Programme Area: Smart Systems and Heat

Project: WP1 Building Retrofits

Title: Key Performance Results from ETI Retrofit Demonstration Project

Abstract:

This document is one of two final summative reports produced by PRP for the ETI funded Buildings Retrofit project. This report focuses on the key performance results from the retrofitting work and the second report contains the project conclusions and opportunities for improving the delivery of whole house retrofit. This report contains the energy use pre and post retrofitting activities, post installation problems, cost breakdowns and co benefits from the retrofitting activities.

Context:

The aim of the project is to validate the cost, time and energy effectiveness of domestic retrofit across different house types, using an approach that could be employed to improve the energy efficiency of the vast majority of the existing 26 million homes in the UK which will still be in existence by 2050. The novel, mass-scale retrofit approach being tested was first developed in a deskbased ETI project ("Optimising Thermal Efficiency of Existing Housing") completed in 2012, as part of the ETI Buildings programme. The 20-month long, £475,000 project will retrofit five types of domestic property, identified and prioritised in the earlier ETI project.

Smart Systems and Heat (SSH) Technology Programme

Domestic Retrofit Demonstration

Project Summative Report 1

Key Performance Results from the ETI Retrofit Demonstration Project

Preface

PRP and Peabody were part of a consortium that undertook the Optimising Thermal Efficiency of Existing Housing (OTEoEH) research study for the Energy Technologies Institute. The purpose of the study was to develop proposals for the mass implementation of low carbon retrofit for all existing housing stock in the UK.

The project identified how approaches to retrofitting existing residential properties in the UK could be accelerated by industrialising the processes of design, the supply of resource and materials and the installation of retrofit works, while stimulating demand for retrofit from householders by exploiting additional opportunities that are provided by other home refurbishment work such as a new bathroom. Appropriate technical solutions were developed for a variety of dwelling types while considering the costs, technical viability, quality, legislation and customer acceptance. The socio-cultural issues associated with retrofit were examined and the consortium analysed demographic attitudes toward energy conservation in the home through surveys, focus groups and in-home interviews. This provided valuable insight into resident energy use and behaviour which informed the development of effective and attractive retrofit packages.

The project identified the top 10 house typologies in the UK based on the typical total carbon dioxide emissions from each typology and the total number of that typology in the UK, i.e. the groups of houses by type which emit the most carbon dioxide emissions. Through modelling of the associated energy consumption reductions and quantification of the corresponding carbon dioxide emission savings, packages of retrofit measures where developed for each of the 10 housing groups. It was determined that the retrofit solutions should deal with the whole of the external fabric of the house and not parts of it, to ensure maximum resultant energy consumption reduction and to minimise the resultant consequential performance risks from not doing whole house retrofit such as surface condensation. Two whole house packages per dwelling type where developed, RetroFix^{TM} and RetroPlus^{TM} with the former including wall and roof insulation with air permeability sealing, heating system upgrade and mechanical ventilation with heat recovery. The latter included the RetroFix^{TM} measures as well as new windows and external doors and ground floor insulation. The developed packages of measures are largely appropriate for all house typologies in the UK with consideration required for individual homes in relation to local physical conditions such as boundaries and access as well as the house’s characteristics, current layout and construction.

A top-to-bottom retrofit installation process was developed, using a method of analysing the most cost-effective package of retrofit measures suitable for a particular property; through to how these would be installed with the minimum disruption to the householder. This included identifying the skills required of the workers in the installation team as well as the optimum material distribution networks to supply them with exactly what is required and when. It was determined that time and cost is wasted due to the multiple trades (e.g. electrician, heating engineer) visiting a house to undertake retrofit work, often in sequence over many weeks. Besides the impact this has on increasing costs, and lengthening installation programmes, it has a disruption impact on householders. It was therefore proposed that a multi-skilled team (poly competent team) of 4 people should be used to complete work on individual homes. That team would not rely on external trades to complete the work and would undertake the whole work to each home before moving to another home.

The Performance Targets proposed by the team were:

RetroFix^{TM}

Installation period - maximum two weeks

Capital cost of £10,000

Primary energy consumption reduction of 25% - 40%

RetroPlus™

Installation period - maximum three weeks

Capital cost of £15,000 - £20,000

Primary energy consumption reduction of 40% - 60%

The package of retrofit measures along with the supply chain delivery plans plus the multi-skilled installation team solution developed in the project are referred to as the 'Retrofit Approach' in these reports. Building on the mass-scale whole house retrofit approach that was developed in the desk-based OTEoEH study, ETI decided to run a demonstrator project to trial the developed Retrofit Approach on five occupied houses. The demonstration project aimed to validate the approach in relation to the cost, time and energy effectiveness of the RetroFix™ and RetroPlus™ packages. PRP led the project with partner Peabody, supported by subcontractor Total Flow, an insulation manufacturer and a national construction contractor for the retrofit of four houses in London and a regional construction contractor for one home in the North of England. The ETI selected five house types, which were representative of the top five typology groups of the ten identified in the OTEoEH project. The consortium undertook analysis of the survey, design and installation processes as well as the resulting performance of the retrofit installations including the gathering of quantitative data from each house and qualitative feedback from the installation team and householders.

The demonstration project also trialled a test developed by Loughborough University which analyses the amount of heat energy used by a home prior to and after retrofit.

Some industry recognised terms and there abbreviations are used in the reports and we have provided definitions here for the general reader not familiar with these.

External Wall Insulation (EWI) – insulation and an outer weatherproof finish applied to the outside of house walls; finish is often render but could be thin bricks or weatherboard cladding
Internal Wall Insulation (IWI) – insulation and board finish applied to the inside of house walls

Content

1. Executive Summary

1.1. Project Background and Objectives

The Retrofit Demonstration project involved the retrofitting of five occupied properties of a mix of tenures, the typologies of which were identified and prioritised by ETI, with four homes selected by the project team in the greater London area and one home located in the North of England. Originally it was planned to retrofit five properties each differing in age and construction, but although the design and planning work was completed, the final property was not retrofitted as it was determined that the Retrofit Approach had been tested well enough and that another home would not provide additional data above that already collected in the project. Each property was retrofitted according to tailored but replicable packages of retrofit whole house measures. The property types were a pre-1919 mid-terrace house (RD1), a pre-1919 detached house (not retrofitted), a 1919-44 semi-detached house (RD9), a 1945-64 semi-detached house (RD5) and a post-1980 semi-detached house (RD27).

The project's core objective was to test and validate within the parameters of the Demonstration Project the Retrofit Approach and assess any changes in process or ambition which enable an acceleration of cost-effective retrofit delivery to large numbers of dwellings. The four core aspects of a successful retrofit are:

- Resulting Energy Performance
- Retrofit Costs
- Installation Quality and Reduced Installation Time
- Householder Experience of Retrofit.

This report, the first part of a two part summative report provides details of the key findings from the demonstration project including the challenges encountered and resultant retrofit performance. The second report analyses the project findings and their implications, it also makes recommendations for improving the Retrofit Approach including a roadmap to the further development and commercialisation of the Approach.

1.2. Key findings

The overall findings of the report are:

- **Supply Chain** – the supply chain is not yet ready for individual home retrofit delivery logistics at a small scale (a few homes in disparate locations), a larger scale programme of retrofit of at least 100 homes, is required to enable the supply chain to see any commercial benefit in adapting delivery models to provide the frequent delivery service required and to enable greater time and cost efficiencies and to reduce material wastage. In reality, to see a full step change in the supply chain, retrofit programmes of 1000's of homes are required.
- **Thermal Performance** targets as set out in the Retrofit Approach are achievable through the use of correct insulation products, good technical detailing and adherence to quality on site. However, the elemental air leakage targets were found to be more difficult to achieve in occupied homes and in particular in more modern homes with plasterboard internal linings rather than traditional plaster wall finishes, where there is an air route behind the plasterboard due to how it is bonded to walls. Allowance must be made for the disturbance, time and cost in undertaking air sealing work.
- **In use heat testing** works with residents' in-situ but would benefit from further validation. As four homes are not deemed to be a wide enough trial to sufficiently validate a test method prior to industry commercialisation of the test. Data collected during periods with cold external temperatures are crucial to the test's success as a greater than 10℃ difference is required between internal and external temperatures. Heat gains from the sun through windows should also be avoided as it confuses the test results.
- **Energy Performance** – Data analysis from the in use heat balance test and in house monitoring, confirmed the potential for 20% to 50% of total household gas consumption reduction through retrofit while the qualitative interviews recorded that resident's comfort and well-being were also improved**.**

- **Survey** – Detailed surveys are imperative to informing the design solutions and installation methods as well as reducing cost and programme overrun risks. They also support the achievement of the required post retrofit energy performance targets. The current costs of the required surveys are prohibitive to achieving the Retrofit Approach target retrofit cost and new survey methods should be developed to reduce the time on site and costs involved.
- **Design solutions** – a suite of standard installation details in drawing format should be prepared for use across similar housing typologies to reduce the upfront design costs on each project (i.e. not producing new drawings for each house) and the time taken to make decisions on site (i.e. less need to query what an installation detail is as there are drawings already) as well as enabling the installation teams to become more familiar with the details through familiarity of standard details, thus contributing to reducing the installation programme and enabling installation quality to be improved.
- **Installation Quality & Detailing** – Experience on this project has been that the retrofit teams generally have standards of quality and attention to detail below the requirements for effective retrofit and consumer acceptance. Although in the project teams experience, this level of quality does not apply to all retrofit contractors, it does apply to many, largely due to a lack of understanding of the need to install to a high level of quality or the benefits brought by doing so (e.g. reduced risks, improved performance etc.). Performance and quality requirements need to be clearly set out and products and processes adapted to ensure that teams can be capable of repeatedly meeting the aesthetic and thermal standards.
- **Condensation and mould growth** are major risks for the health of householders and also building fabric condition and can be common in badly retrofitted homes. Work in this project and outside of this project by PRP and others, has demonstrated the need for minimised thermal bridging on retrofit projects. Thermal bridging details such as those adopted on this project must be used on site to ensure good thermal performance of the fabric and consequentially minimise heat loss and the risk of mould and condensation. Ventilation methods as part of the retrofit strategy are also imperative for reducing condensation and mould and improving good indoor air quality.
- **Costs and Installation Processes** have been reviewed in detail and significant opportunities identified to improve product, process and costs. However, a confirmed route to achieving the £10,000 cost target for a typical 3 bedroom semi-detached property has not yet been identified. The team has delivered it for £18,000 on an associated project and continues to work on driving this price down.
- **Material costs** – Significant material discounts are possible from volume pricing, but wastage is endemic (as system generated off-cuts). Brick slip finishes have an appealing aesthetic (vs. render) but come with a cost and labour time premium. There is a need for innovation in heating and ventilation solutions which enable rapid installation – particularly at system interfaces. Increased scale for current niche products (e.g. heat recovery ventilation, roof insulation trays) will reduce current costs but only if the demand roadmap is clear.
- **Labour costs** – Currently EWI installers are paid close to (or potentially below) minimum wage, but the project team decided to use more sustainable rates. This puts a cost premium on the retrofit installation work but ensures installers are paid a living wage.
- **Installation Programme** – The cost analysis demonstrates that it is crucial to achieve an installation programme of two working weeks or less to reduce costs close to the £10,000 target. More than two weeks for a four person team will exceed the target cost due to salary costs. Two weeks also supports the householder tolerance for work in their home. This two week target was only achieved on one house in this project.
- **Overhead & Profit** are significant elements of cost for scaffolding, welfare facilities, management and profit. Setting fixed fees for profit within the contract with the retrofit installation contractor, will incentivise a focus on short programmes and right first time quality.
- **Risk** – Building condition, particularly on older properties, has been confirmed as having a potentially significant impact on cost and programme. More work is needed to manage this risk.
- **Householder Journey –** a key lesson is that the householder wants regular and high quality communication with regard to the project start date, programme and the work schedule so they can understand the impact on their daily lives and plan accordingly. The amount of time required for communication should not be underestimated and lessons from this project show that ideally communication is via one team member to encourage trust and rapport between them and the householders.

- **Spin-off benefits** – of whole house retrofit are valued by residents, but despite a potential £1,000 benefit from the works; few would recognise investment in property maintenance as a reason to trigger retrofit. Benefits are from those tasks completed as part of the retrofit works, which have a value but that the owner would not invest in until a failure or urgent need therefore don't recognise the value. Retrofit works have the potential to enable added value works at a marginal cost, through use of the scaffold and the already on-site team, i.e. the replacement of rainwater gutters which saves money on a periodic gutter clean out, removes existing leaks and improves the homes appearance. Oversized gutters can also be installed to reduce future overflow as weather patterns change and heavy rain is experienced.

To develop the Retrofit Approach to a point of commercial viability will require the current target costs to be proven, and ideally improved upon on, during further larger scale demonstration trials. To achieve the target costs, will require investment in the industrialisation of products and processes to develop solutions which can support delivery at the cost. Industry and the wider supply chain are unlikely to make this investment without a clear market demand or funding mechanisms. There may be a need for market stimulus in some form, potentially funding or financial incentives but lessons from other recent programmes such as the Green Deal and the Feed in Tariff programme must be considered.

2. Introduction

The objective of the Retrofit Demonstration project was to test and evaluate each performance target of the Retrofit Approach, in as near commercially realistic conditions as possible. This required collecting comprehensive datasets relating to design, delivery and resulting performance, and assessing their resulting impact on three key target areas of performance;

- Energy Performance
- Installation Process and Programme
- Retrofit Costs

The collected datasets have been used to assess the commercial viability of the Retrofit Approach as delivered across the four properties. Conclusions and future opportunities for the Retrofit Approach are set out in the accompanying Report 2.

2.1 Project Hypotheses and Targets

The underpinning hypothesis for this project is that the Retrofit Approach can be developed to meet the related performance targets set in the previous ETI's Optimising Thermal Efficiency of Existing Housing Project and viably delivered to large numbers of dwellings.

The core aspects of the Retrofit Approach are:

- Whole house retrofit – rather than individual unconnected measures
- A poly-competent team of 4 people to deliver the whole works
- A significant saving in heat energy 25%-40% of total gas consumption
- An installation programme of 2 weeks or less
- Delivered at best price to the customer

These targets are discussed in more detail in the following sections.

2.1.1. Energy Performance

This dataset looks at the change in energy consumption pre- to post-retrofit, establishing the effectiveness of the overall retrofit solution performance.

The retrofit packages have been designed to meet the energy savings targets set out in the Retrofit Approach. Based on the previous modelling work carried out during the Optimising Thermal Efficiency of Existing Housing Project, the potential for savings in delivered energy consumption ranged between 25%-40% for RetroFix^{TM} (equivalent to annual energy consumption between 7,580kWh and 31,300kWh after retrofit) and 40%-60% for RetroPlus^{TM} (equivalent to annual energy consumption between 6,530kWh and 20,700kWh after retrofit). These figures are for delivered primary energy only (with delivered energy referring to gas boilers and the fuel used after combustion and the associated losses due to the level of efficiency of the boiler) and include ventilation fans, lighting and appliance use, as well as water heating use. The target consumption savings do not include electricity consumption for white goods or electrical appliances. It should be noted that boiler and heating control replacement, lighting or appliance upgrades did not form part of this demonstration project at ETI's request, although boiler and heating controls are included as part of the standard Retrofit Approach packages.

In summary, the RetroFix^{TM} package targeted a total average energy reduction of 25%-40% from a home, and the RetroPlus^{TM} package targeted a total average energy reduction of 40%-60%.

2.1.2. Installation Process and Programme

The objective for the installation process is to minimise disruption to householders in-situ by developing a short retrofit installation programme which has limited impact on the residents' use of their home.

The target installation time for a terraced or semi-detached property is two weeks or less for the RetroFix^{TM} scenario and three weeks for the RetroPlus^{TM}.

2.1.3. Retrofit Costs

The ETI's Optimising Thermal Efficiency of Existing Housing project identified that few owner-occupiers are willing or able to invest more than £10,000 in a home-improvement project.

In addition a simplified Net Present Value calculation from the project suggested that the Net Present Value of Retrofit to the householder is less than £8,000 for a typical 3 bedroom property. This is based on an average £1200/year energy bill, 40% heat saving from retrofit, with a 40-year lifespan of the solutions.

This led that project team to set a benchmark cost of £10,000 for the RetroFix^{TM} scenario and between £15,000 and £20,000 for the RetroPlus^{TM}.

The dataset outputs will demonstrate both the current performance against the above criteria, but also enable a thorough evaluation of the potential for further improvement based on opportunities identified during and post retrofit delivery.

The datasets from the four different retrofitted typologies have built a 'library' of data to add to previous work to enable the following to be considered in the accompanying Report 2

Which housing archetypes or characteristics are closest to having a commercially viable solution?

What product or process innovations are required to improve the Retrofit Approach cost effectiveness?

How can viable retrofit solutions be developed for characteristics of houses which are more problematic to retrofit?

This has enabled the preparation of a 'Retrofit Roadmap', included in Report 2, to plot the path to commercialisation of the Retrofit Approach by identifying key activities and improvements which would accelerate delivery to large numbers of dwellings.

3. Energy Use/Patterns

3.1. Methodology

Environmental data collected and analysed in this study, coupled with the residents' qualitative interviews and observations on site during the retrofit installation, have allowed us to understand any changes to the energy usage in the property following the installation of retrofit measures.

3.1.1. Data collection

Monitoring equipment was installed at the properties to collect environmental performance data, which included:

- Data loggers to record the temperature and relative humidity of the external environment
- Data loggers to record the temperature and relative humidity of the principal habitable rooms within the property, including living room, master bedroom, kitchen and also the hallway (where the thermostat is located)
- Data loggers to record the temperature of some radiators in the principal habitable rooms, including living room, master bedroom, kitchen and also the hallway (where the thermostat is located)
- Data loggers to record the CO_2 levels in the master bedroom
- Secondary meters to record the use of electricity and gas in the property

Data was collected at 10-minute intervals, between November 2014 and March 2016. This enabled us to compare the internal temperatures, relative humidity and heating patterns of the properties pre- and post-retrofit.

In addition the following tests / surveys were carried out, pre- and post-retrofit, for evaluation and comparison of the building thermal performance:

- Air permeability test
- Thermal imaging survey

3.1.2. Data analysis - Environmental data analysis

Comparisons were undertaken based on the data collected and graphs were produced. Graphs are displayed in this report showing monthly average, weekly average and hourly average as appropriate, using the following headings:

Internal room temperature

Comparisons were carried out on the internal temperature of the principal habitable rooms and the external temperature, pre- and post-retrofit. Heating degree hours were calculated in order to understand the correlation between the patterns of internal temperature and external temperature. See below for the definition on heating degree hours.

Relative humidity

Comparisons were carried out on the relative humidity of the principal habitable rooms and the external relative humidity, to understand the impact of retrofit works to the relative humidity levels in the property.

CO_2 levels in master bedroom

The CO_2 data is plotted against the internal temperature of the master bedroom to understand the correlation between the two pre- and post-retrofit.

Gas consumption

Gas consumption data was plotted against the heating degree hours to understand if there is any impact to the gas consumption after the retrofit works were carried out at the property. Heating degree hours have been used to make an estimation of the heating required for the home, in order to make comparison of the gas usage in the months with similar heating degree hours pre and post retrofit.

Heating Degree Days (HDD)

Heating degree days are a measure of how much (in degrees), and for how long (in days), the air temperature was below a certain level (base temperature). The use of heating degree days helps understanding the heating requirement of a building.

A base temperature of a building is the temperature below which the building needs heating. The base temperature is typically 15.5°C.

The heating degree days can be calculated using the following formula:

HDD = (outside air temperature - base temperature (15.5°C)) * 1 day

Heating Degree Hours (HDH)

Heating degree hours are a more granular expression of the HDD, taken as an hourly rather than daily basis. This has been used in the data analysis.

Radiators Degree Hours

While gas consumption data has been collected in this study, it does not provide an accurate representation of heating energy use, as the gas consumption data would have included activities such as cooking or hot water use. In order to provide a more accurate representation of when heating is used in the property, the radiator degree hours have been applied to show how frequently the radiators are turned on and how warm they get (to account for radiator temperature controls). The radiators degree hours are calculated as a cumulative hourly difference between the radiator and the room temperature. This measure acts as a tool in understanding the frequency and intensity of heating for each room in the property.

3.1.3. Data analysis - Loughborough University's in use heat balance test

In use heat balance tests were undertaken for each property pre- and post-retrofit for data comparison. The in use heat balance test is a non-intrusive tool developed by Loughborough University to measure the rate at which heat is lost per degree Celsius temperature between the inside and the outside of a home. Such measure is called heat transfer coefficient (HTC), and use W/K as a unit. A lower HTC means a lower rate of heat loss in the home. For these tests a minimum sample of 21 days of temperature and energy consumption data is required.

