulated ceiling.
		
		Above the WC and bedroom 3 cupboard there were missing areas of insulation around the downlighters and where a roll of loft insulation appeared to have been rolled back to expose the plaster ceiling beneath.
		
		

Internal Thermographic Observations 17-Nov-2023 (no induced pressure differential):

Hall, Stairs & Landing		
		The hall ceiling, showing the central heating pipework for the radiator in bedroom.
		The WC ceiling, showing uninsulated area around the downlighters and where the piece of insulation in the loft had been rolled back.
Bathroom		
		Gaps in loft insulation around the downlighters and underneath the water tank in the loft.
		
Bedroom 1 (Rear-Facing)		
		Thermal bridging at the ceiling perimeter in bedroom 1 where the chimney extends into the loft space, and potential thermal bypass beneath.

<table>
<tr><td colspan="3">Bedroom 2 (Front-Facing)</td></tr>
<tr><td></td><td></td><td>Colder strip observed at the ceiling perimeter along the bay roof junction,</td></tr>
</table>

Thermographic Leakage Detection 17-Nov-2023 (-50.2 Pa):

<table>
<tr><td colspan="3">Lounge</td></tr>
<tr><td></td><td></td><td rowspan="2">Direct sunlight on the bay window prevented thermal imaging, but air movement around the frames under depressurisation could be detected by hand.
Thermal imaging did show significant air movement from the floor void, between floorboards and around the entire floor perimeter.</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="3">Kitchen</td></tr>
<tr><td></td><td></td><td>Air leakage was detected around the kitchen door frame and between the door and frame.</td></tr>
</table>