3.1.4. Data analysis - Air permeability test

Air permeability was measured for pre- and post-retrofit through the use of an air test. During the test the property was temporarily sealed and the air flow was manipulated to create a negative and then a positive pressure in the property, in order to identify the air leakage points and to measure the air permeability. A lower value in the air permeability means that there is a lower rate of heat loss in the property.

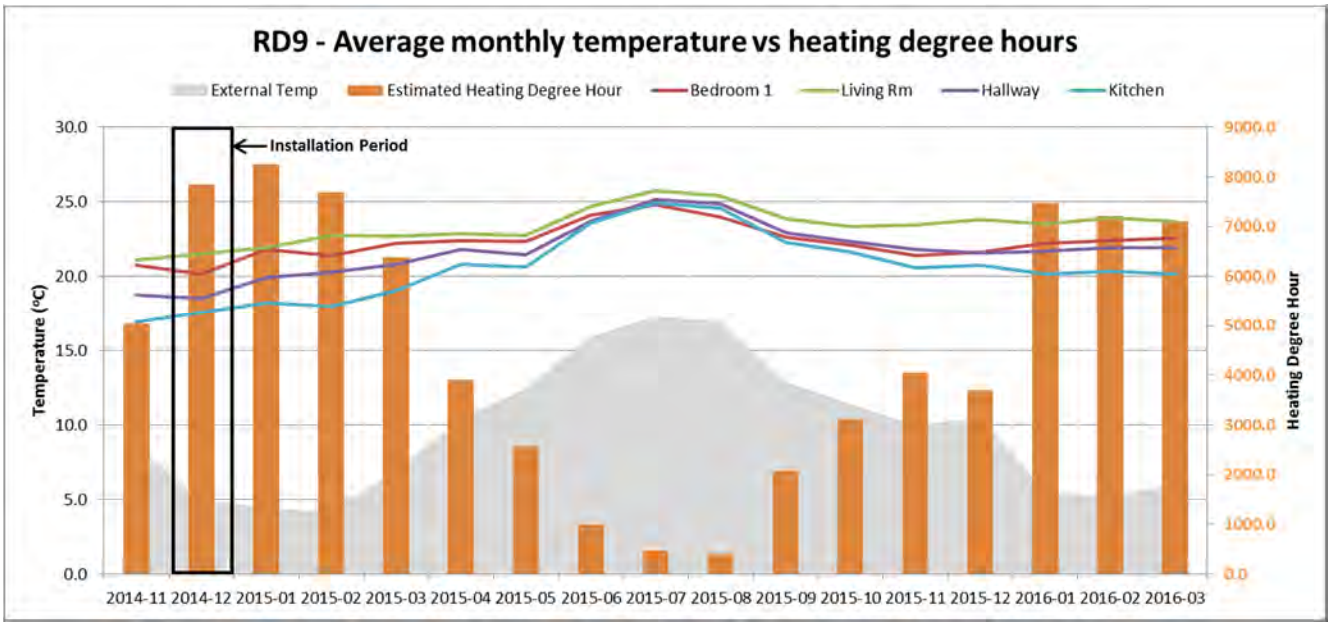
The interpretation of key findings is summarised for each property in the following sections.

3.2. Key Findings

3.2.1. RD9 - 1919-44 Semi-detached

This was the first property to be retrofitted in December 2014. The installation period is shown as a black-lined box in the following charts for ease of reference.

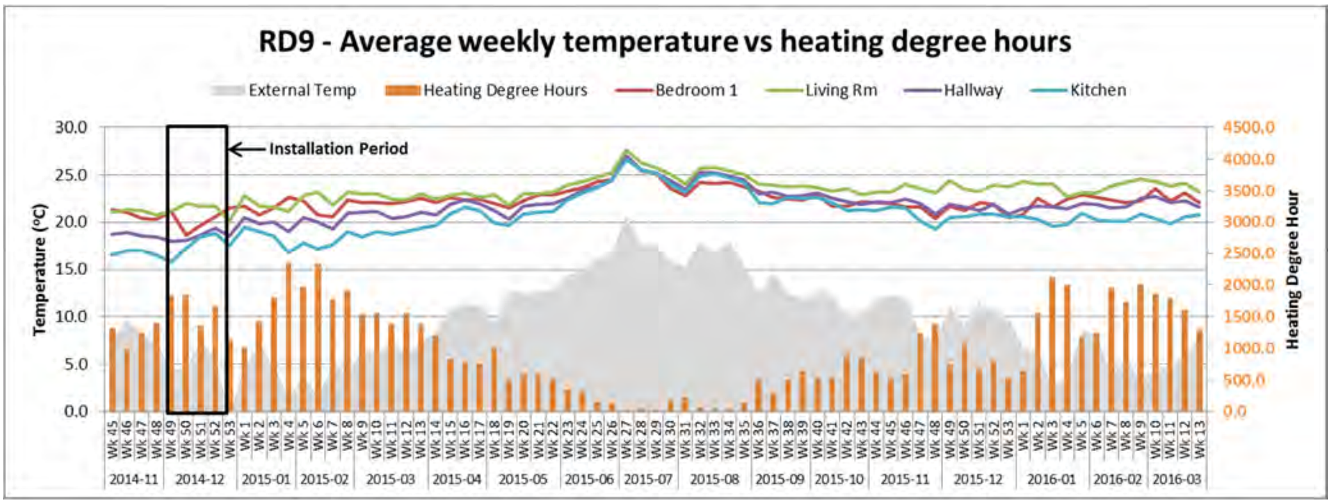
Internal temperature



The above graph shows that the average monthly internal room temperatures are higher post retrofit, and are usually above 20ºC. This is in line with the resident's perception of the rooms after the completion of the retrofit works; the resident expressed that they feel the whole house is warmer and is of a more desirable temperature.

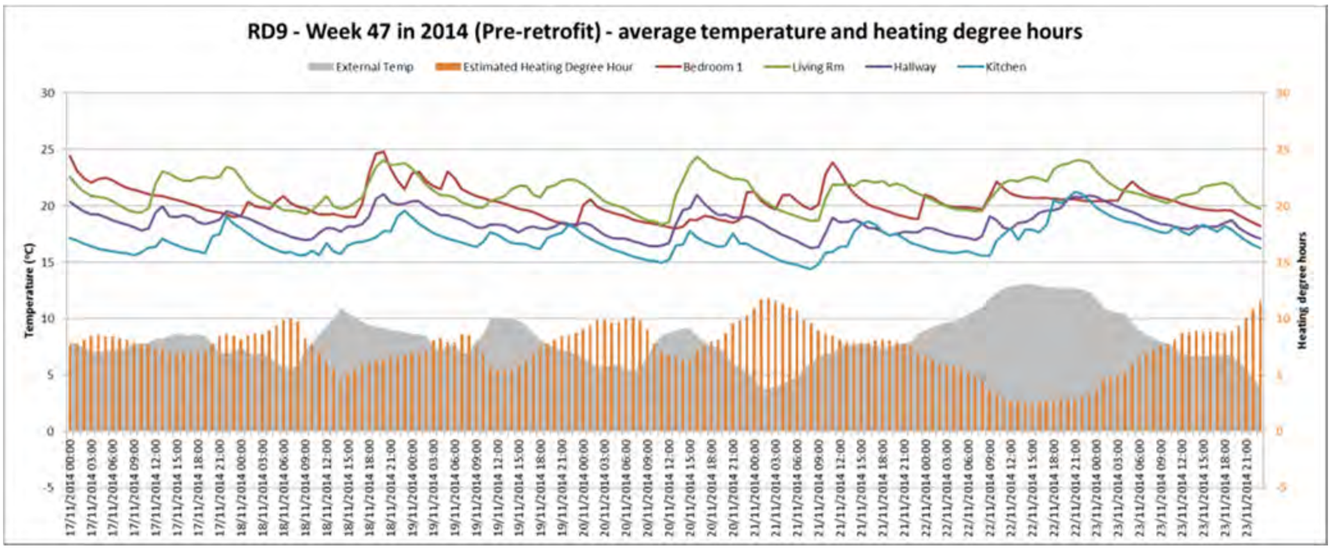
A comparison of internal room temperature in November 2014 (prior to retrofit) and November 2015 (after retrofit) is as follows:

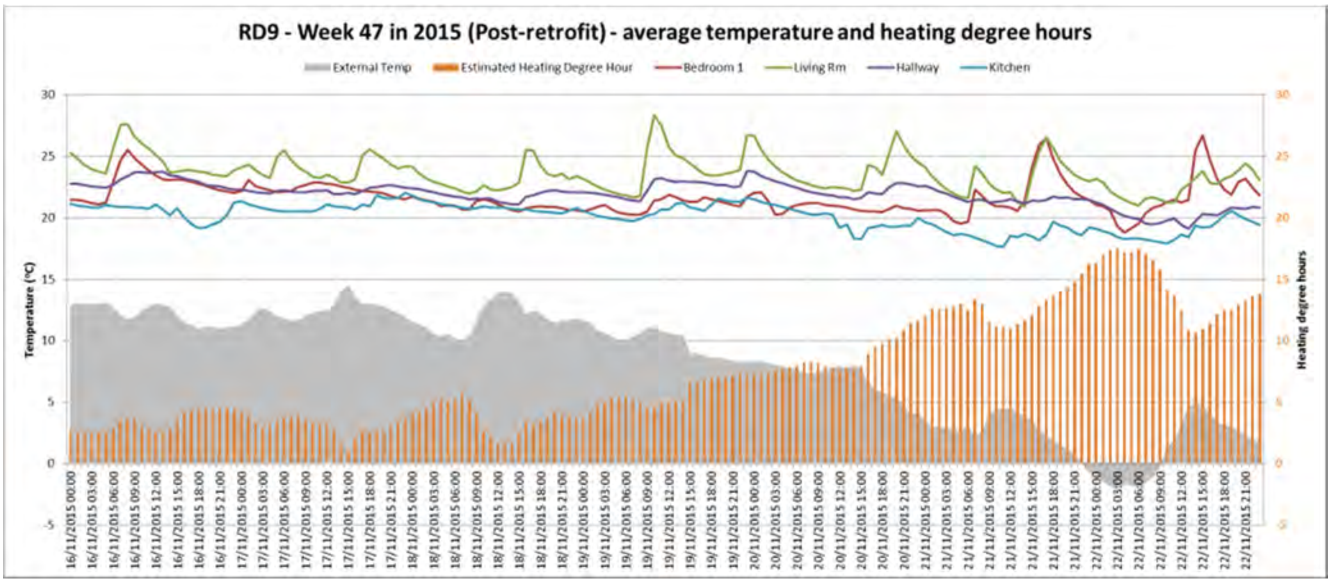
Month	**External temperature**	**Master Bedroom**	**Living Room**	**Hallway**	**Kitchen**	**Heating Degree Hours**
November 2014	8.5 ºC	20.7 ºC	21.1 ºC	18.7 ºC	16.9 ºC	5040.3
November 2015	9.9 ºC	21.4 ºC	23.5 ºC	21.8 ºC	20.6 ºC	4044.1
Difference	1.4 ºC	0.7 ºC	2.4 ºC	3.1 ºC	3.7 ºC	-996.2



From the weekly temperature data, two weekly-intervals have been selected for further analysis, one from the pre-retrofit period, another from the post-retrofit period. The selection was based on their similarities in average external temperatures and heating degree hours, for best possible comparison.

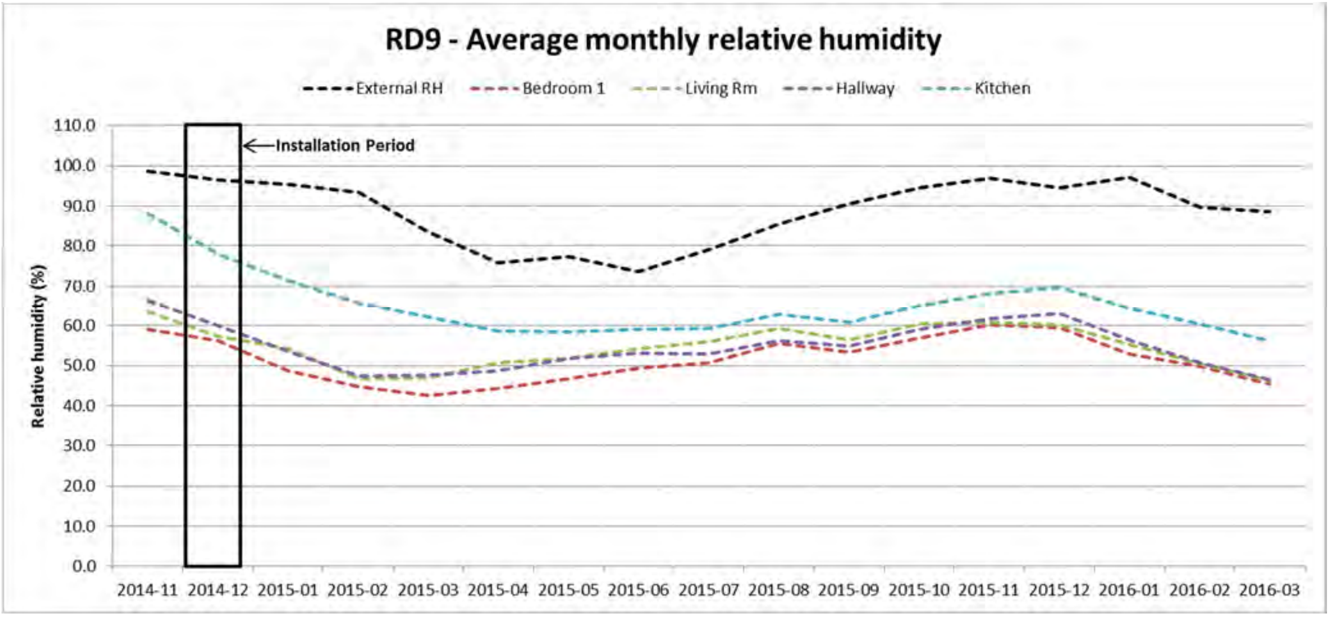
Data collected from week 47 in 2014 (pre-retrofit) and week 47 in 2015 (post-retrofit) is used for the comparison. The average external temperature for both weeks is 8.1°C and the heating degree hours are 1,239.

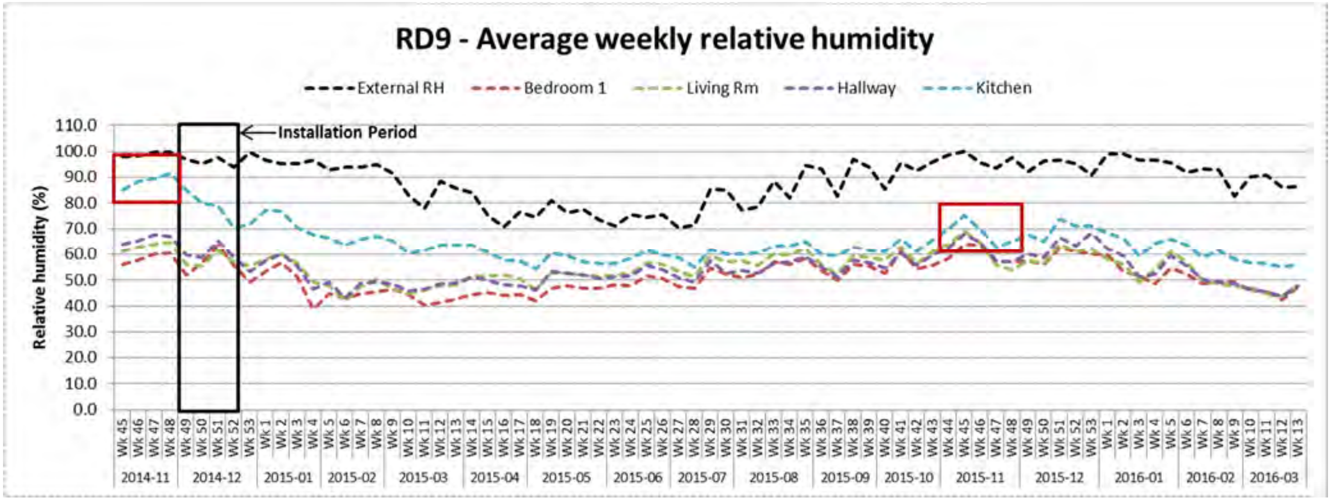




The above graphs show that rooms are generally warmer post-retrofit than pre-retrofit (when comparing the weeks that share similar external temperature conditions). Following the installation of retrofit measures, room temperatures are generally kept between 20°C and 25°C, and are not often cooler than 18°C.

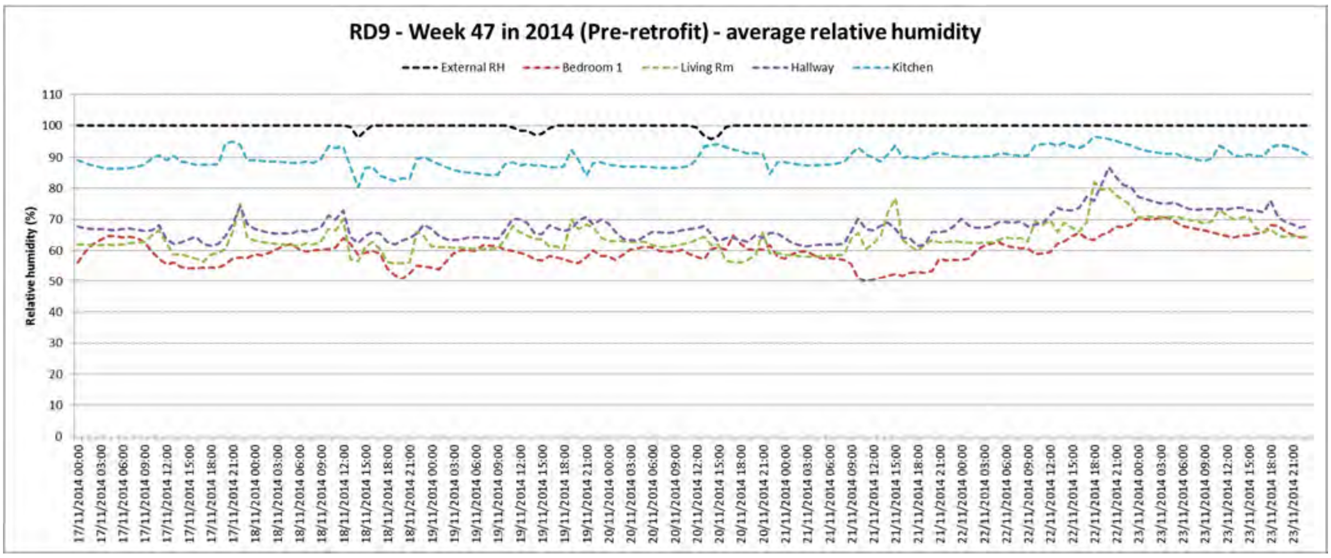
Relative humidity

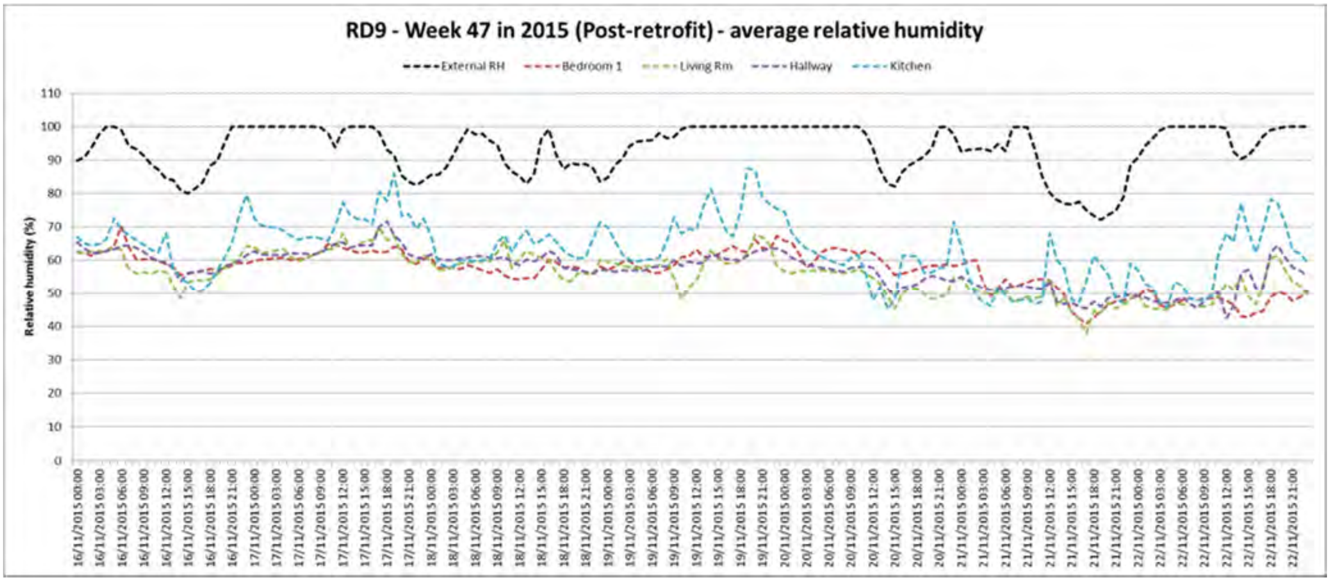




The above graphs show that the relative humidity levels in the kitchen are significantly higher than those in the other habitable rooms before the installation of the retrofit measures. The relative humidity levels in the kitchen in November 2014 (pre-retrofit) are averaging above 80% and on occasion reaching 90% which means that there could be a risk of condensation and mould growth in the kitchen. The installation of a single room heat recovery unit in the kitchen has tackled and minimised this risk and the results can be seen in the above graphs. The relative humidity levels in the kitchen have been reduced to below 80% post-retrofit, and are more in line with the relative humidity levels in the other habitable rooms.

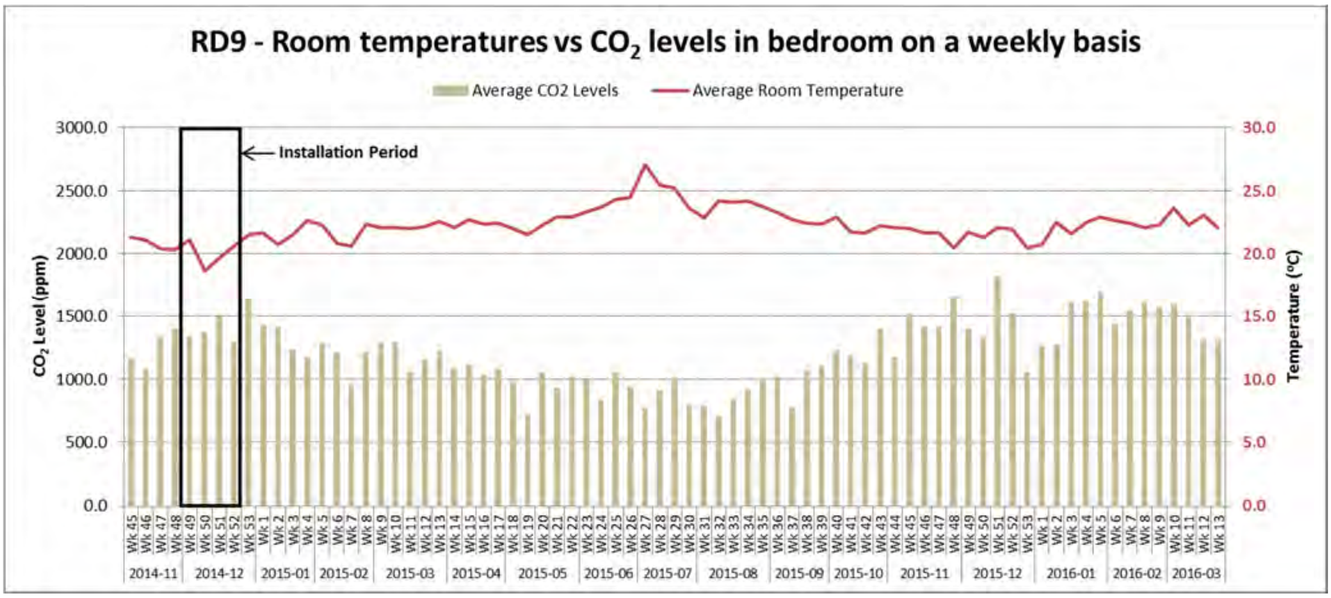
The above graphs also show that the relative humidity levels in the master bedroom, living room and hallway remain below 80% post-retrofit, which means that there is very unlikely to be a risk of condensation and mould growth in these rooms.



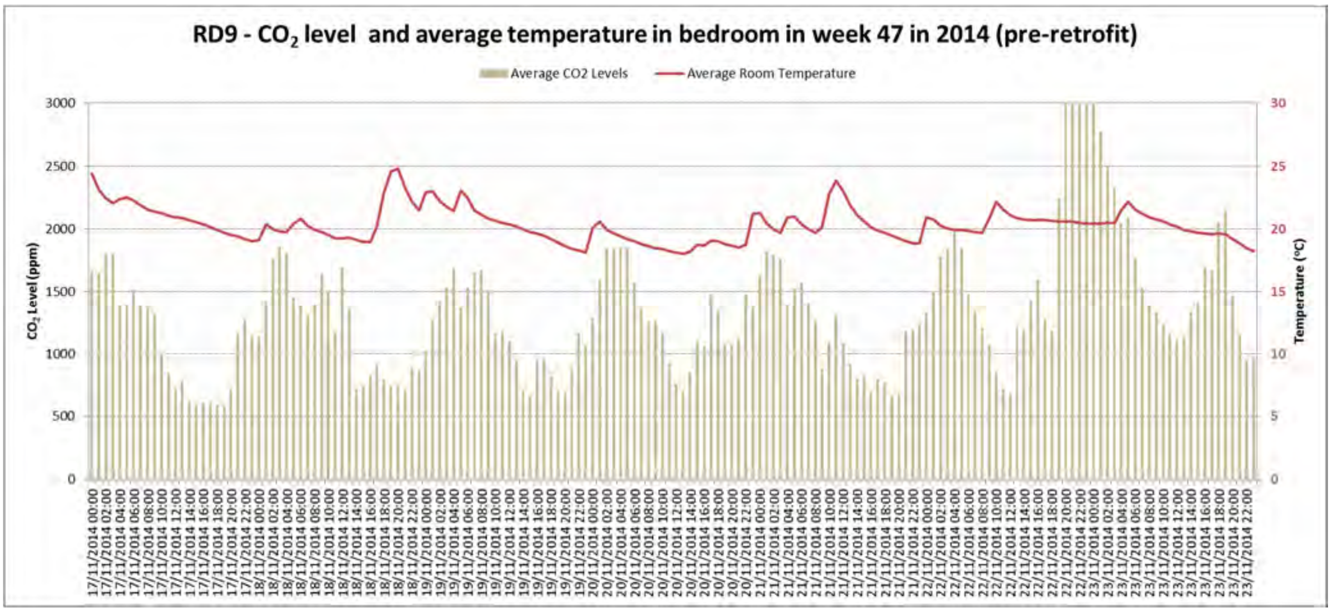


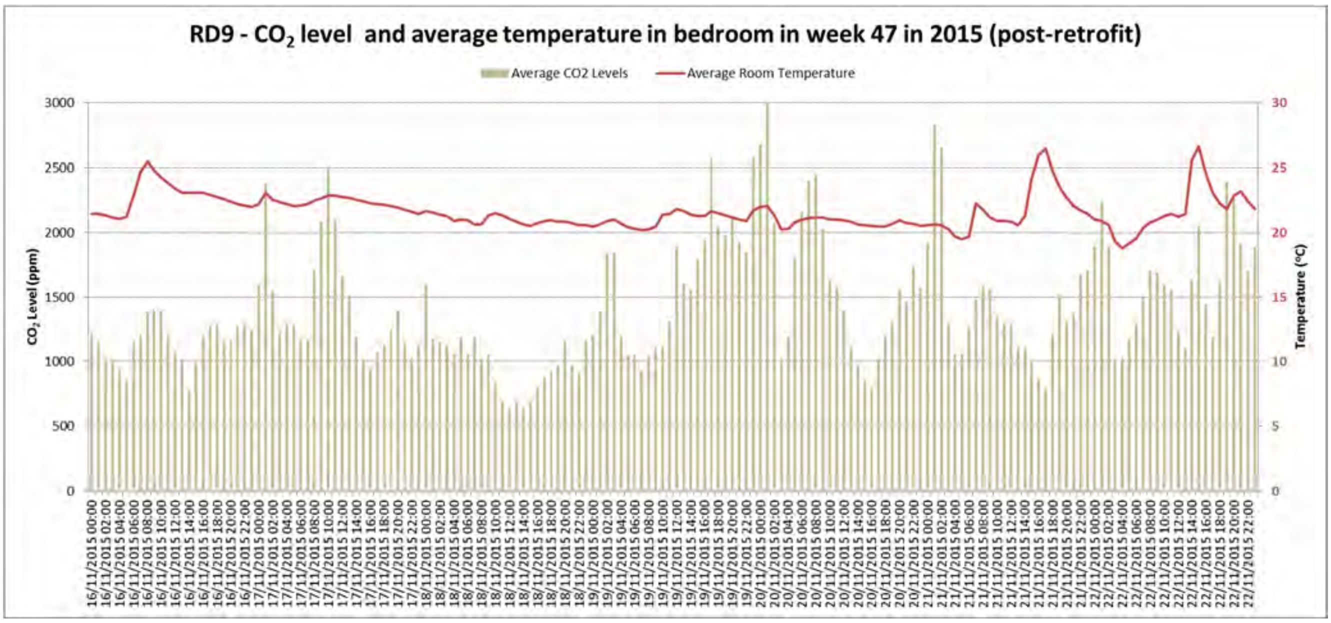
Closer inspection of the weekly data shows that the average relative humidity levels in the kitchen have been dropped from a constant 90% (prior to retrofit) to below 80% (after the retrofit), and are more in line with the other rooms. This suggests that the installation of a single room heat recovery unit in the kitchen has reduced the risk of condensation and consequently, potential mould growth in the kitchen.

CO_2 levels in master bedroom



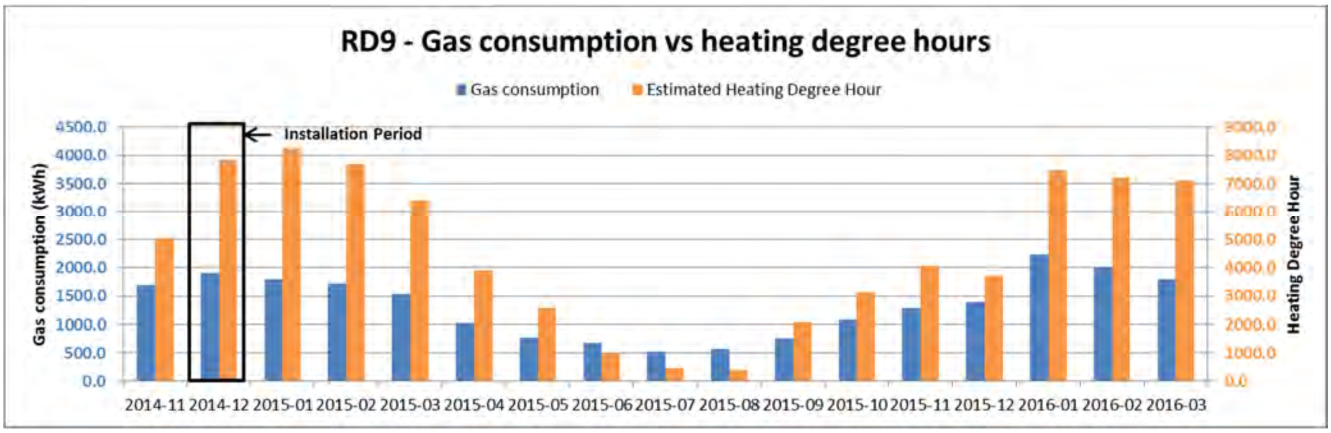
The average CO_2 levels have increased slightly in the colder months post-retrofit, but the level is below 2,000 ppm which is the recommended threshold for good indoor air quality.

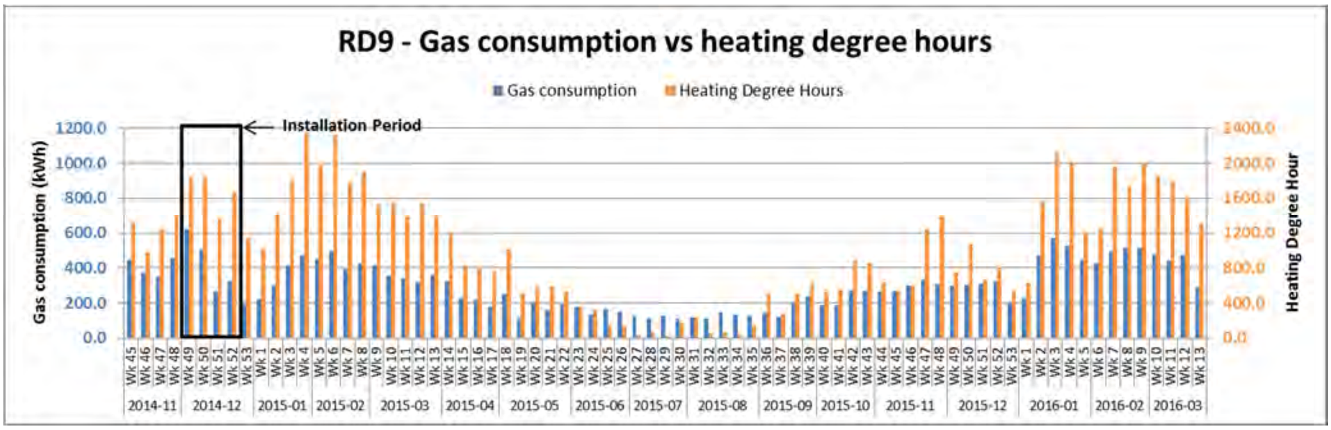




The above graphs from the selected weeks pre- and post-retrofit show that while there is an increase in CO$_2$ levels post-retrofit, it is generally below 1,000ppm which is the typical level of occupied indoor spaces with good air exchange.

Gas consumption





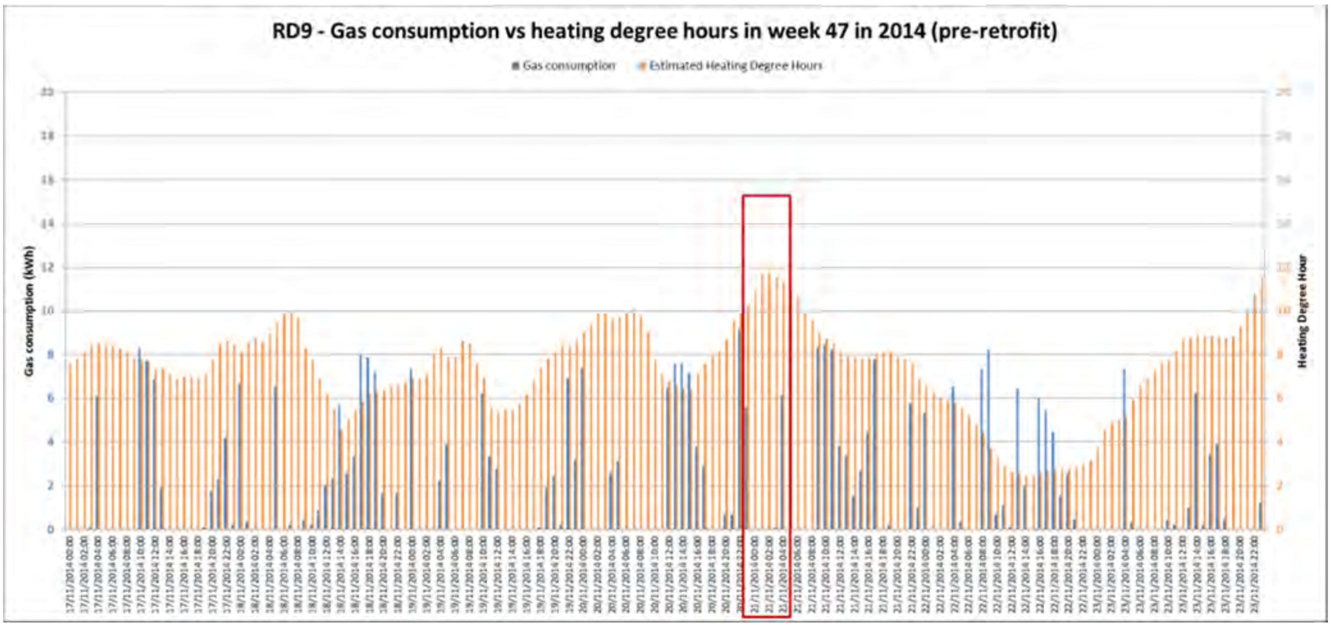
The above graphs show the total gas consumption against the heating degree hours, by month and by week respectively.

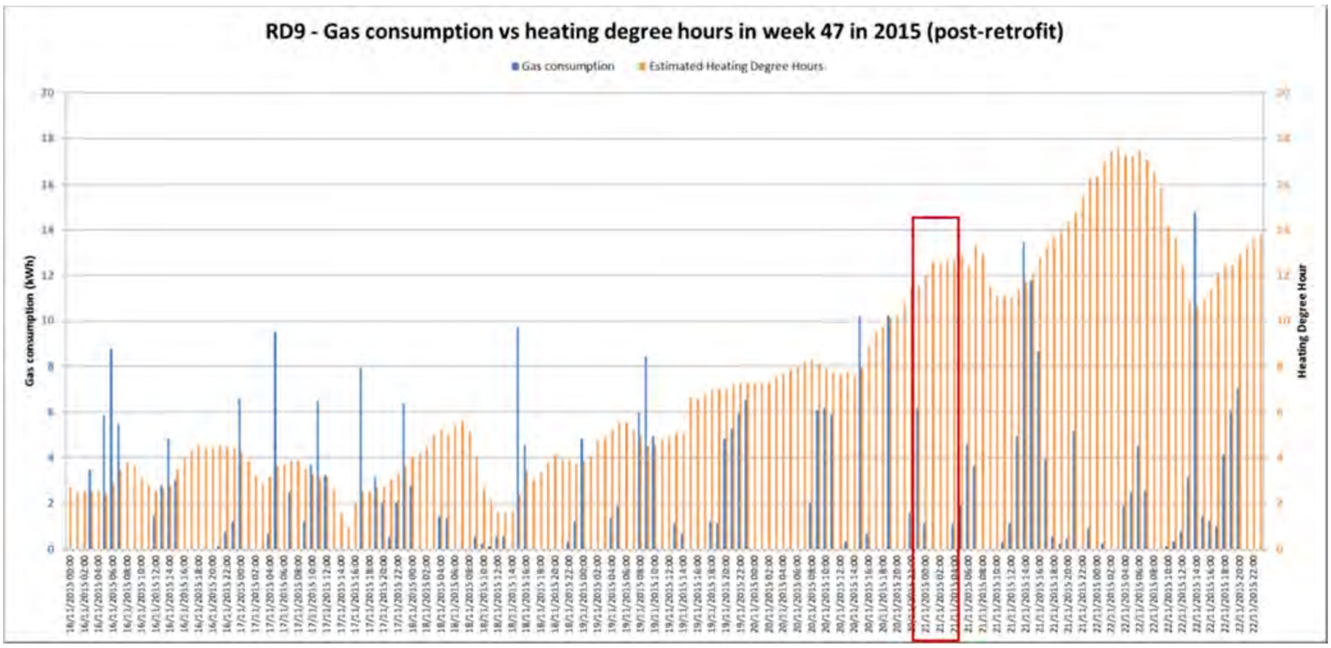
The graphs shows that in the months that followed immediately after the installation of the retrofit measures (January 2015 to Mach 2015), there is a reduction of gas consumption with respect to the estimated heating required to keep the property warm. The resident has stated in the post-retrofit interview that the heating system needs to be used less.

The total gas consumption in November 2014 is 1683.1kWh and the total gas consumption January 2015 is 1795.7kWh.

Taking into account the total heating degree hours for these periods, the average amount of gas used per heating degree hour is 0.33kWh pre-retrofit and 0.22kWh post-retrofit, which suggests a 35% reduction in gas consumption following the installation of retrofit measures.

However, it appears that the gas consumption is much higher between January 2016 and March 2016. This increase in the gas consumption can be attributed to the increase in the household occupancy.





The above graphs suggest that less heating is needed to keep the rooms warm post-retrofit. A period between 11pm to 4am has been selected for further analysis pre- and post-retrofit; both periods share a similar heating requirement (67 and 74 heating degree hours respectively, as highlighted in the red boxes). A calculation shows that the amount of gas required per heating degree hour is 0.18 kWh pre-retrofit, while it is 0.11 kWh post-retrofit, a 35% reduction.

In use heat balance test

		1st test		2nd test	
Property Reference	**Pre-Retrofit Total HTC (W/K)**	**Post-Retrofit Total HTC (W/K)**	**Fabric thermal performance of the house due to retrofit (%)**	**Post-Retrofit Total HTC (W/K)**	**Fabric thermal performance of the house due to retrofit (%)**
RD9 (1919-1944 semi-detached)	244	168	+31%	178	+27%

Two post-retrofit tests were carried out, the first one prior to the completion of the snagging works and the second one after all snagging was completed. On both occasions there is an improvement to the thermal performance of over 25%.

Air permeability test

Property Reference	**Target Air Permeability ($m^3/h.m^2$)**	**Air Permeability Pre-Retrofit ($m^3/h.m^2$)**	**Air Permeability Post-Retrofit ($m^3/h.m^2$)**	**Changes Due to Retrofit (%)**
RD9 (1919-1944 semi-detached)	8.0	8.47	6.69	-21.0%

The air permeability has reduced by 21%, which is very good considering that the existing air permeability was already low.