<table>
<tr>
<td></td>
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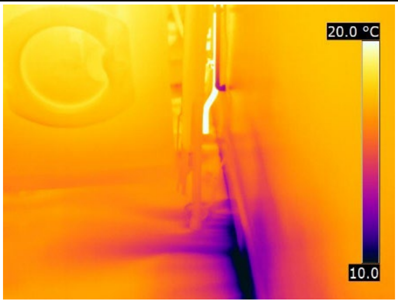
<td>Under depressurisation, there was significant air movement emerging from behind/beneath the kitchen units, further investigation would be necessary to determine where this air was entering the building envelope.</td>
</tr>
<tr>
<td></td>
<td>
</td>
<td>In the kitchen cupboard there was a section of the junctions between the floor and external wall showing a major infiltration pathway, with air emerging under the skirting and could be observed flowing underneath the lino floor covering.</td>
</tr>
<tr>
<td colspan="3">Dining Room</td>
</tr>
<tr>
<td></td>
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</td>
<td rowspan="3">More minor air leakage was observed around the floor perimeter and through the downlighters in the fireplace, but by far the most significant air leakage paths in the dining room existed around the patio doors. Under depressurisation air was emerging all around the frame but particularly at the threshold, and at numerous areas between and around the sliding doors.</td>
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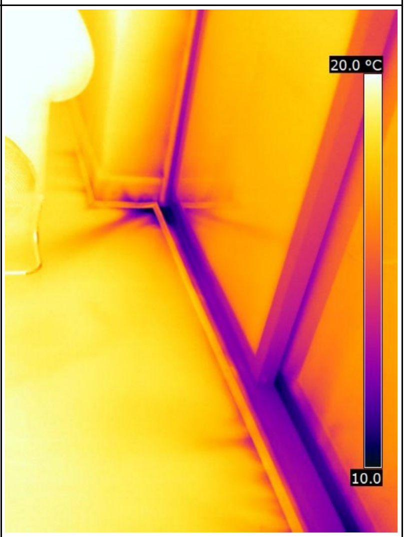
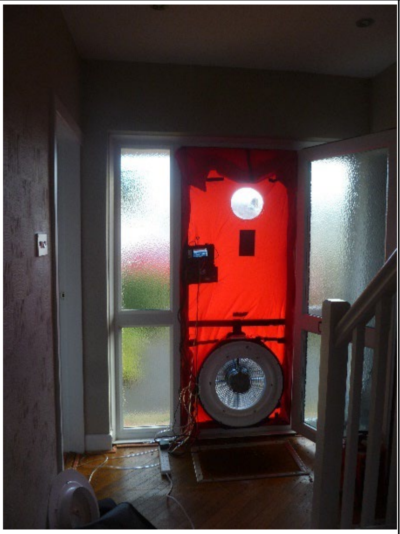
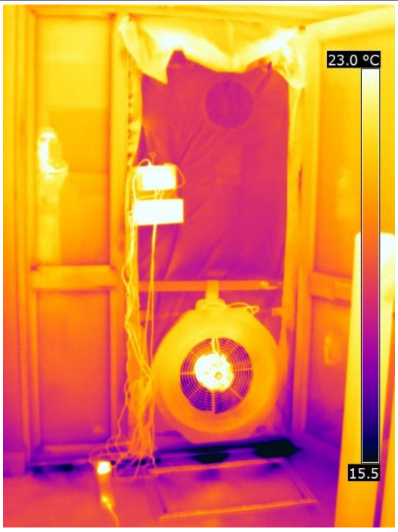
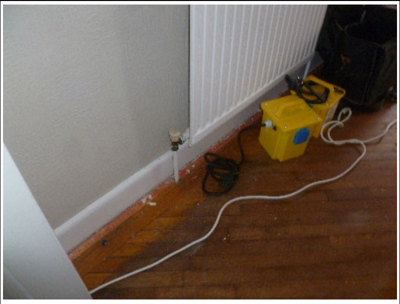
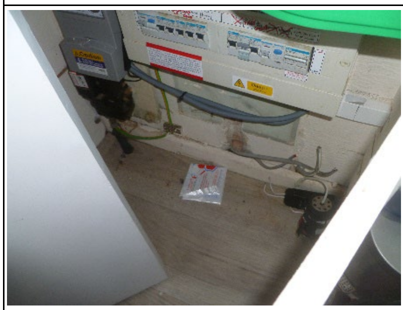
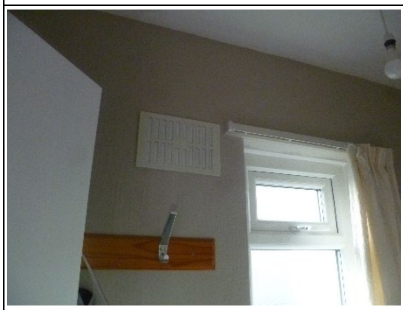
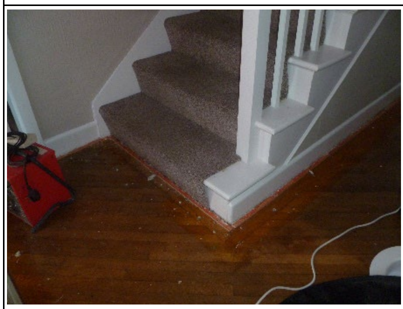
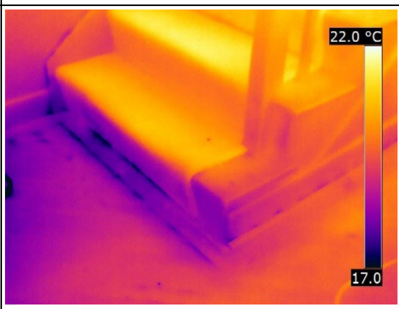
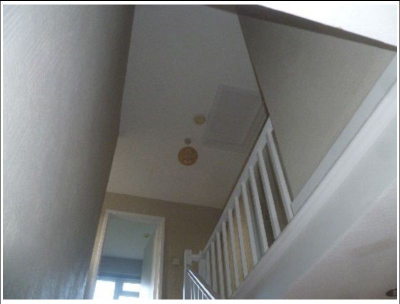
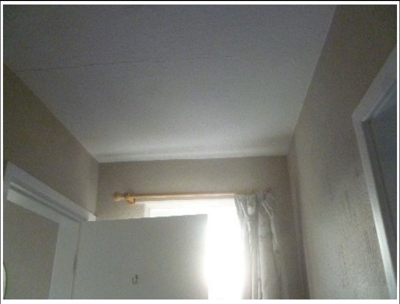
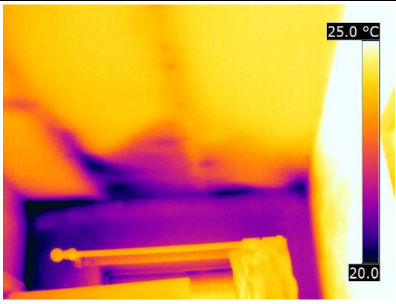
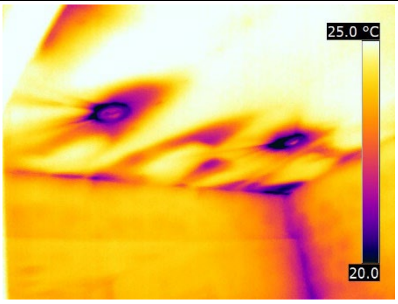
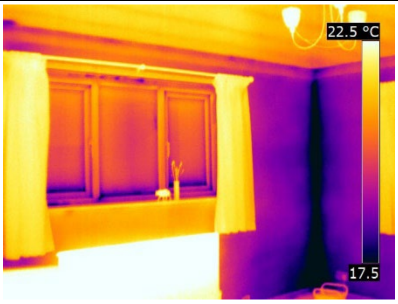
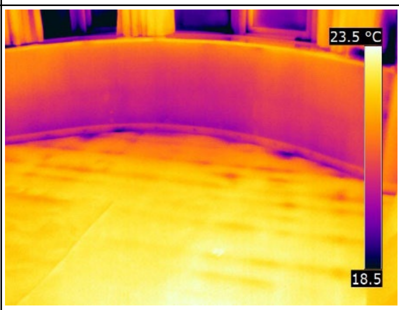
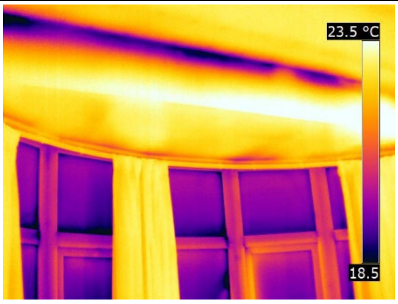
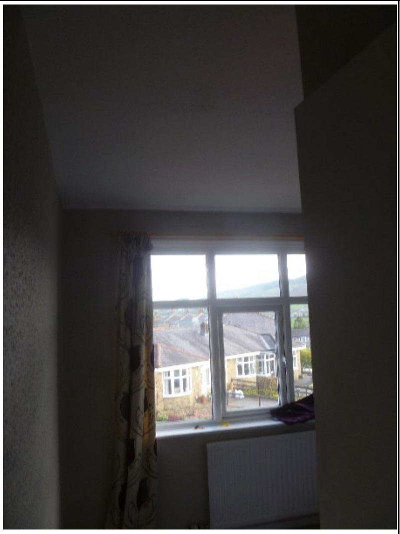
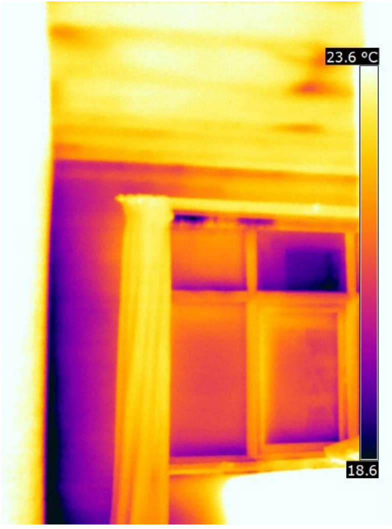
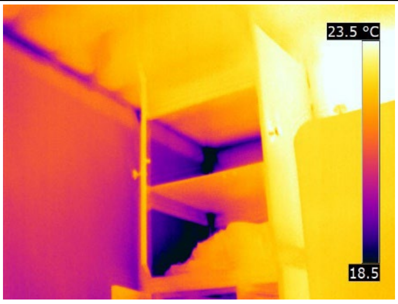
<td>
</td>
</tr>
</table>