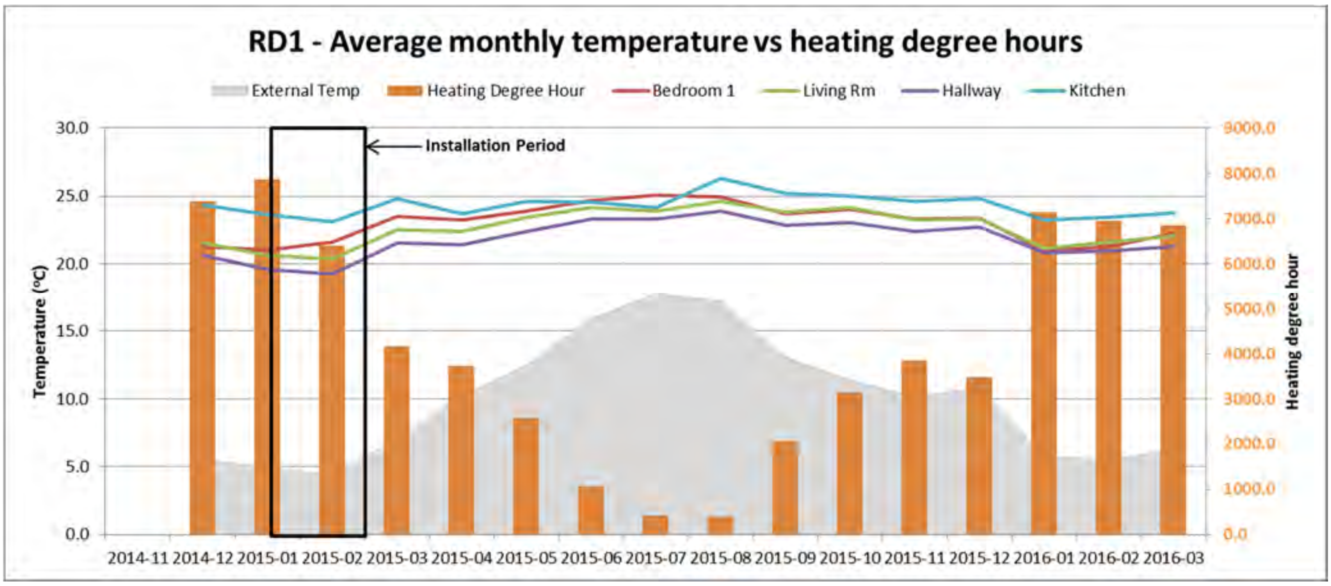
Summary of findings - RD9

- Rooms are generally warmer post-retrofit and can be maintained at a temperature that the resident desired without using more heating.
- The installation of single room heat recovery system in the kitchen has reduced the risk of condensation and mould growth.
- There is a 35% reduction in gas consumption post-retrofit on the weeks analysed, which is comparable to the in use heat balance test results.

3.2.2. RD1- Pre-1919 Mid-terrace

This was the second property to be retrofitted and the work was undertaken between 26 January 2015 and 27 February 2015. The installation period is shown as a black-lined box in the following charts for ease of reference.

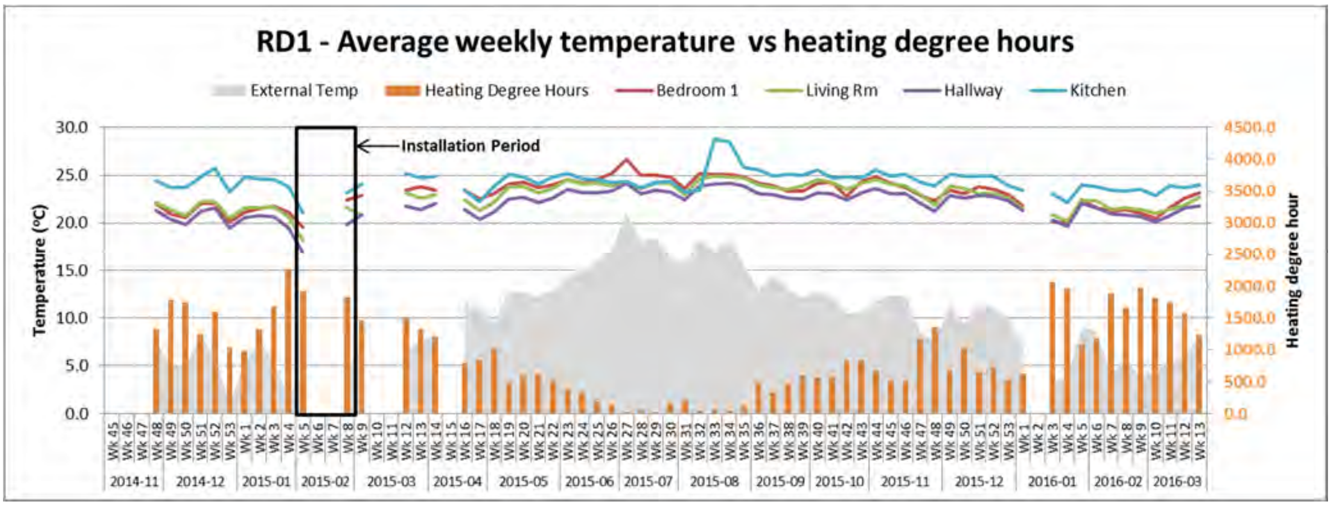
Internal temperature



The above graph shows that the average monthly internal room temperatures are consistent pre- and post-retrofit, and are usually above 20ºC, although the resident has expressed that the rooms felt warmer after the works have been carried out.

A comparison of internal room temperature in November 2014 (prior to retrofit) and November 2015 (after retrofit) is as follows:

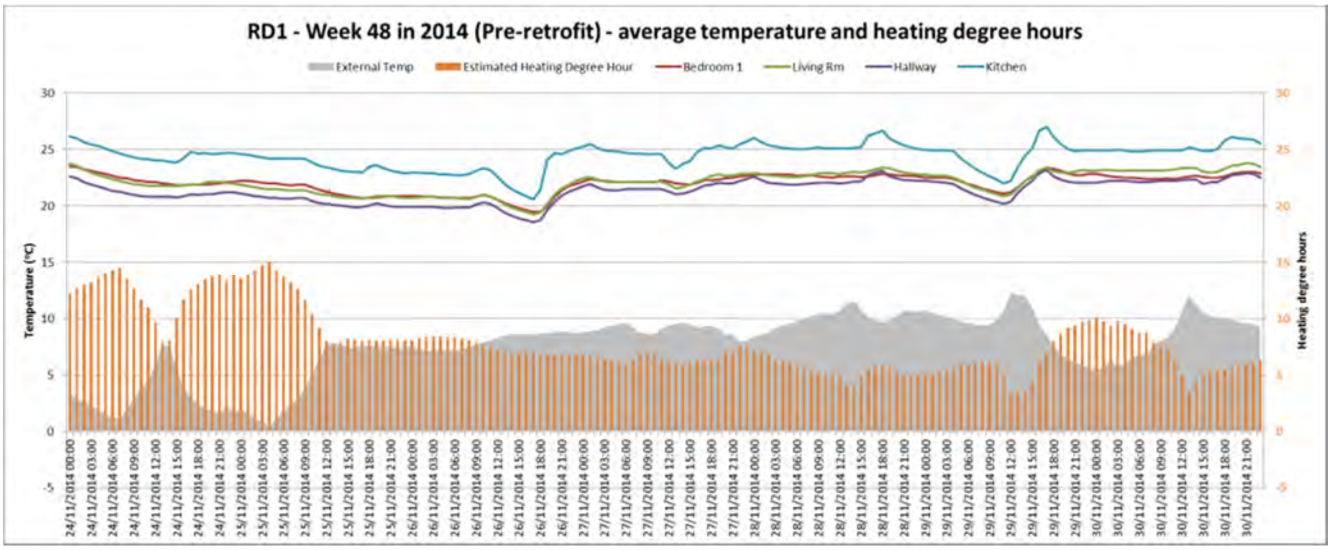
Month	**External temperature**	**Master Bedroom**	**Living Room**	**Hallway**	**Kitchen**	**Heating Degree Hours**
November 2014	5.6 ºC	21.3 ºC	21.5 ºC	20.6 ºC	24.4 ºC	7389.0
November 2015	5.5 ºC	21.3 ºC	21.6 ºC	20.9 ºC	23.5 ºC	6962.8
Difference	-0.1 ºC	0 ºC	0.1 ºC	0.3 ºC	-0.9 ºC	-426.2

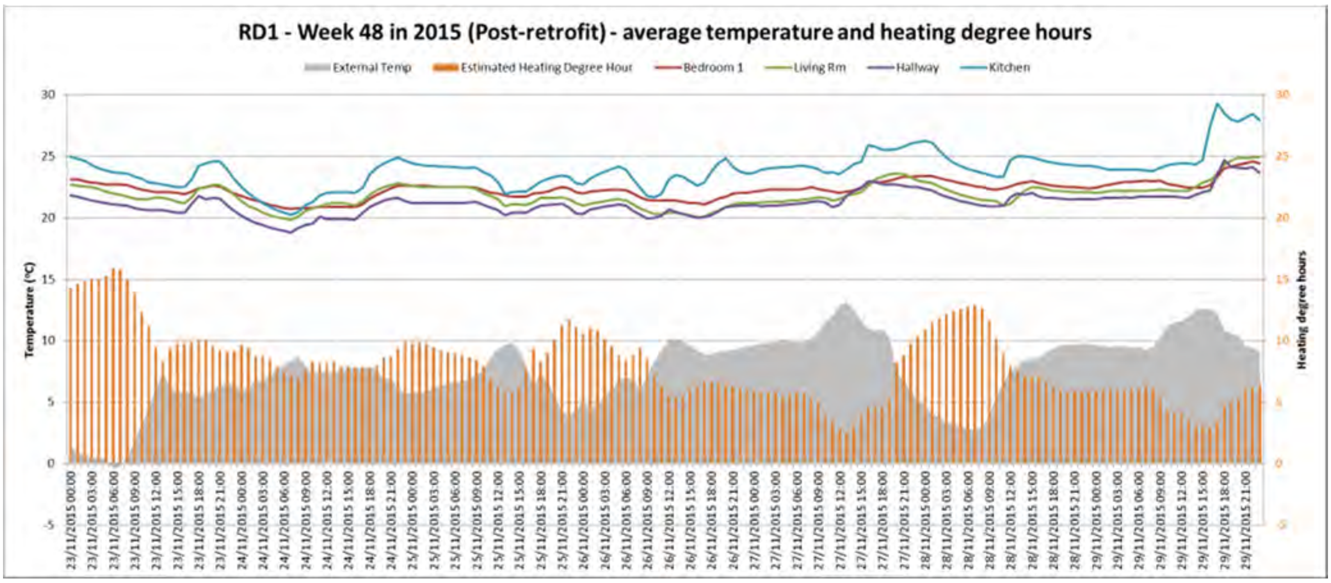


*note that due to some issues with the monitoring system (e.g. resident unplugging the system), not a full week's worth of data is collect in week 6, 7 10, 11 and 15 in 2015 and week 2 in 2016 and therefore these weeks are omitted from the analysis.

From the weekly temperature data, two weekly-intervals have been selected for further analysis, one from the pre-retrofit period, another from the post-retrofit period. The selection was based on their similarities in average external temperatures and heating degree hours, for best possible comparison.

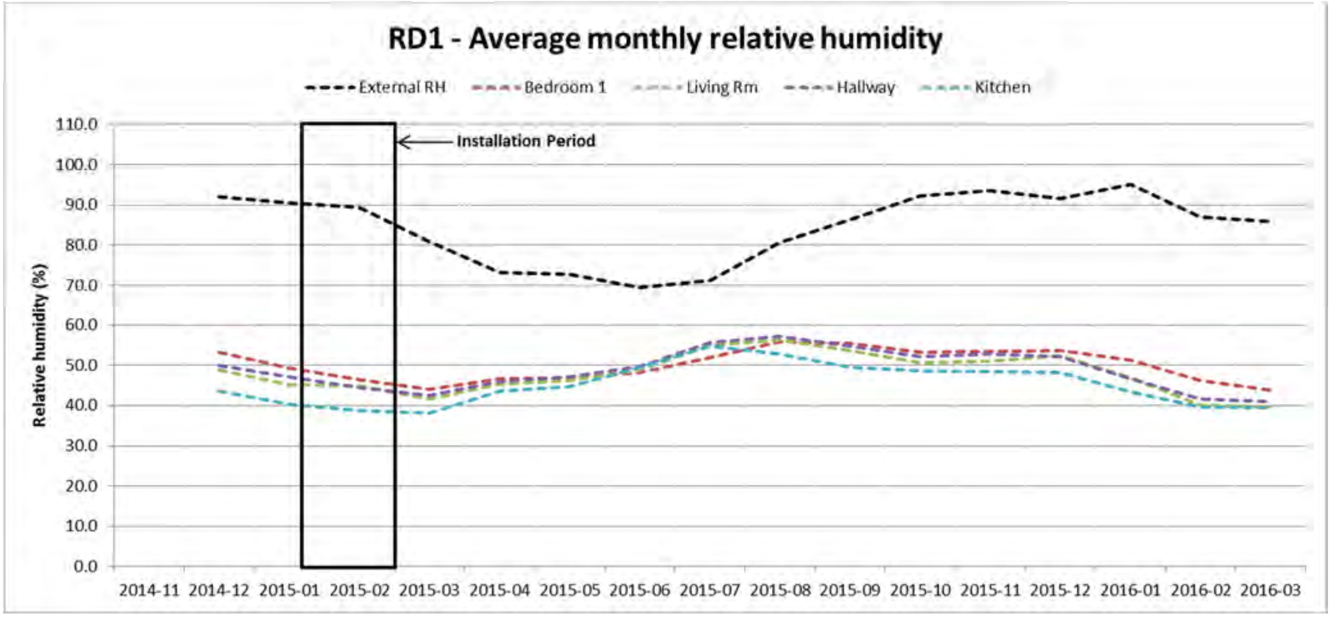
Data collected from week 48 in 2014 (pre-retrofit) and week 48 in 2015 (post-retrofit) is used for the comparison. The average external temperature for both weeks is 7.5ºC and the estimated heating degree hour is 1,330 (pre-retrofit) and 1,350 (post-retrofit) respectively.

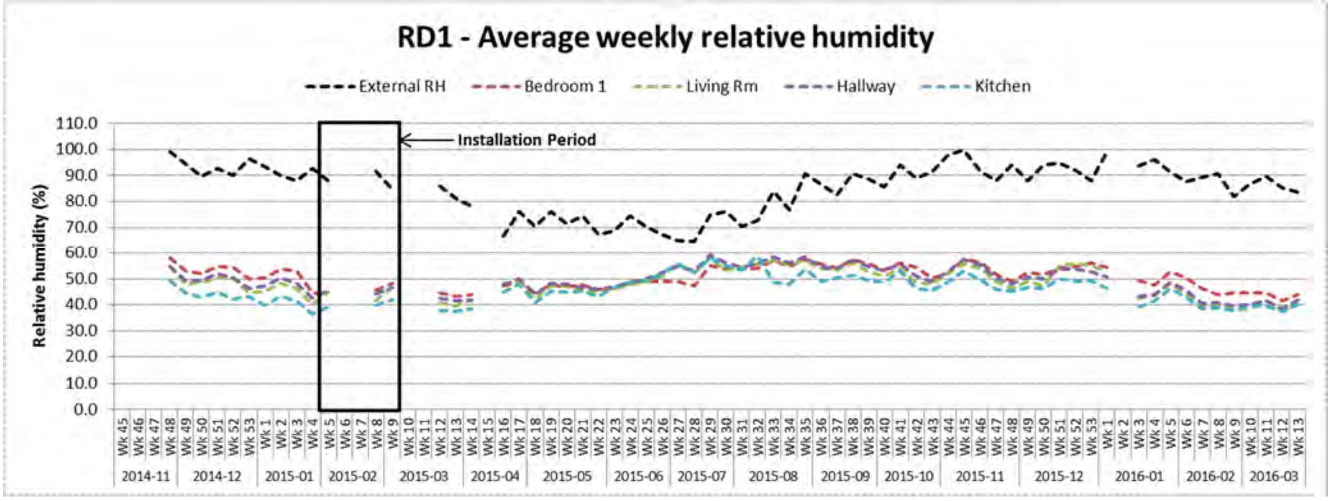


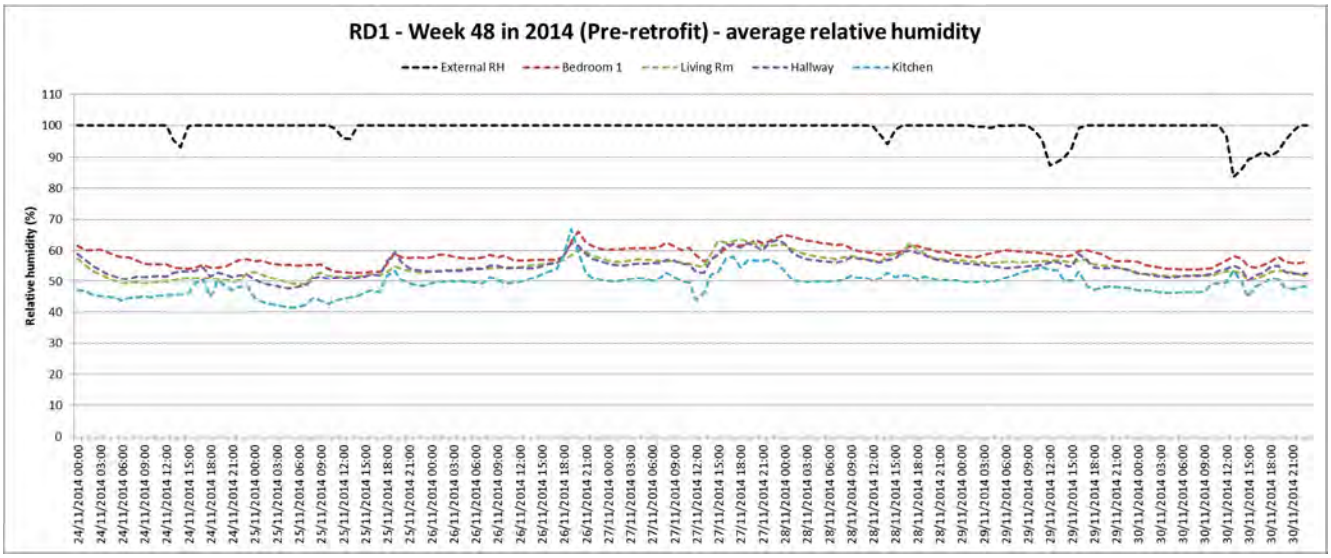


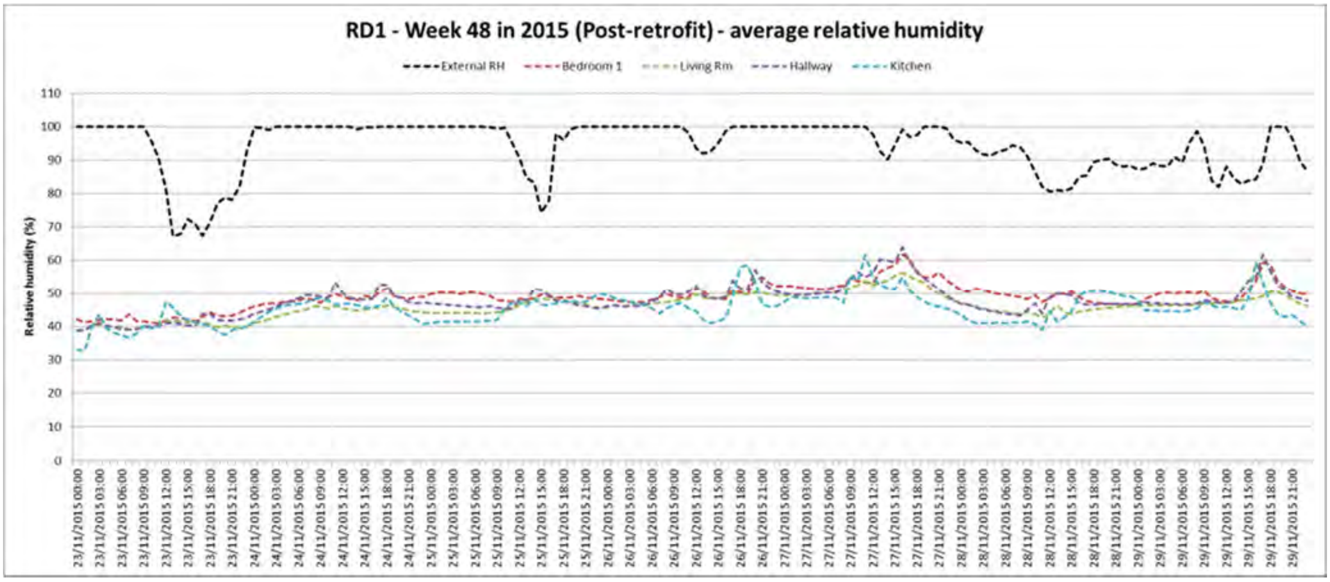
The above graphs show that there is a slight increase in the internal temperature post-retrofit (when comparing the weeks that share similar external temperature conditions), and that the rooms are generally kept between 20°C and 25°C.

Relative humidity



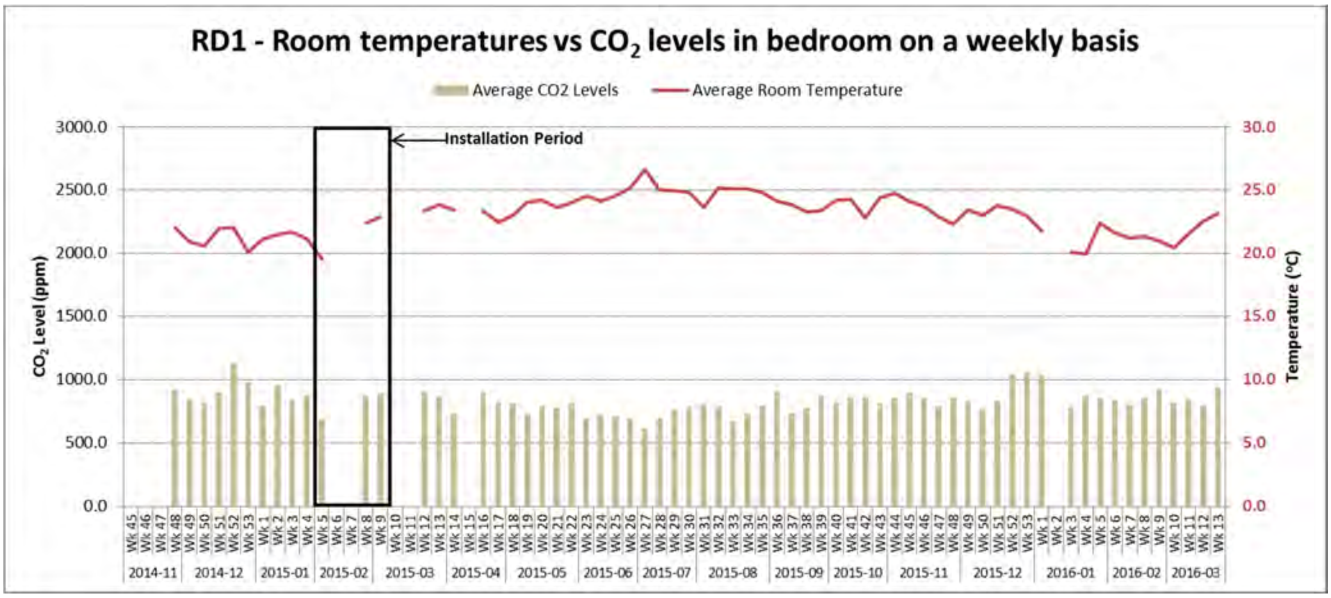




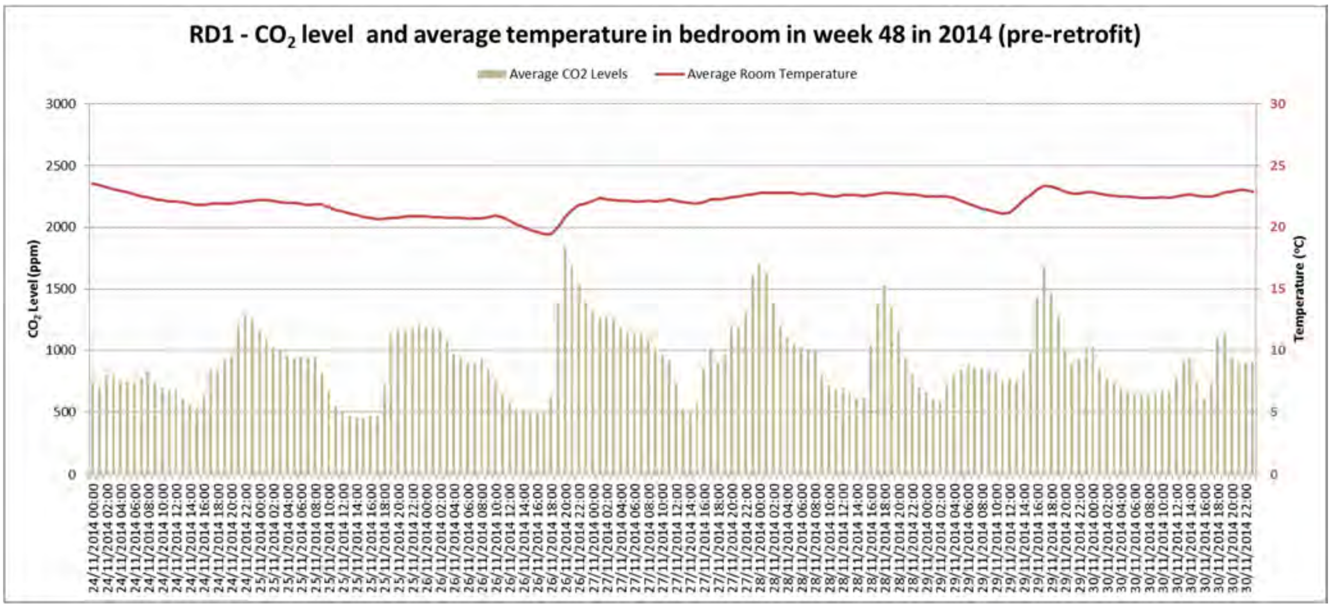


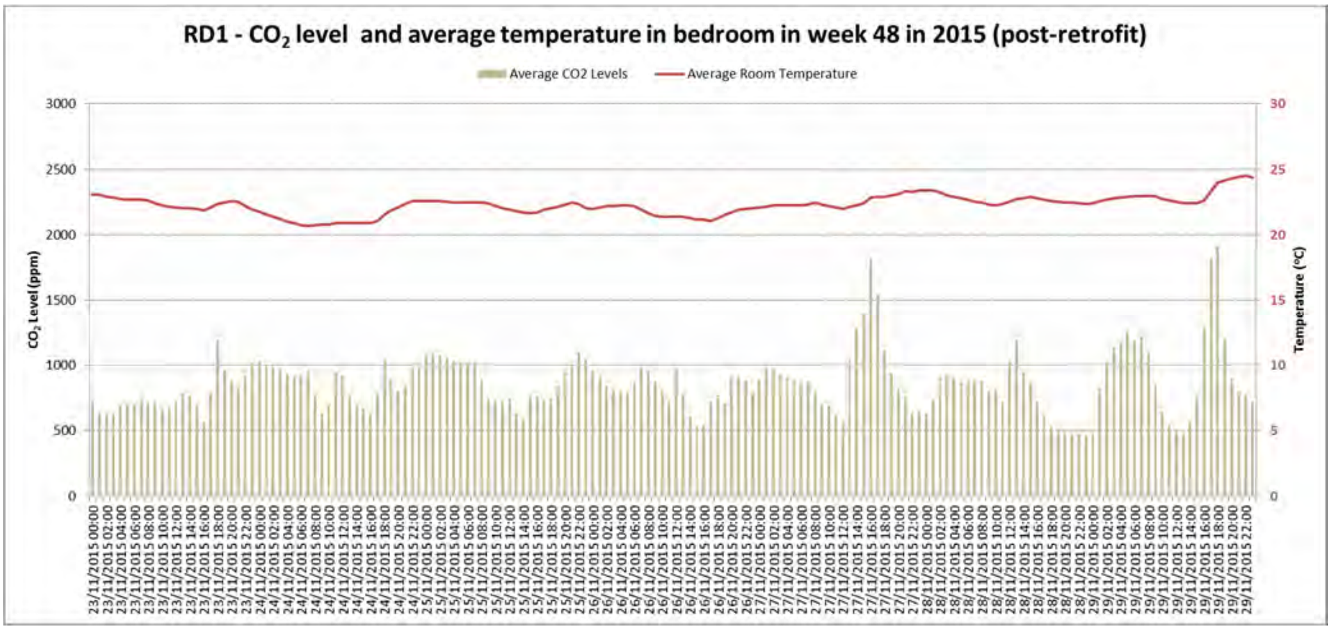
The above graphs show that the relative humidity levels remain below 80% post-retrofit, which means that the rooms are very unlikely to be susceptible to surface condensation and mould growth. The relative humidity levels are typically a little lower post-retrofit.

CO_2 levels in master bedroom



The above graph shows that the CO_2 levels in the master bedroom remain the same post-retrofit. It is generally below 1,000 ppm which is the typical level of occupied indoor spaces with good air exchange.

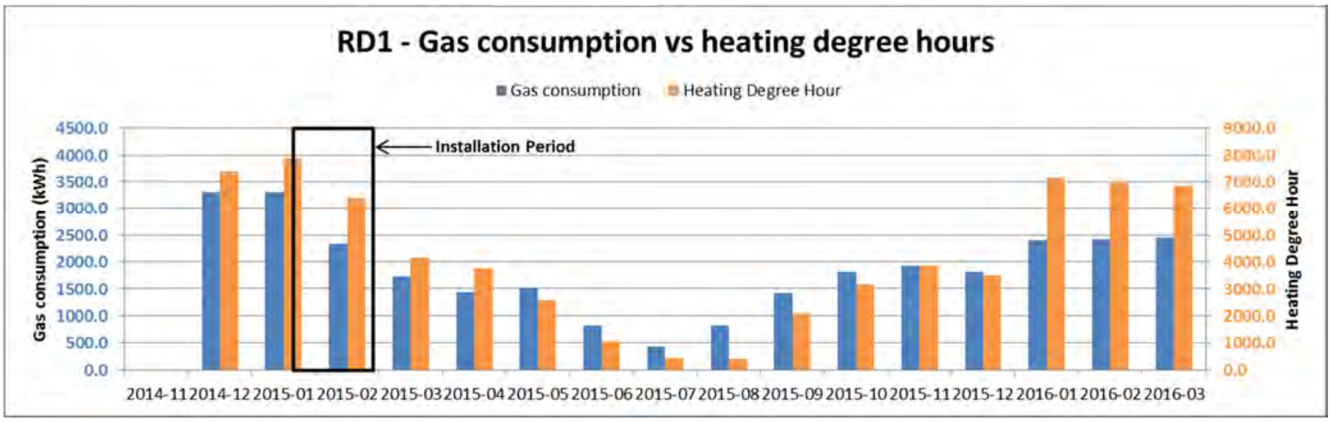

RD1 - CO_2 level and average temperature in bedroom in week 48 in 2014 (pre-retrofit)

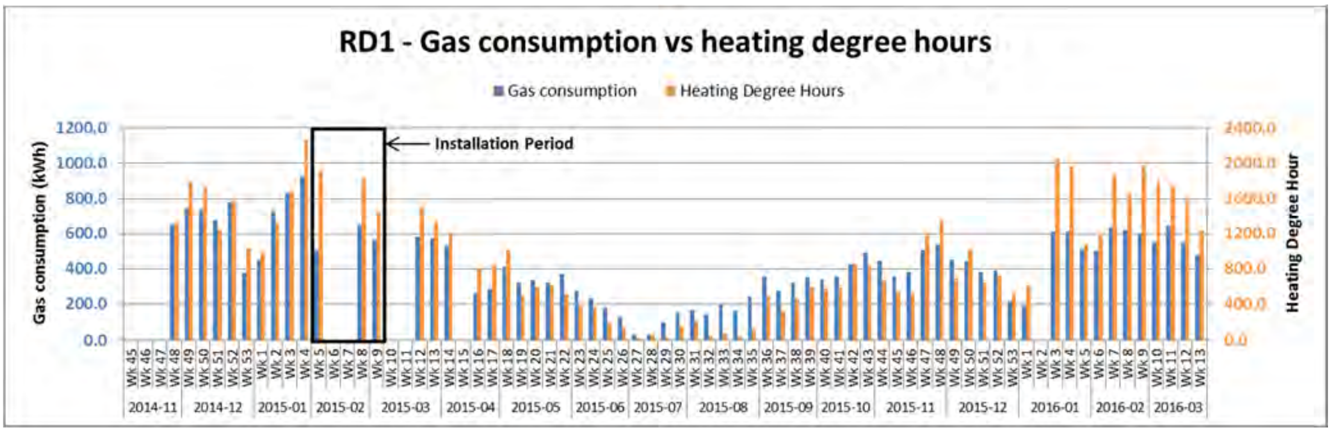

RD1 - CO_2 level and average temperature in bedroom in week 48 in 2015 (post-retrofit)

These weekly graphs show that the CO_2 levels are usually between 500ppm and 1,000ppm, which is the typical level of occupied indoor spaces with good air exchange. The graph for the pre-retrofit week shows that the CO_2 level typically goes above 1,000ppm between the hours of 8pm to 2am on Monday to Thursday, and during early evenings on Friday and Saturday of that week. However, the graph for the post-retrofit week shows that the CO_2 level only peaks on two occasions, on Friday afternoon and Sunday afternoon. This shows a potential improvement in the air quality in the master bedroom post-retrofit.

As part of the retrofit works, in addition to the installation of single heat recovery units in the kitchen and the bathroom, small gaps have been created between all internal doors and the floor in order to create a natural circulation of air even when the doors are shut. The graphs above suggest that the improvement in the air quality could be a result of such measure being installed because of the improvement in the internal air circulation between the rooms. However, it should also be noted that there are a number of other factors contributing to the CO_2 levels in the master bedroom, resident behaviour being one of them and this should be taken into account when looking at the monitoring results.

Gas consumption



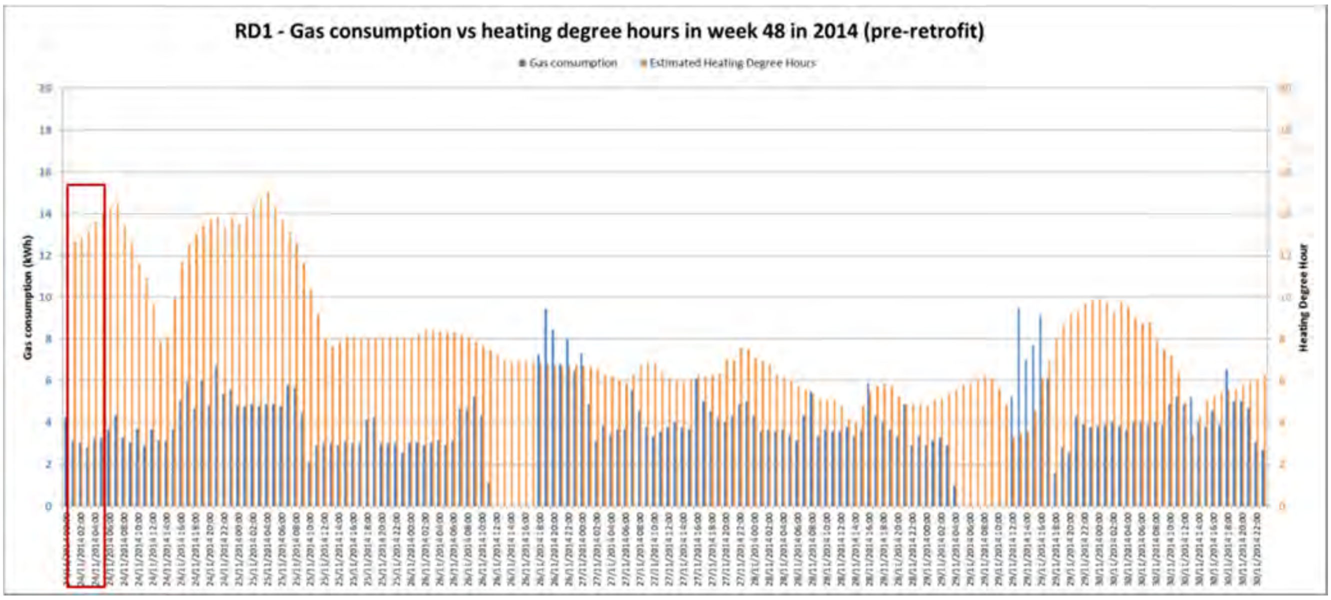


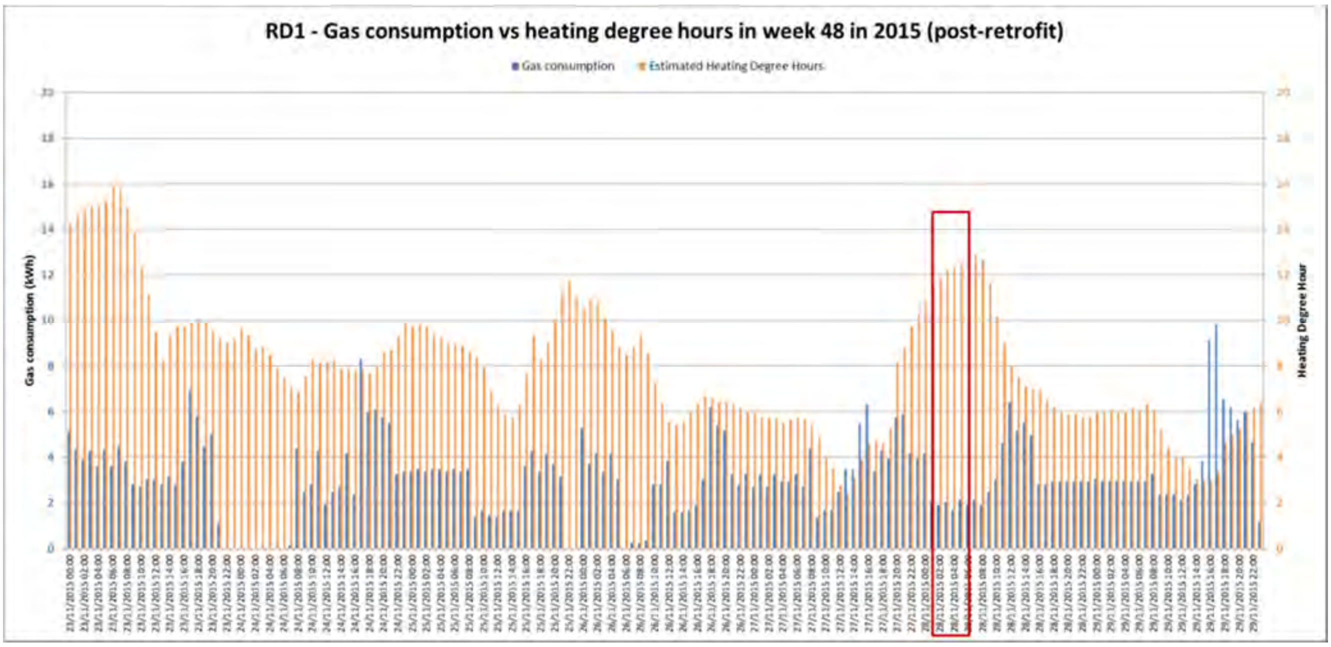
The above graphs show the total gas consumption against the heating degree hours, by month and by week respectively.

The graphs show that when like for like conditions are compared (December 2014 vs January 2016), there is a reduction of gas consumption with respect to the estimated heating required to keep the property warm. This is in line with the responses at the resident's interview regarding the use of heating at the property, whereby the resident expressed that "the house is warmer, not using heating as much, it is kept quite low".

The total gas consumption in December 2014 is 3313.1kWh and the total gas consumption in January 2016 is 2409.9kWh.

Taking into account the total heating degree hours for these periods, the average amount of gas used per heating degree hour is 0.45kWh pre-retrofit and 0.35kWh post-retrofit, which suggests a 22% reduction following the installation of retrofit measures.


RD1 - Gas consumption vs heating degree hours in week 48 in 2014 (pre-retrofit)


RD1 - Gas consumption vs heating degree hours in week 48 in 2015 (post-retrofit)

The above graphs also suggest that less heating is needed to keep the rooms warm post-retrofit. A period between 1am to 5am has been selected for further analysis pre- and post-retrofit; both periods share a similar heating requirement (approximately 65 heating degree hours, as highlighted in red boxes). Calculation shows that the amount of gas required per heating degree hour is 0.23 kWh pre-retrofit, while it is 0.16 kWh post-retrofit, a 30% reduction.

In use heat balance test

		1st test		2nd test	
Property Reference	**Pre-Retrofit Total HTC (W/K)**	**Post-Retrofit Total HTC (W/K)**	**Fabric thermal performance of the house due to retrofit (%)**	**Post-Retrofit Total HTC (W/K)**	**Fabric thermal performance of the house due to retrofit (%)**
RD1 (Pre-1919 mid-terrace)	258	240	+7%	193	+25%

Two tests were carried out at RD1 because the first result might have been affected by the unusually warm weather and high solar radiation during the testing period. A second test was undertaken in the following winter season, and it shows an improvement of 25% in the thermal performance of the property.