Hall, Stairs & Landing		
		Around the front door the most severe air leakage was observed at the threshold. With the blower door frame positioned in the front door it was not possible to assess the airtightness of the front door and letterbox.
		Although the floor itself appeared airtight there was air entering around the floor perimeter and old radiator pipework holes which remained unfilled.
		Although affected by direct sunlight through the window, the hall cupboard displayed air leakage around penetrations for the electric meter through the floor and through/around the closed wall vent.
		
		Significant air movement was detected emerging around the bottom riser of the stairs.

		Under depressurisation there was notable infiltration between the loft door and surround, lesser air leakage through ceiling penetrations are barely visible in this thermal image due to the severity of air movement at the loft hatch. The cooler area of ceiling above the landing window appeared to have worsened under depressurisation, but this would require further investigation to confirm.
		
WC & Bathroom		
		Air movement around the downlighters was detected, but the more severe air leakage paths appeared to be at the wall vent (as in the hall cupboard) and into the boxed-in service services for the toilet and basin.
		
		As in the WC airflow around the downlighters was observed, it appeared more severe as the ambient temperature in the bathroom was higher (emerging air temperature and airflow were similar for both rooms).

<table>
<tr><td colspan="3">Bedroom 1 (Rear-Facing)</td></tr>
<tr><td></td><td>
</td><td rowspan="2">Again, the closed wall vent allowed significant infiltration. Air leakage around the window was again present, but minor in comparison.</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="3">Bedroom 2 (Front-Facing)</td></tr>
<tr><td></td><td>
</td><td rowspan="2">Air movement was observed around the central light rose, around the bay window and up through the intermediate floor.

Leakage around the bay window frames and casements appeared similar to the bay in the lounge, with less direct sunlight it was possible to see some of this in the thermal image.</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td></td><td>
</td><td>Air emerging from the floor appeared coolest in the actual bay, getting warmer toward the centre of the house.</td></tr>
</table>

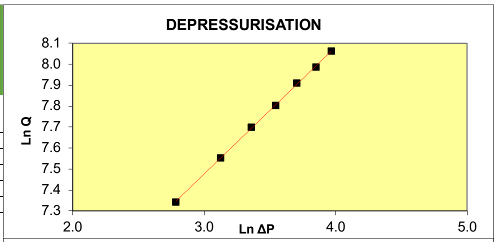
		The thermal bridge at the ceiling junction with the external front wall did not appear to alter noticeably during depressurisation, indicating that the excessive heat loss causing the cold strip is more likely to be due to thermal bridging than air movement related issues.
		
Bedroom 3 (Front-Facing)		
		Again, the airtight performance of the window was reasonable and fairly typical with the rest of the house.
		Some minor air leakage around shrinkage cracks at the loft perimeter. The external wall in the cupboard was cooler than expected, but the doors had been closed previous preventing warmed air from entering.
		As in bedroom 2 the coolest air coming up from the intermediate floor was nearer the edges of the house, particularly in the external corner above the front porch where the intermediate floor was exposed beneath.

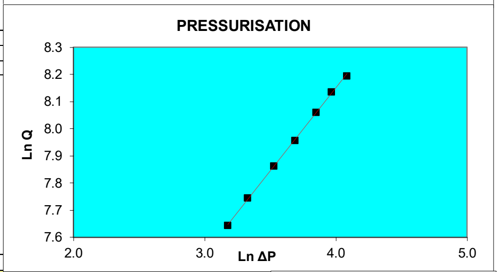
Airtightness Spreadsheet 17-Nov-2023:

LEEDS BECKETT UNIVERSITY — Leeds Sustainability Institute

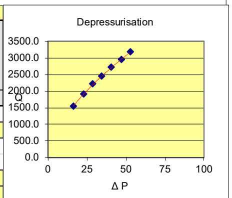
MINNEAPOLIS BLOWER DOOR DATA INPUT AND CALCULATION

date:	17/11/2023		Version 16e	##################	
test house address:	49 Regent Road				
company:	SBS				
house type:	detached				
tester:	FT, AH, DMS				
test reference number:			Blower Door & Gauge Used	Model 3 with DG700	
outdoor temp (°C)	11	°C	Note: ENSURE THAT FLOW SETTINGS ARE IN m3/h - When using the DG700 gauge run baseline pressure adjustment for minimum 60s with fan switched on but not rotating		
indoor temp (°C)	20.1	°C			
outdoor humidity (%rh)	68.2	%RH			
indoor humidity (%rh)	50.5	%RH			
outdoor barometric pressure	999.3	mbar or hPa	Calculated Outdoor Air Density	1.22	kg/m^3
indoor barometric pressure	999.3	mbar or hPa	Calculated Indoor Air Density	1.18	kg/m^3
temperature corr. fact. depress.	0.969		description of main construction details:		
temperature corr. fact. press.	1.032		3 bed, masonry, pre-refurbishment		
wind speed (m/s):	0				
baseline pressure diff (Pa) (+/-)		Pa			
house width:	7.3	m			
house depth:	8	m			
house height:	5.3	m			
floor area:	55.2	m^2			
volume:	296.6	m^3			
envelope area including floor:	277.3	m^2			
Pressure Difference for ELA	10	Pa			
RESULTS:					
Q50 Mean Flow at 50Pa =	3181.71	m^3/h			
Mean Air Leakage at 50Pa =	10.73	h^{-1}			
Mean Air Permeability at 50 Pa =	11.47	m/h or m^3h/m^2			
Equivalent Leakage Area =	0.133	m^2 at	10	Pa	