Air permeability test

Property Reference	**Target Air Permeability ($m^3/h.m^2$)**	**Air Permeability Pre-Retrofit ($m^3/h.m^2$)**	**Air Permeability Post-Retrofit ($m^3/h.m^2$)**	**Changes Due to Retrofit (%)**
RD1 (Pre-1919 mid-terrace)	6.0	13.33	9.52	-28.6%

There is an improvement to the air permeability of the property. There could be further improvement if sealing works were carried out to the windows that were replaced prior to this project, however, the works could not be done on this project due to access and responsibility issues.

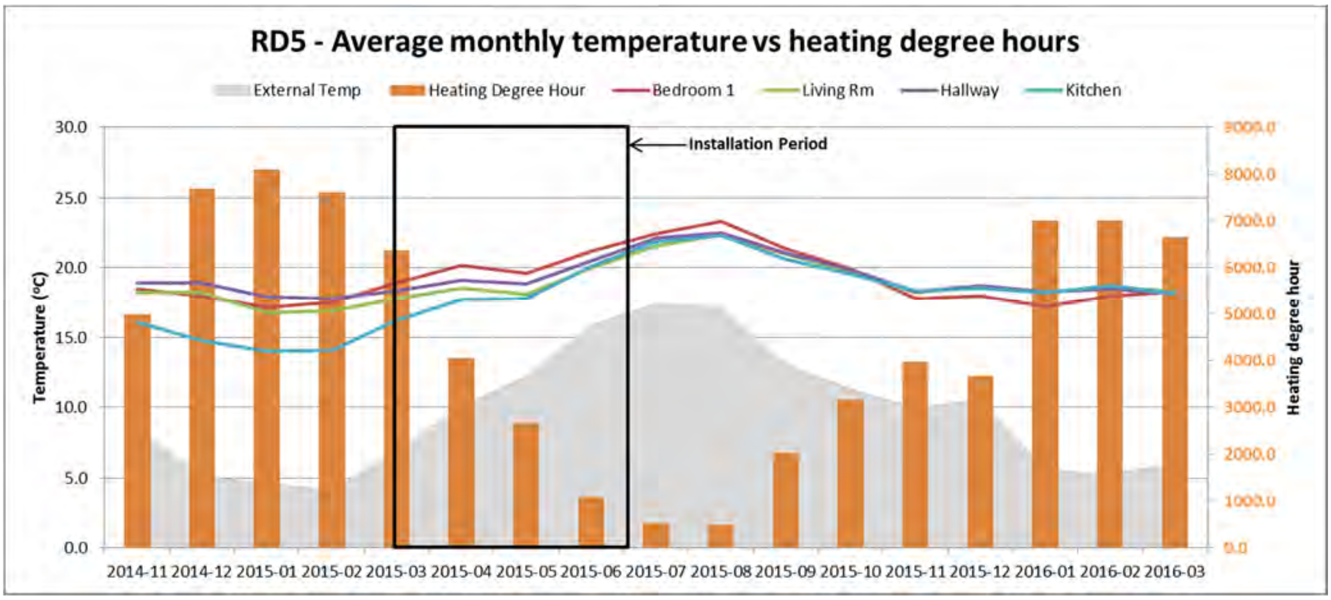
Summary of Findings - RD1

- After the installation of the retrofit measures, rooms can be maintained at a temperature that the resident desired without using more heat energy.
- There is a 22%-30% reduction in gas consumption post-retrofit for the weeks analysed, which is comparable with the results from the in use heat balance test.

3.2.3. RD5 - 1944-64 Semi-detached

This was the third property to be retrofitted and installation took place between 16 March 2015 and 25 June 2015. The installation period is shown as a black-lined box in the following charts for ease of reference.

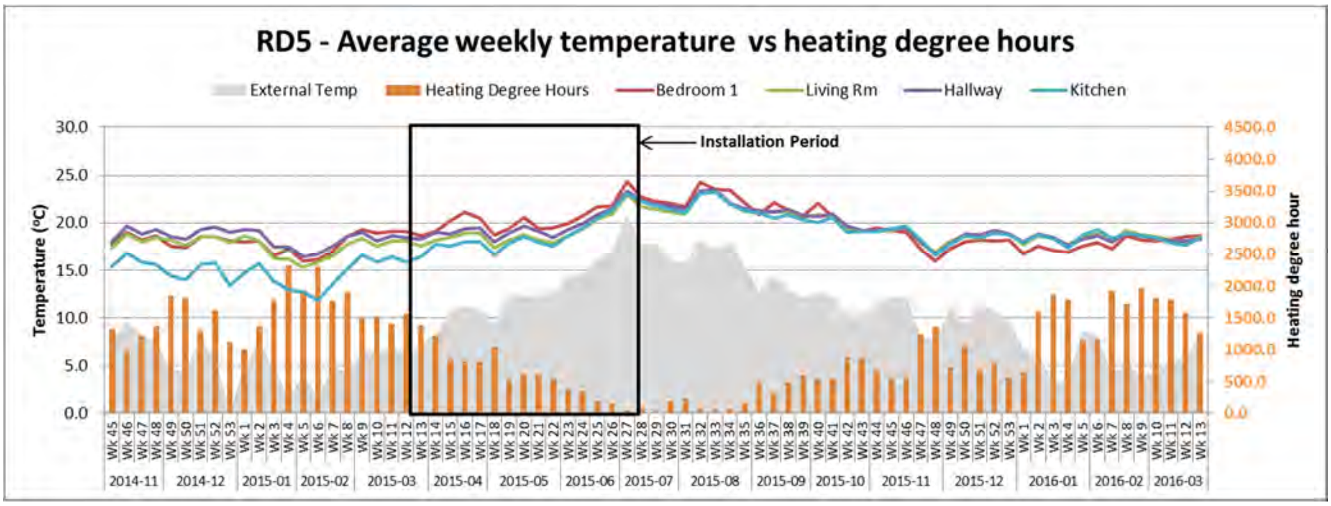
Internal temperature



The above graph shows that the average monthly internal room temperatures remain consistent pre- and post-retrofit, with the exception of the kitchen whereby there is an increase of average internal room temperature post-retrofit, from 15ºC to 18ºC. The average internal temperature in the kitchen is more consistent with the other habitable rooms post-retrofit, which suggests that the retrofit works have improved the resident's thermal comfort in the kitchen.

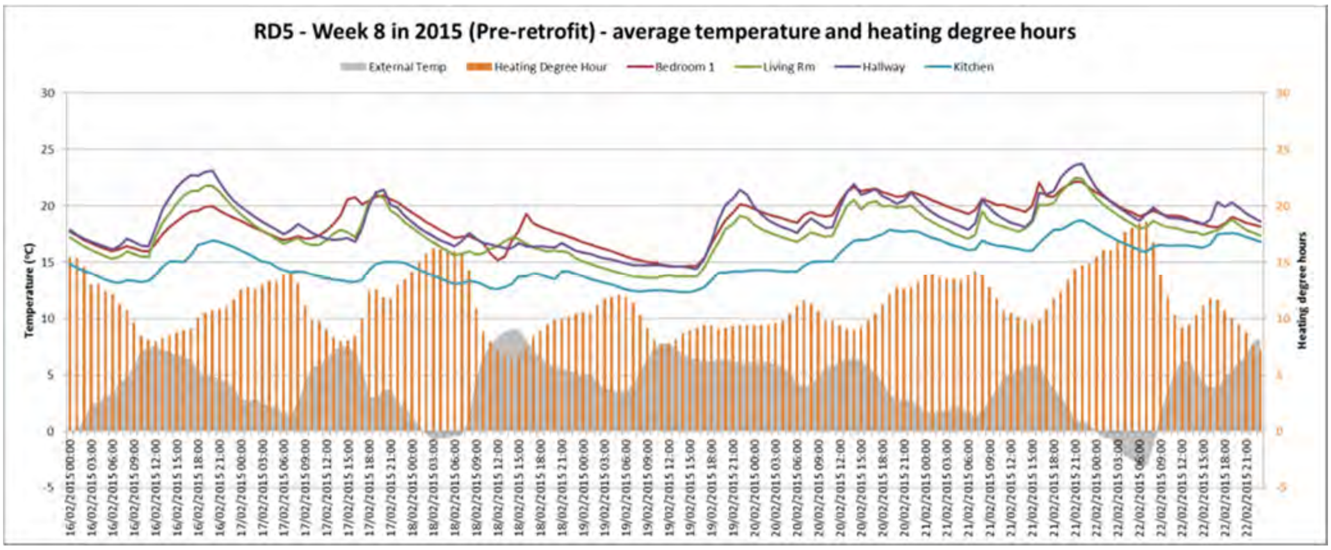
A comparison of internal room temperature in December 2014 (prior to retrofit) and February 2016 (after retrofit) is as follows:

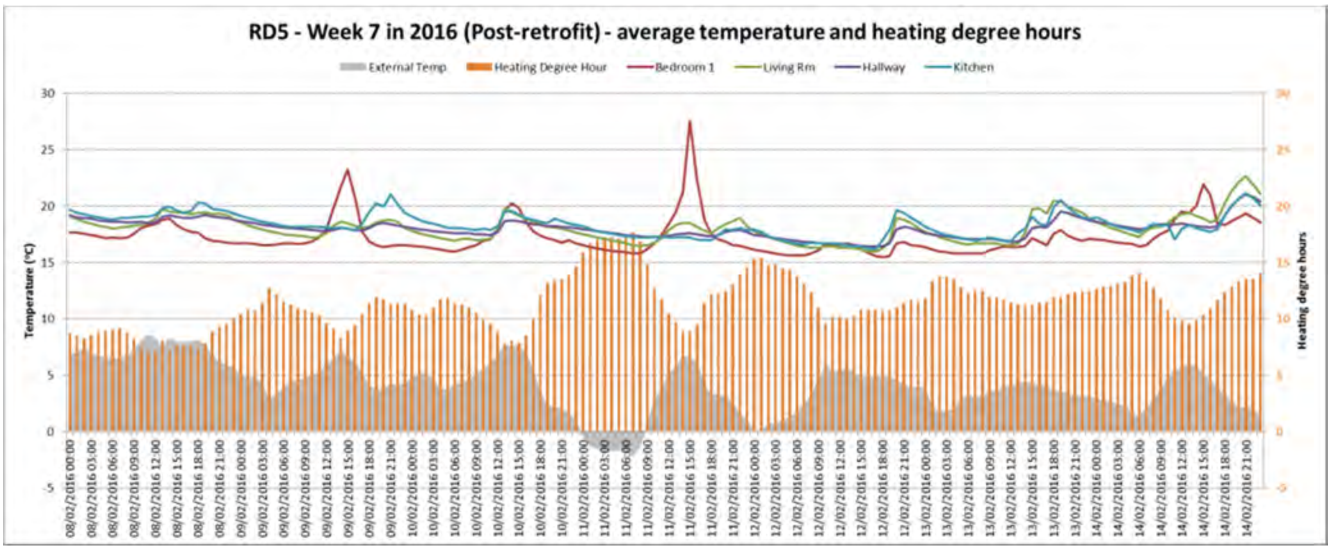
Month	**External temperature**	**Master Bedroom**	**Living Room**	**Hallway**	**Kitchen**	**Heating Degree Hours**
December 2014	5.2 ºC	18 ºC	18.2 ºC	18.9 ºC	14.8 ºC	7691.5
February 2016	5.3 ºC	18 ºC	18.7 ºC	18.5 ºC	18.7 ºC	7018.2
Difference	0.1 ºC	0 ºC	0.5 ºC	-0.4 ºC	3.9 ºC	-673.3



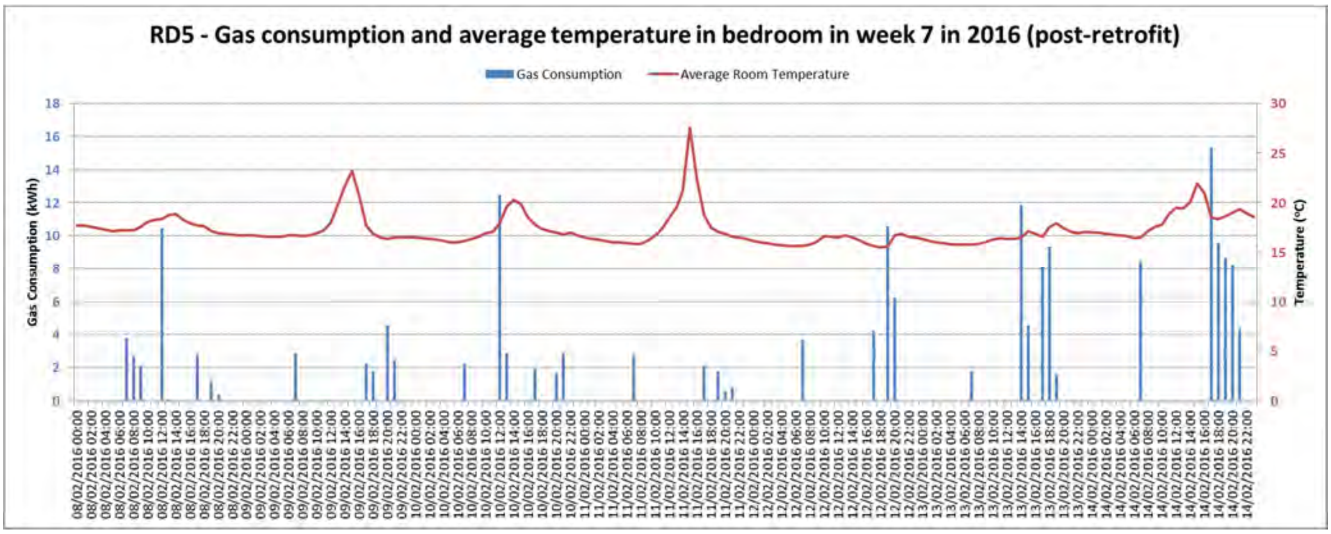
From the weekly temperature data, two weekly-intervals have been selected for further analysis, one from the pre-retrofit period, another from the post-retrofit period. The selection was based on their similarities in average external temperatures and heating degree hours, for best possible comparison.

Data collected from week 8 in 2015 (pre-retrofit) and week 7 in 2016 (post-retrofit) is used for the comparison. The average external temperature for both weeks is 4.1°C and the heating degree hour is 1,900 (pre-retrofit) and 1,920 (post-retrofit).



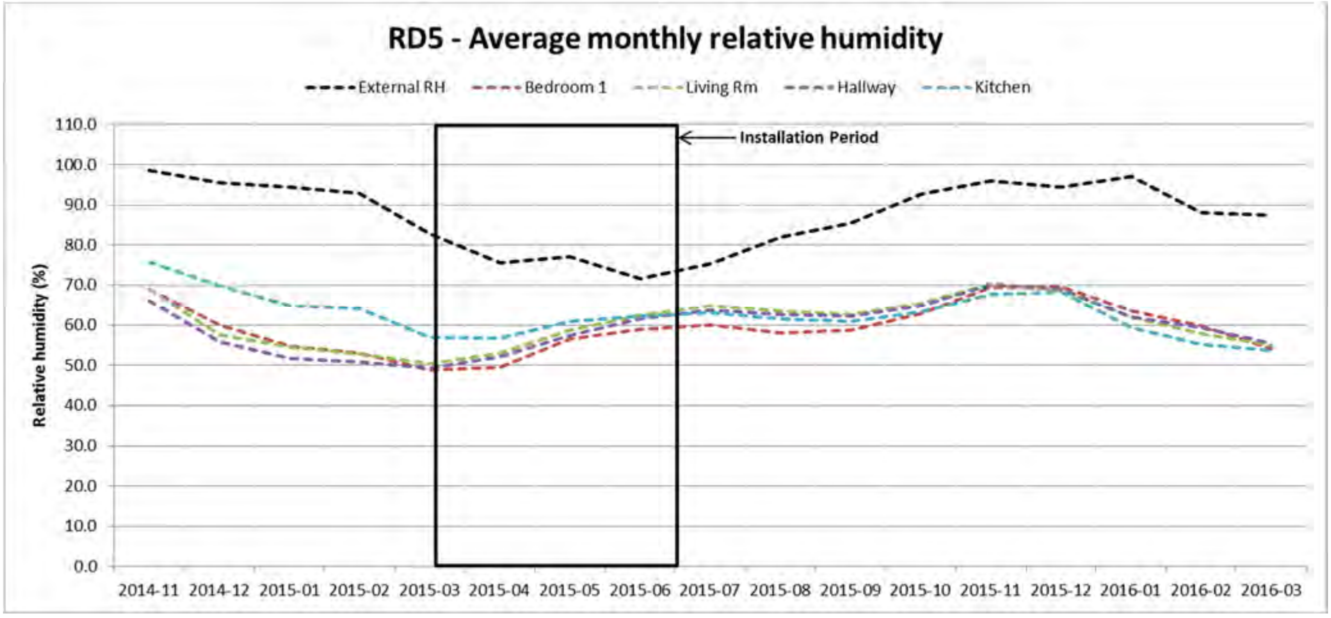


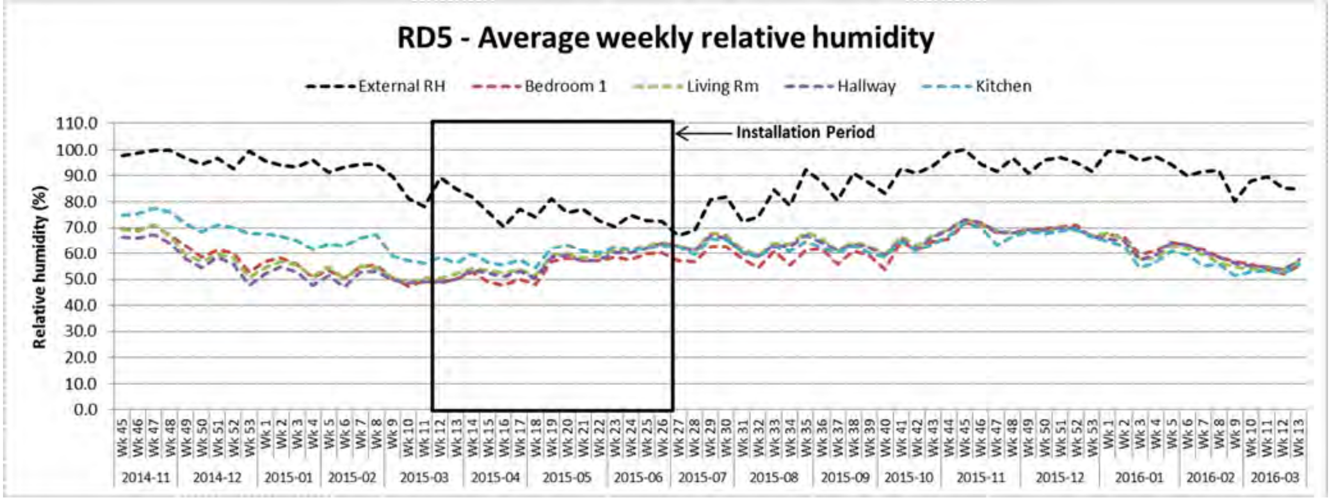
The above graphs show that there is an increase in the internal temperature post-retrofit (when comparing the weeks that share similar external temperature conditions). The internal temperature post-retrofit are generally kept between 15°C and 20°C. It is evident that the kitchen has benefited the most from the retrofit works as the internal temperatures in kitchen are now more consistent with the other habitable rooms and are generally around 18°C.



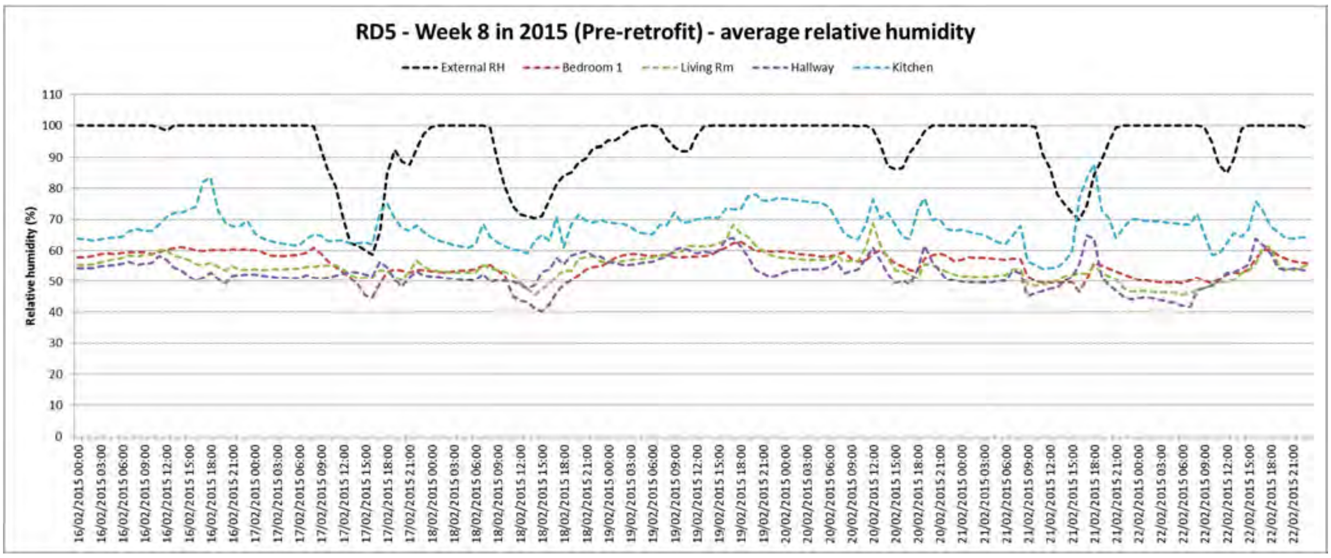
There is an interesting spike in the second graph, and further analysis shows that it is not related to the heating / gas consumption.

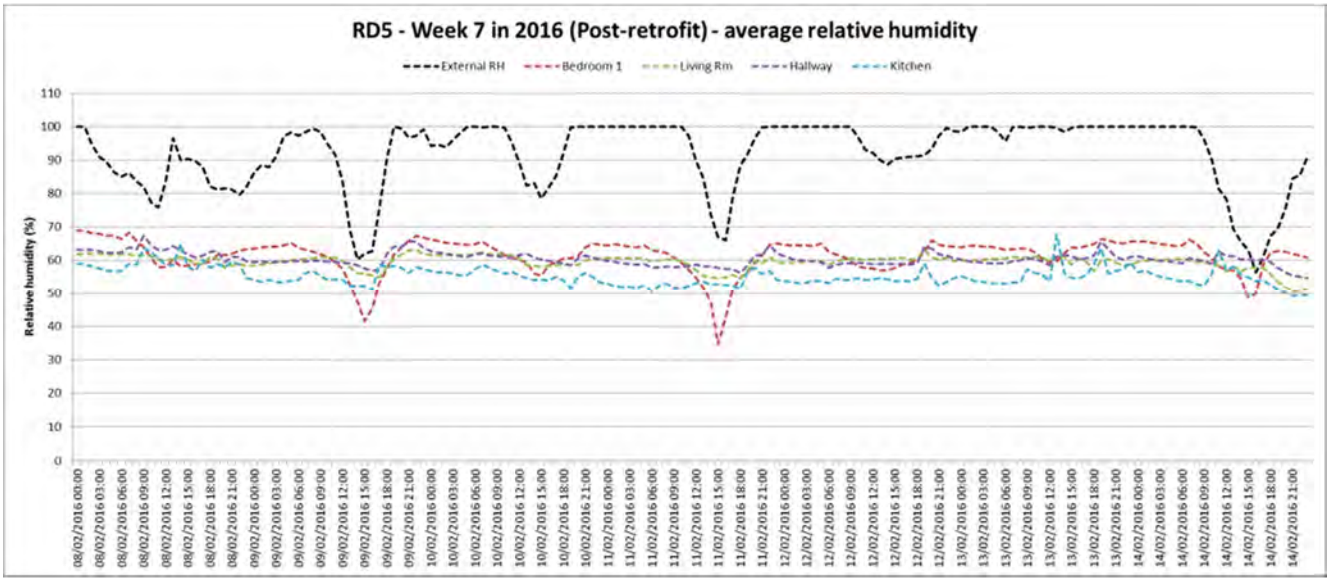
Relative humidity





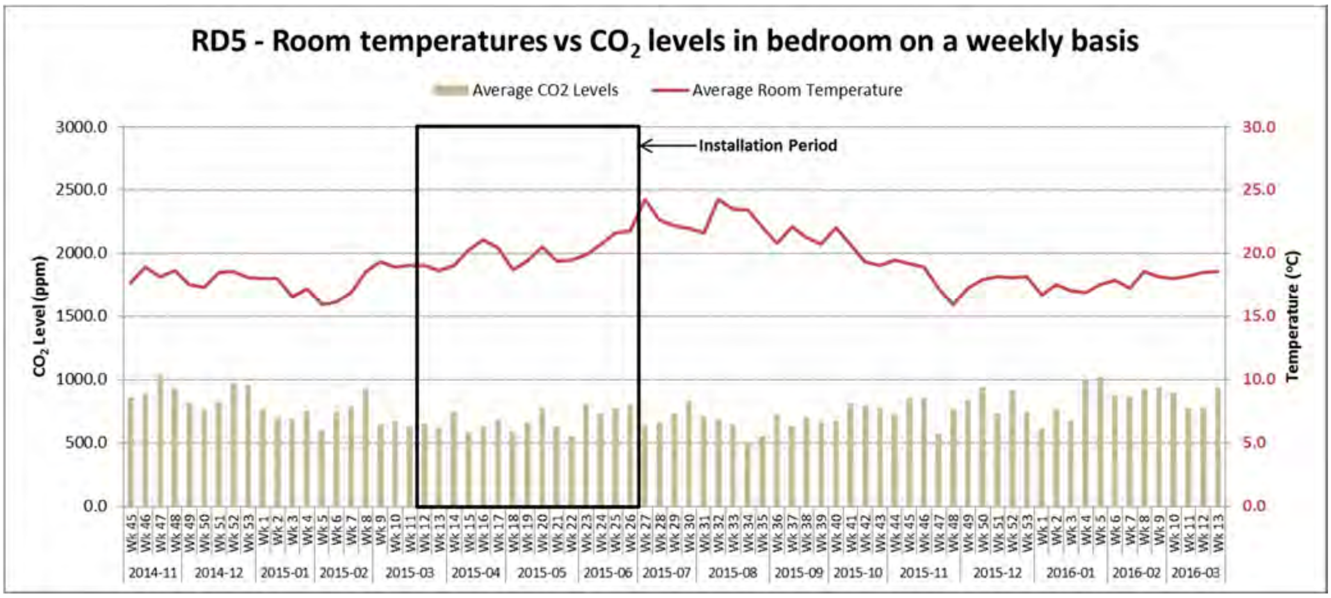
The above graphs show that the relative humidity levels remain below 80% most of the time following the installation of retrofit measures, which means the risks of surface condensation and associated potential mould growth are very unlikely.



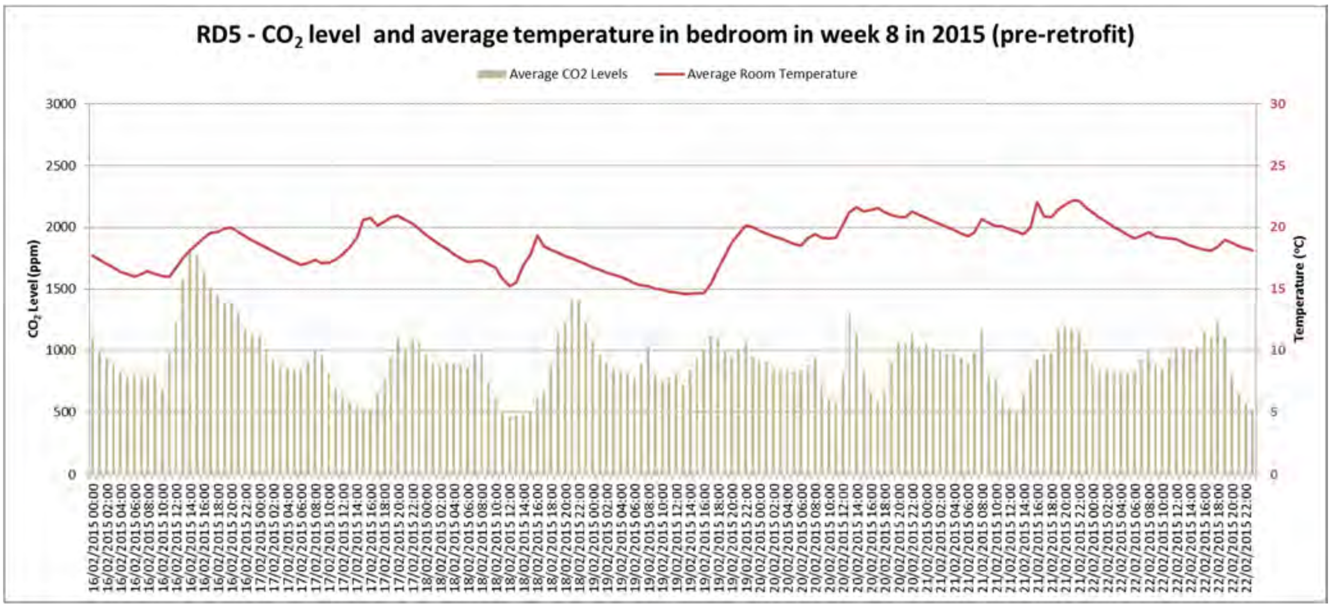


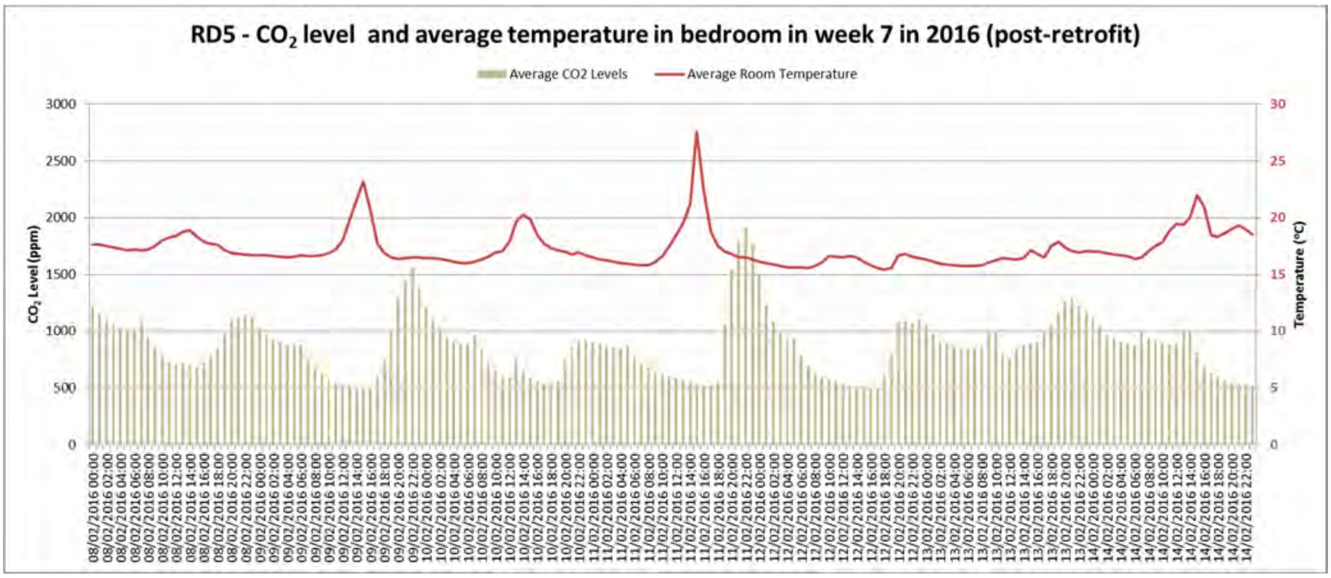
Closer inspection of the weekly data shows that the average relative humidity levels in the kitchen have been reduced from 70% to below 60% after the retrofit works, with little variations between the highest and the lowest average.

CO_2 levels in master bedroom



The above graph shows that the CO_2 levels in the master bedroom remain approximately the same post-retrofit. It is generally below 1,000ppm which is the typical level of occupied indoor spaces with good air exchange.

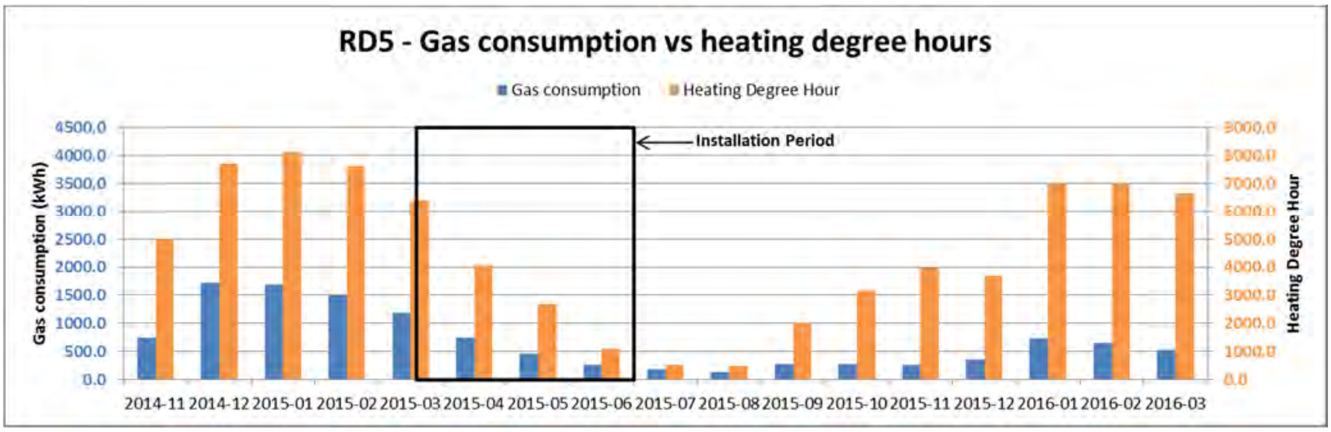


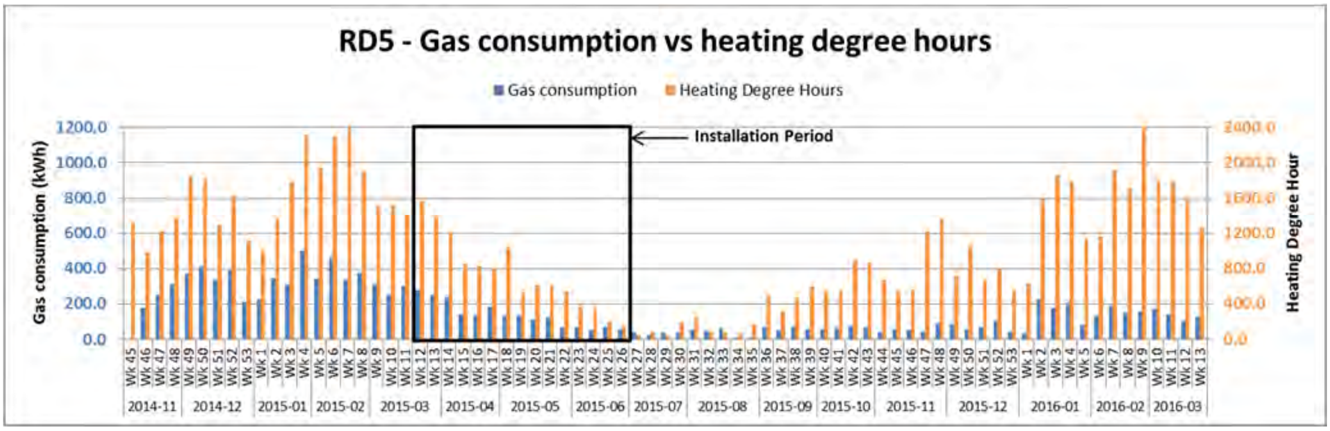


These weekly graphs show that the CO_2 levels are closer to 500ppm between the hours of 8am and 6pm on Monday to Friday of the week post-retrofit. This shows a potential improvement in the air quality in the master bedroom post-retrofit.

As part of the retrofit works, in addition to the installation of single heat recovery units in the kitchen and the bathroom, small gaps have been created between all internal doors and the floor in order to create a natural circulation of air even when the doors are shut. The graphs above suggest that the improvement in the air quality could be a result of such measure being installed because of the improvement in the internal air circulation between the rooms. However, it should also be noted that there are a number of other factors contributing to the CO_2 levels in the master bedroom, resident behaviour being one of them and this should be taken into account when looking at the monitoring results.

Gas consumption



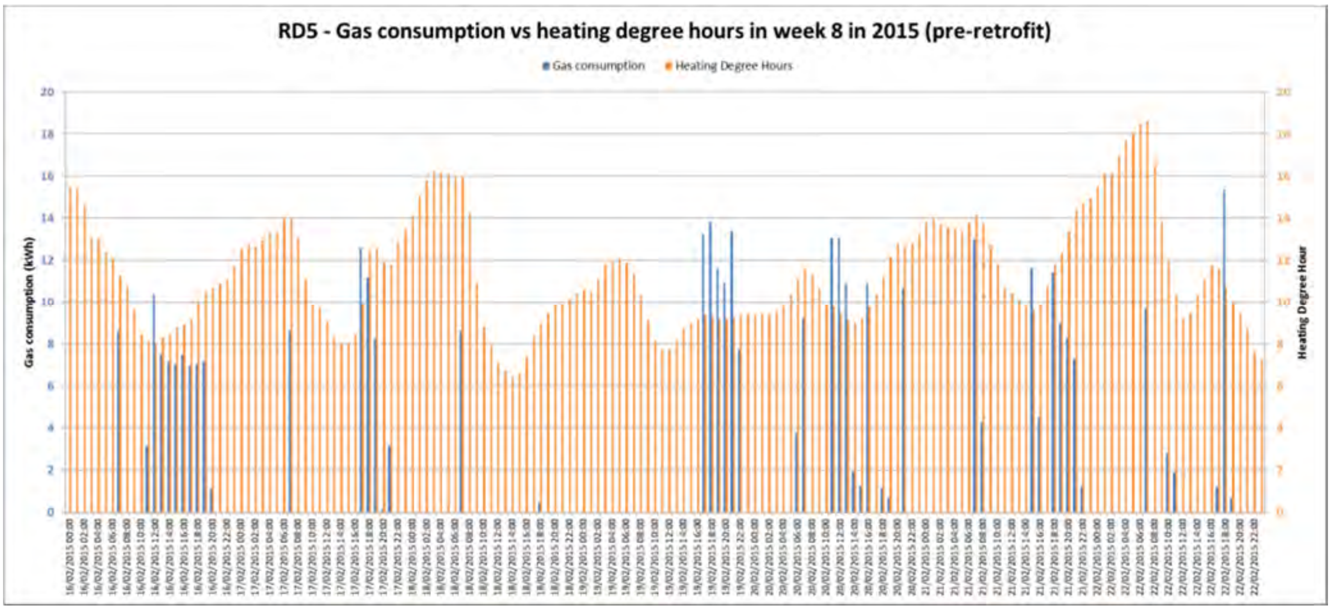


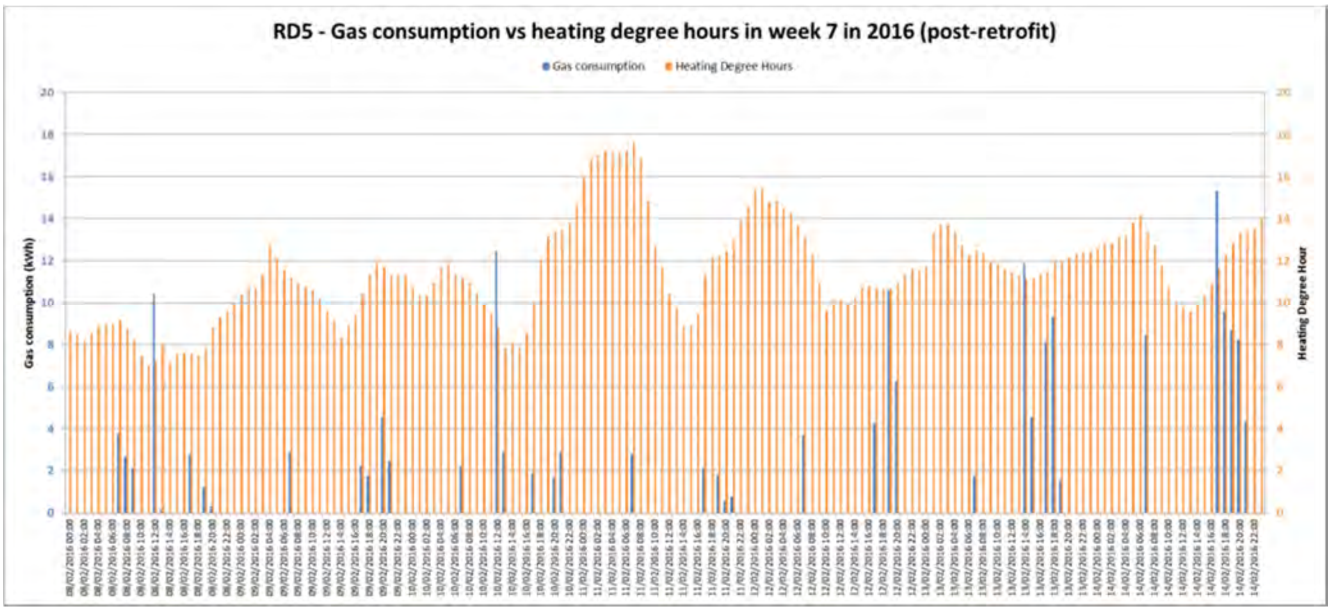
The above graphs show the total gas consumption against the heating degree hours, by month and by week respectively.