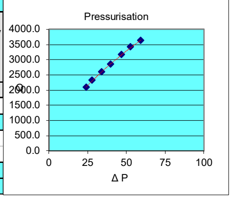




DEPRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Depressurisation Only ($m^3/(h.m^2)$)	Air Leakage Depressurisation Only (h^{-1})
Approx 65 Pa	A	52.7	3279	3173.7	OK	52.7	3.965	8.063	3093.82	11.16	10.43
Approx 57 Pa	A	47	3037	2939.5	OK	47	3.850	7.986	r^2	1.000	
Approx 49 Pa	A	40.6	2812	2721.7	OK	40.6	3.704	7.909	C_{env}	285.458	$m^3/h.Pa^n$
Approx 41 Pa	A	34.5	2527	2445.9	OK	34.5	3.541	7.802	n	0.607	
Approx 33 Pa	A	28.7	2283	2209.7	OK	28.7	3.357	7.701			
Approx 25 Pa	A	22.8	1970	1906.7	OK	22.8	3.127	7.553	C_L (corrected)	287.407	$m^3/h.Pa^n$
Approx 20 Pa	A	16.2	1596	1544.8	OK	16.2	2.785	7.343			



PRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Pressurisation Only ($m^3/(h.m^2)$)	Air Leakage Pressurisation Only (h^{-1})
Approx 65 Pa	A	59.3	3508	3624.4	OK	59.3	4.083	8.195	3269.60	11.79	11.02
Approx 57 Pa	A	52.6	3308	3417.7	OK	52.6	3.963	8.137	r^2	0.999	
Approx 49 Pa	A	46.9	3065	3166.7	OK	46.9	3.848	8.060	C_{env}	303.065	$m^3/h.Pa^n$
Approx 41 Pa	A	39.8	2763	2854.7	OK	39.8	3.684	7.957	n	0.610	
Approx 33 Pa	A	33.9	2516	2599.5	OK	33.9	3.523	7.863			
Approx 25 Pa	A	27.8	2234	2308.1	OK	27.8	3.325	7.744	C_L (corrected)	301.259	$m^3/h.Pa^n$
Approx 20 Pa	A	23.9	2022	2089.1	OK	23.9	3.174	7.644			



Spot 50Pa measurements

Pressure or Depress? Input D or P	RING (O=open or A,B,C)	FAN PRESSURE (Pa)	FLOW (m3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Air Density Corrected Flow at 50Pa (m3/h)	ACH (ach)	Air Permeability (m/h)	Comment
d	a	51.9	3166	OK	51.9	3067.70	10.34	11.06	sealed chimney vents in lounge
d	a	51.7	3180	OK	51.7	3081.27	10.39	11.11	sealed chimney vents in lounge

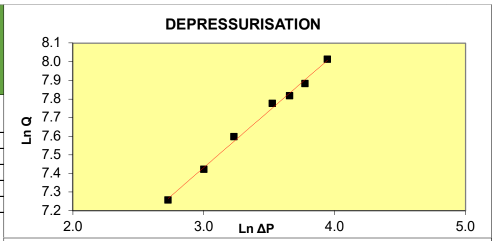
Airtightness Spreadsheet 18-Dec-2023:

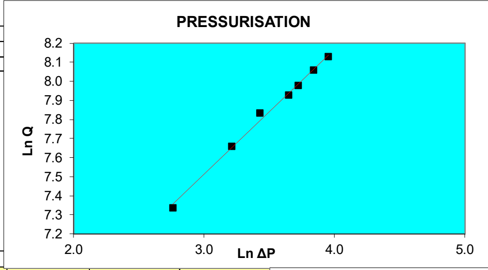
LEEDS BECKETT UNIVERSITY

Leeds Sustainability Institute

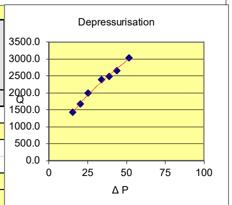
MINNEAPOLIS BLOWER DOOR DATA INPUT AND CALCULATION

date:	18/12/2023		Version 16e	##################	
test house address:	49 Regent Road				
company:	SBS				
house type:	detached				
tester:	FT				
test reference number:			Blower Door & Gauge Used	Model 3 with DG700	
outdoor temp (°C)	12.6	°C	Note: ENSURE THAT FLOW SETTINGS ARE IN m3/h - When using the DG700 gauge run baseline pressure adjustment for minimum 60s with fan switched on but not rotating		
indoor temp (°C)	22.6	°C			
outdoor humidity (%rh)	85	%RH			
indoor humidity (%rh)	47.5	%RH			
outdoor barometric pressure	1022.5	mbar or hPa	Calculated Outdoor Air Density	1.24	kg/m^3
indoor barometric pressure	1022.4	mbar or hPa	Calculated Indoor Air Density	1.20	kg/m^3
temperature corr. fact. depress.	0.966		description of main construction details:		
temperature corr. fact. press.	1.035		3 bed, masonry, pre-refurbishment, Post coheat. Wind gusting from the south		
wind speed (m/s):	1				
baseline pressure diff (Pa) (+/-)		Pa			
house width:	7.3	m			
house depth:	8	m			
house height:	5.3	m			
floor area:	55.2	m^2			
volume:	296.6	m^3			
envelope area including floor:	277.3	m^2			
Pressure Difference for ELA	10	Pa			
RESULTS:					
Q50 Mean Flow at 50Pa =	3154.74	m^3/h			
Mean Air Leakage at 50Pa =	10.64	h^{-1}			
Mean Air Permeability at 50 Pa =	11.38	m/h or m^3h/m^2			
Equivalent Leakage Area =	0.128	m^2 at	10	Pa	

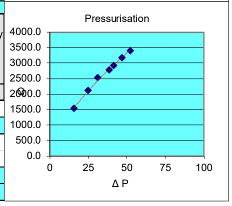




DEPRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Depressurisation Only ($m^3/(h.m^2)$)	Air Leakage Depressurisation Only (h^{-1})
Approx 65 Pa	A	51.8	3133	3026.1	OK	51.8	3.947	8.015	2981.60	10.75	10.05
Approx 57 Pa	A	43.6	2744	2650.3	OK	43.6	3.775	7.882	r^2	0.995	
Approx 49 Pa	A	38.8	2571	2483.3	OK	38.8	3.658	7.817	C_{env}	271.461	$m^3/h.Pa^n$
Approx 41 Pa	A	33.9	2464	2379.9	OK	33.9	3.523	7.775	n	0.609	
Approx 33 Pa	A	25.3	2061	1990.7	OK	25.3	3.231	7.596			
Approx 25 Pa	A	20.1	1731	1671.9	OK	20.1	3.001	7.422	C_L (corrected)	275.034	$m^3/h.Pa^n$
Approx 20 Pa	A	15.3	1469	1418.9	OUT OF RANGE	15.3	2.728	7.258			



PRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Pressurisation Only ($m^3/(h.m^2)$)	Air Leakage Pressurisation Only (h^{-1})
Approx 65 Pa	A	52.1	3274	3389.7	OK	52.1	3.953	8.128	3327.89	12.00	11.22
Approx 57 Pa	A	46.6	3058	3166.1	OK	46.6	3.842	8.060	r^2	0.995	
Approx 49 Pa	A	41.3	2821	2920.7	OK	41.3	3.721	7.980	C_{env}	256.397	$m^3/h.Pa^n$
Approx 41 Pa	A	38.5	2679	2773.7	OK	38.5	3.651	7.928	n	0.655	
Approx 33 Pa	A	30.8	2439	2525.2	OK	30.8	3.428	7.834			
Approx 25 Pa	A	24.8	2046	2118.3	OK	24.8	3.211	7.658	C_L (corrected)	256.286	$m^3/h.Pa^n$
Approx 20 Pa	A	15.8	1484	1536.4	OUT OF RANGE	15.8	2.760	7.337			



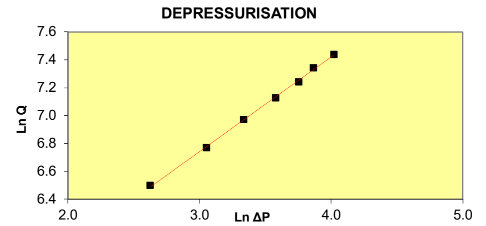
Airtightness Spreadsheet 06-Dec-2024:

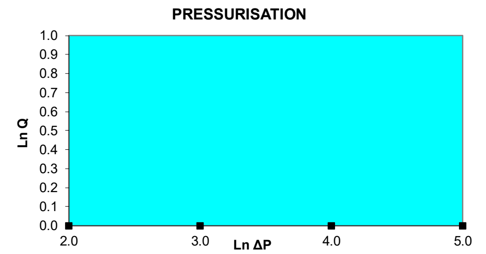
LEEDS BECKETT UNIVERSITY

Leeds Sustainability Institute

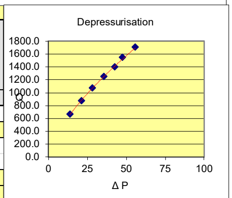
MINNEAPOLIS BLOWER DOOR DATA INPUT AND CALCULATION

date:	06/12/2024		Version 16f	17 November 2023	
test house address:	49 Regent Road				
company:	SBS				
house type:	detached				
tester:	FT, AH, DMS				
test reference number:			Blower Door & Gauge Used	Model 4 with DG1000	
outdoor temp (°C)	8.1	°C	Note: ENSURE THAT FLOW SETTINGS ARE IN m^3/h - When using the DG700/1000 gauge run baseline pressure adjustment for minimum 30s with fan switched on but not rotating		
indoor temp (°C)	21.4	°C			
outdoor humidity (%rh)	69.8	%RH			
indoor humidity (%rh)	50.1	%RH			
outdoor barometric pressure	1004.1	mbar or hPa	Calculated Outdoor Air Density	1.24	kg/m^3
indoor barometric pressure	1004.1	mbar or hPa	Calculated Indoor Air Density	1.18	kg/m^3
temperature corr. fact. depress.	0.955	WARNING!!	description of main construction details:		
temperature corr. fact. press.	1.047	Extreme Test	3 bed, masonry, post-refurbishment		
wind speed (m/s):	0.4	Conditions			
baseline pressure diff (Pa) (+/-)		Pa			
house width:	7.3	m			
house depth:	8	m			
house height:	5.3	m			
floor area:	55.2	m^2			
volume:	296.6	m^3			
envelope area including floor:	277.3	m^2			
Pressure Difference for ELA	10	Pa			
RESULTS:					
Q50 Mean Flow at 50Pa =		m^3/h			
Mean Air Leakage at 50Pa =		h^{-1}			
Mean Air Permeability at 50 Pa =		m/h or $m^3/(h.m^2)$			
Equivalent Leakage Area =		m^2 at	10	Pa	

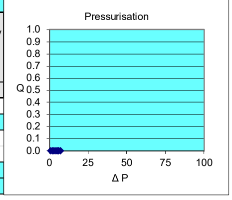




DEPRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Depressurisation Only ($m^3/(h.m^2)$)	Air Leakage Depressurisation Only (h^{-1})
Approx 65 Pa	A	55.7	1786	1702.0	OK	55.7	4.020	7.440	1591.21	5.74	5.36
Approx 57 Pa	A	47.6	1619	1542.8	OK	47.6	3.863	7.341	r^2	0.999	
Approx 49 Pa	B	42.6	1466	1397.0	OK	42.6	3.752	7.242	C_{env}	111.375	$m^3/h.Pa^n$
Approx 41 Pa	B	35.7	1305	1243.6	OK	35.7	3.575	7.126	n	0.677	
Approx 33 Pa	B	28	1119	1066.4	OK	28	3.332	6.972			
Approx 25 Pa	B	21.2	913	870.1	OK	21.2	3.054	6.769	C_L (corrected)	112.565	$m^3/h.Pa^n$
Approx 20 Pa	B	13.8	698	665.2	OK	13.8	2.625	6.500			



PRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Pressurisation Only ($m^3/(h.m^2)$)	Air Leakage Pressurisation Only (h^{-1})
Approx 65 Pa											
Approx 57 Pa									r^2		
Approx 49 Pa									C_{env}		$m^3/h.Pa^n$
Approx 41 Pa									n		
Approx 33 Pa											
Approx 25 Pa									C_L (corrected)		$m^3/h.Pa^n$
Approx 20 Pa											



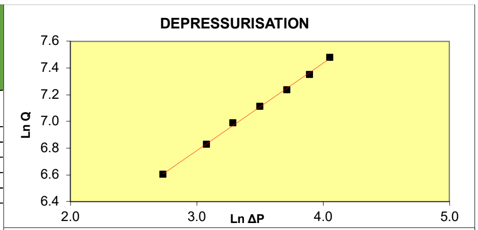
Airtightness Spreadsheet 20-Dec-2024:

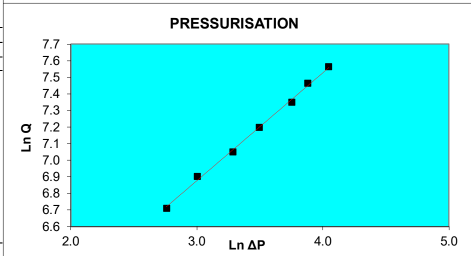
LEEDS BECKETT UNIVERSITY

Leeds Sustainability Institute

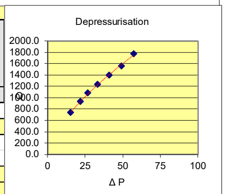
MINNEAPOLIS BLOWER DOOR DATA INPUT AND CALCULATION

date:	20/12/2024		Version 16f	17 November 2023
test house address:	49 Regent Road			
company:	SBS			
house type:	detached			
tester:	MF, AH, DMS			
test reference number:			Blower Door & Gauge Used	Model 4 with DG1000
outdoor temp (°C)	5.3	°C	Note: ENSURE THAT FLOW SETTINGS ARE IN m^3/h - When using the DG700/1000 gauge run baseline pressure adjustment for minimum 30s with fan switched on but not rotating	
indoor temp (°C)	17.9	°C		
outdoor humidity (%rh)	83.3	%RH		
indoor humidity (%rh)	49.3	%RH		
outdoor barometric pressure	1013.4	mbar or hPa	Calculated Outdoor Air Density	1.26 kg/m^3
indoor barometric pressure	1013.4	mbar or hPa	Calculated Indoor Air Density	1.21 kg/m^3
temperature corr. fact. depress.	0.957	WARNING!!	description of main construction details:	
temperature corr. fact. press.	1.045	Extreme Test	3 bed, masonry, post-refurbishment	
wind speed (m/s):	2.2	Conditions		
baseline pressure diff (Pa) (+/-)		Pa		
house width:	7.3	m		
house depth:	8	m		
house height:	5.3	m		
floor area:	55.2	m^2		
volume:	296.6	m^3		
envelope area including floor:	277.3	m^2		
Pressure Difference for ELA	10	Pa		
RESULTS:				
Q50 Mean Flow at 50Pa =	1696.52	m^3/h		
Mean Air Leakage at 50Pa =	5.72	h^{-1}		
Mean Air Permeability at 50 Pa =	6.12	m/h or $m^3/(h.m^2)$		
Equivalent Leakage Area =	0.067	m^2 at	10	Pa





DEPRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Depressurisation Only ($m^3/(h.m^2)$)	Air Leakage Depressurisation Only (h^{-1})
Approx 65 Pa	A	57.4	1855	1772.9	OK	57.4	4.050	7.480	1630.69	5.88	5.50
Approx 57 Pa	A	48.9	1630	1557.9	OK	48.9	3.890	7.351	r^2	0.998	
Approx 49 Pa	B	41	1453	1388.7	OK	41	3.714	7.236	C_{env}	124.388	$m^3/h.Pa^n$
Approx 41 Pa	B	33.1	1284	1227.2	OK	33.1	3.500	7.112	n	0.653	
Approx 33 Pa	B	26.7	1135	1084.8	OK	26.7	3.285	6.989			
Approx 25 Pa	B	21.7	968	925.2	OK	21.7	3.077	6.830	C_L (corrected)	126.661	$m^3/h.Pa^n$
Approx 20 Pa	B	15.4	772	737.8	OK	15.4	2.734	6.604			



PRESSURISATION	RING - O,A,B,C,D,E for BD3 0,1,2,3 for DuctBB	MEASURED FAN PRESSURE (Pa) Max. 90 Pa	MEASURED FLOW (m^3/h)	ADJUSTED FLOW (m^3/h)	FLOW RANGE OK FOR SELECTED RING?	Adjusted Pressure (Pa)	Ln delta P	Ln Q	Q50 Calculated Flow at 50Pa (m^3/h)	Permeability Pressurisation Only ($m^3/(h.m^2)$)	Air Leakage Pressurisation Only (h^{-1})
Approx 65 Pa	A	57.2	1844	1929.4	OK	57.2	4.047	7.565	1762.35	6.36	5.94
Approx 57 Pa	A	48.5	1669	1746.3	OK	48.5	3.882	7.465	r^2	0.998	
Approx 49 Pa	B	42.6	1486	1554.8	OK	42.6	3.752	7.349	C_{env}	136.089	$m^3/h.Pa^n$
Approx 41 Pa	B	33	1277	1336.1	OK	33	3.497	7.198	n	0.654	
Approx 33 Pa	B	26.7	1100	1150.9	OK	26.7	3.285	7.048			
Approx 25 Pa	B	20.2	951	995.0	OK	20.2	3.006	6.903	C_L (corrected)	136.417	$m^3/h.Pa^n$
Approx 20 Pa	B	15.8	785	821.3	OK	15.8	2.760	6.711