The graphs show that when like for like conditions are compared, there is a reduction in gas consumption with respect to the estimated heating required to keep the property warm. There is a significant reduction in the amount of gas consumption post-retrofit.

The total gas consumption between December 2014 and February 2015 is 4938.2kWh and the total gas consumption between December 2015 and February 2016 is 1704.7kWh.

Taking into account the total heating degree hours for these periods, the average amount of gas used per heating degree hour is 0.21kWh pre-retrofit and 0.10kWh post-retrofit, which suggests a 50% reduction in gas consumption following the installation of retrofit measures.





These graphs suggest that there is a large reduction in gas consumption following the installation of the retrofit measures.

The total gas consumption recorded for week 8 in 2015 (pre-retrofit) is 376kWh, and the total gas consumption recorded for week 7 in 2016 (post-retrofit) is 185kWh. Further calculation shows that the amount of gas used per heating degree hour is 0.2 kWh pre-retrofit, while it is 0.1 kWh post-retrofit, a 50% reduction.

In use heat balance test

		1st test	
Property Reference	**Pre-Retrofit Total HTC (W/K)**	**Post-Retrofit Total HTC (W/K)**	**Fabric thermal performance of the house due to retrofit (%)**
RD5 (1945-1964 semi-detached)	207	115	+44%

Air permeability test

Property Reference	**Target Air Permeability ($m^3/h.m^2$)**	**Air Permeability Pre-Retrofit ($m^3/h.m^2$)**	**Air Permeability Post-Retrofit ($m^3/h.m^2$)**	**Changes Due to Retrofit (%)**
RD5 (1945-1964 semi-detached)	7.0	11.01	5.94	-46.0%

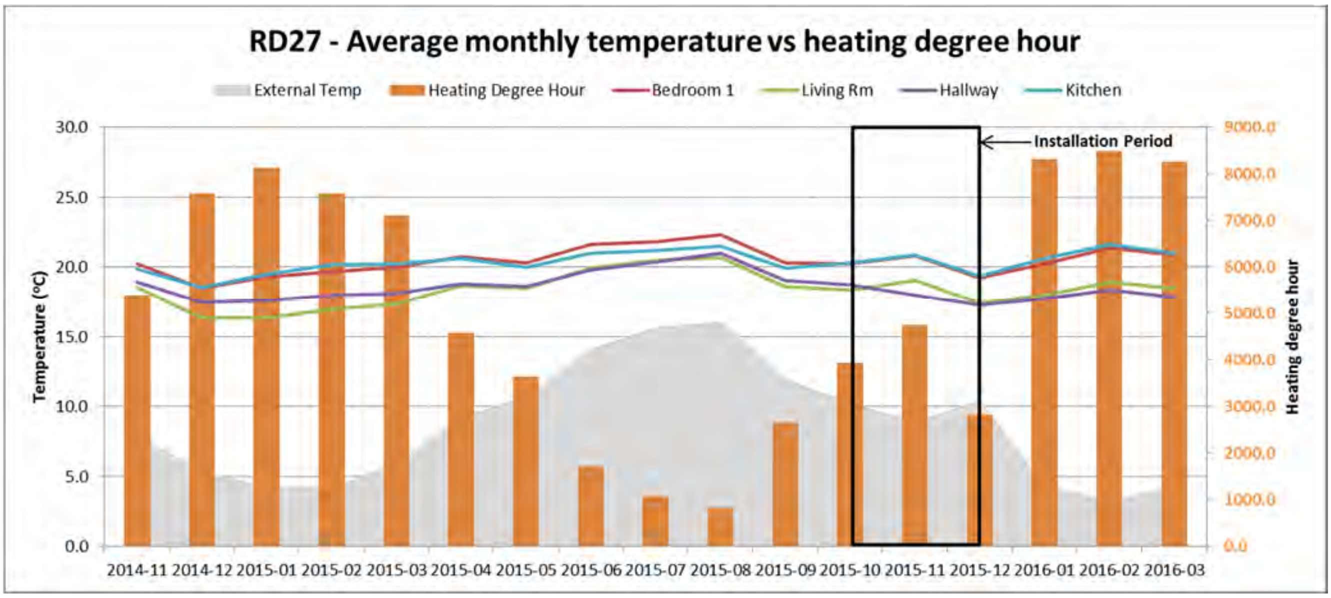
Summary of Findings - RD5

- Rooms are generally warmer post-retrofit and can be maintained at a temperature that the resident desired without using more heating.
- There is an improvement to the temperature levels in the kitchen, which is more consistent with the temperature in the other habitable rooms at the property.
- There is a 50% reduction in gas consumption post-retrofit for the weeks analysed, in line with our findings from the in use heat balance test. This property has the most improvement in thermal performance when compared with the other properties.

3.2.4. RD27 - Post 1980 Semi-detached

This was the final property to be retrofitted and the installation of retrofit measures took place between 19 October 2015 and 18 December 2015. The installation period is shown as a black-lined box in the following charts for ease of reference.

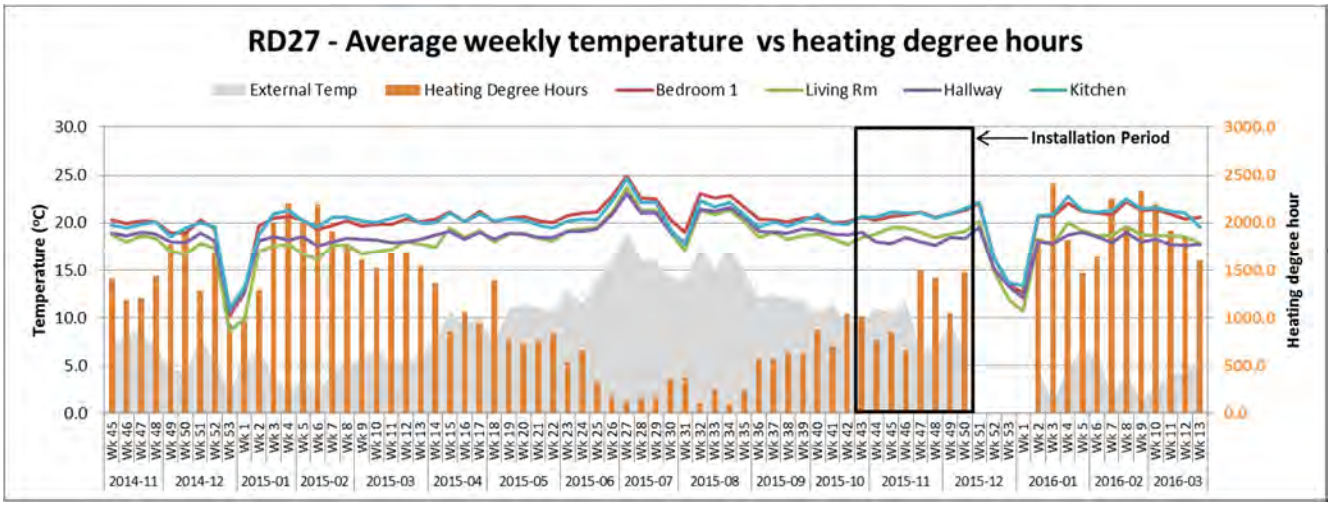
Internal temperature



The above graph shows that there is a slight increase in the average monthly internal room temperatures, which are now usually above 18°C post-retrofit. This is in alignment with the resident's view that the rooms felt warmer after the works had been carried out.

A comparison of internal room temperature in January 2015 (prior to retrofit) and January 2016 (after retrofit) is as follows:

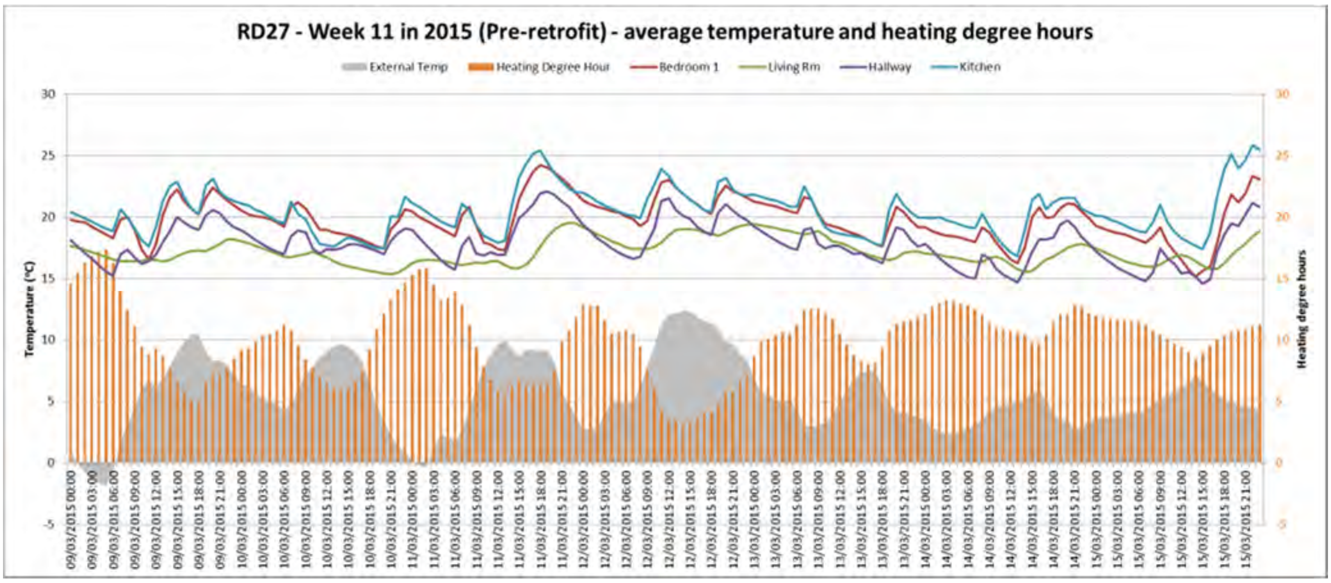
Month	External temperature	Master Bedroom	Living Room	Hallway	Kitchen	Heating Degree Hours
January 2015	4.3 °C	19.3 °C	16.3 °C	17.6 °C	19.5 °C	8125.6
January 2016	4.3 °C	20.3 °C	18 °C	17.8 °C	20.6 °C	8312.1
Difference	0 °C	1 °C	1.7 °C	0.2 °C	1.1 °C	186.5

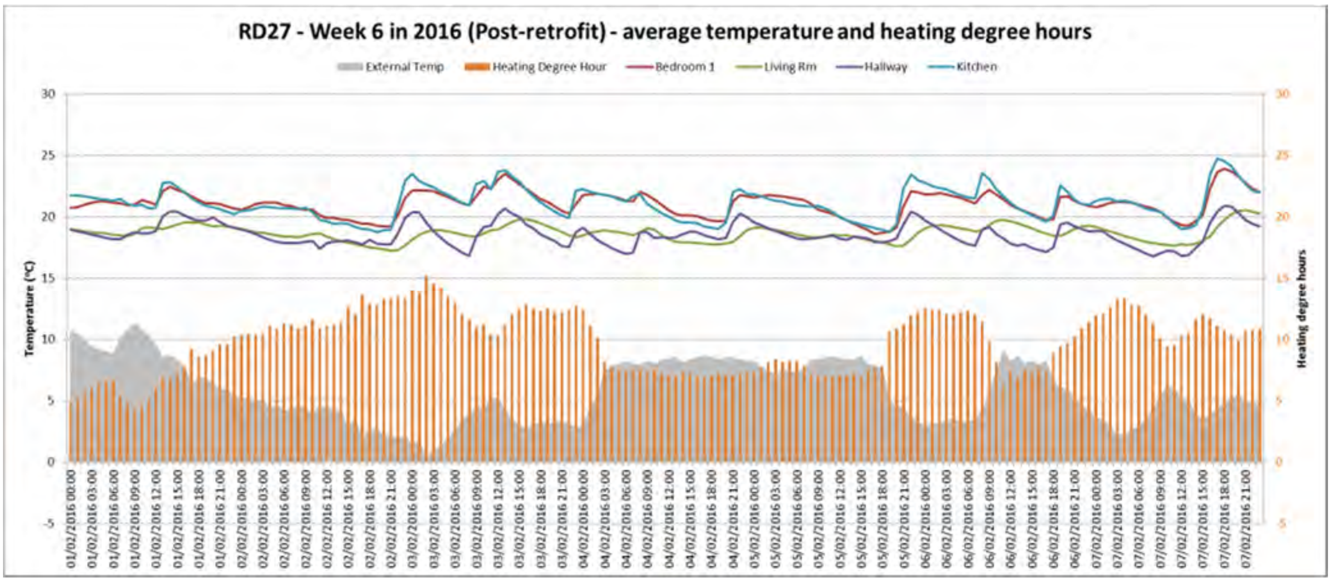


*note that due to a fault with the monitoring system, no external temperatures were recorded between week 51, 2015 and week 1, 2016.

From the weekly temperature data, two weekly-intervals have been selected for further analysis, one from the pre-retrofit period, another from the post-retrofit period. The selection was based on their similarities in average external temperatures and heating degree hours, for best possible comparison.

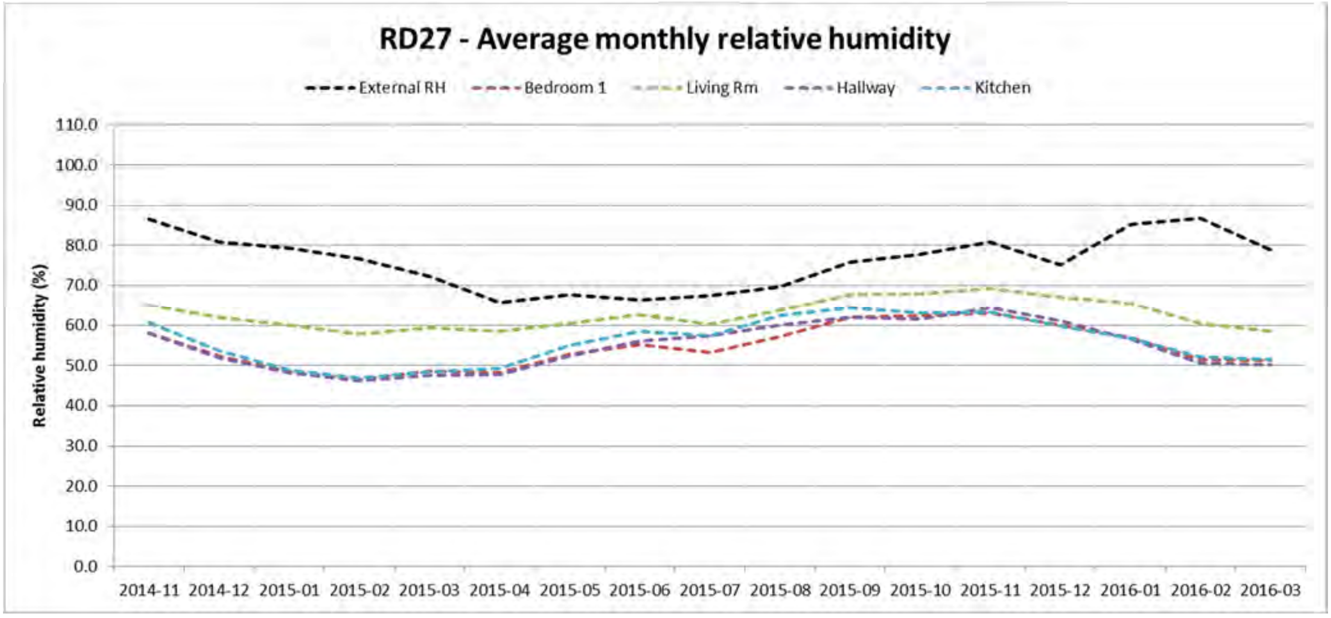
Data collected from week 11 in 2015 (pre-retrofit) and week 6 in 2016 (post-retrofit) is used for the comparison. The average external temperature for both weeks is 5.5ºC and the heating degree hour is 1,680 (pre-retrofit) and 1,645 (post-retrofit).

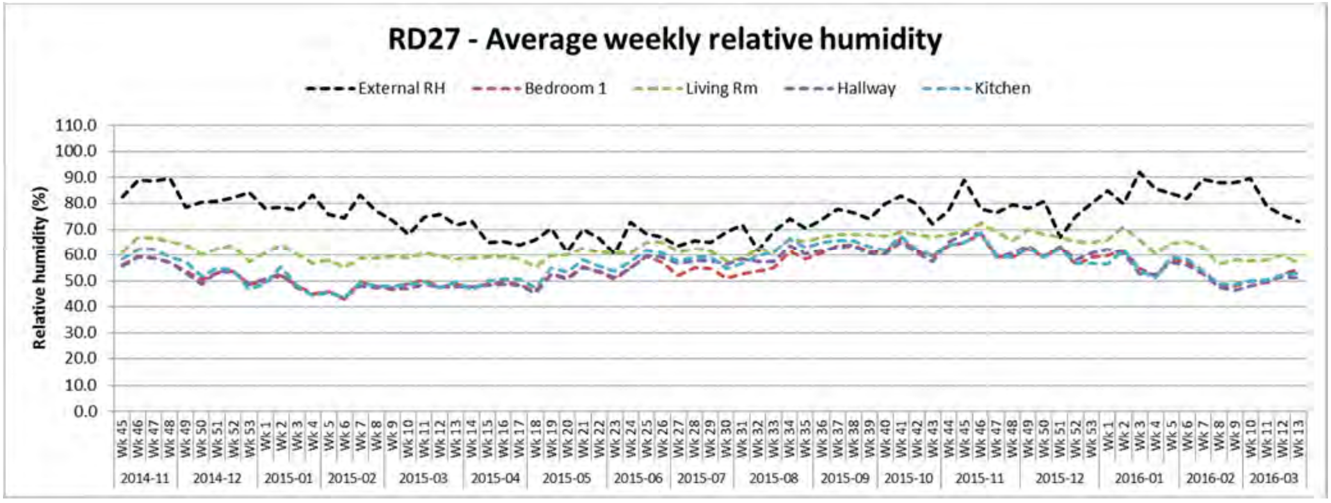


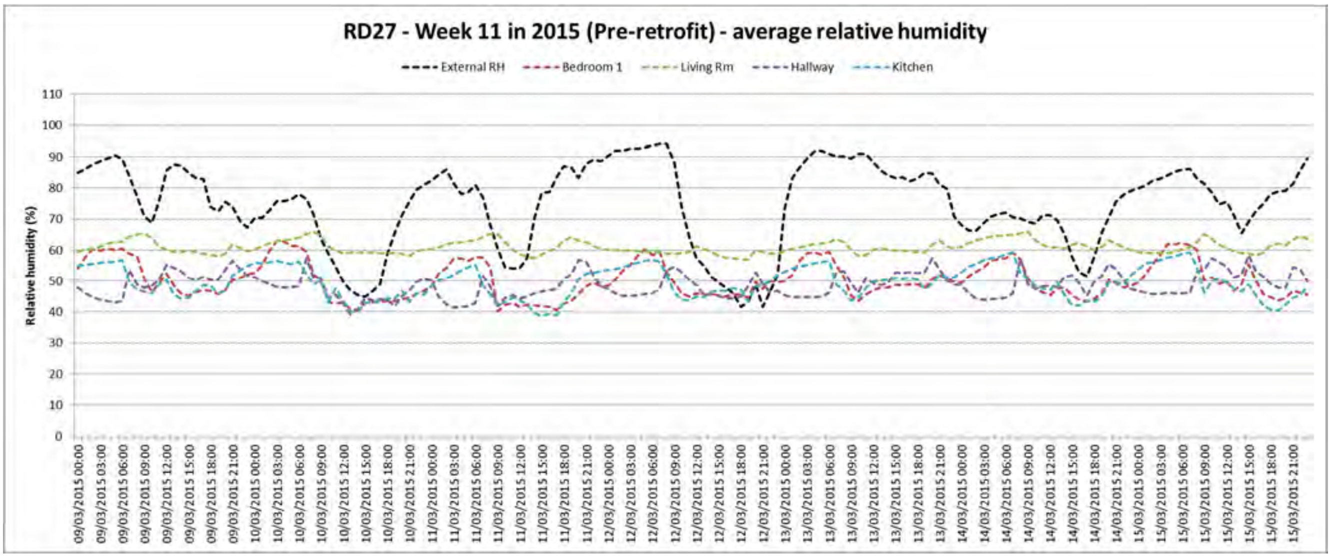


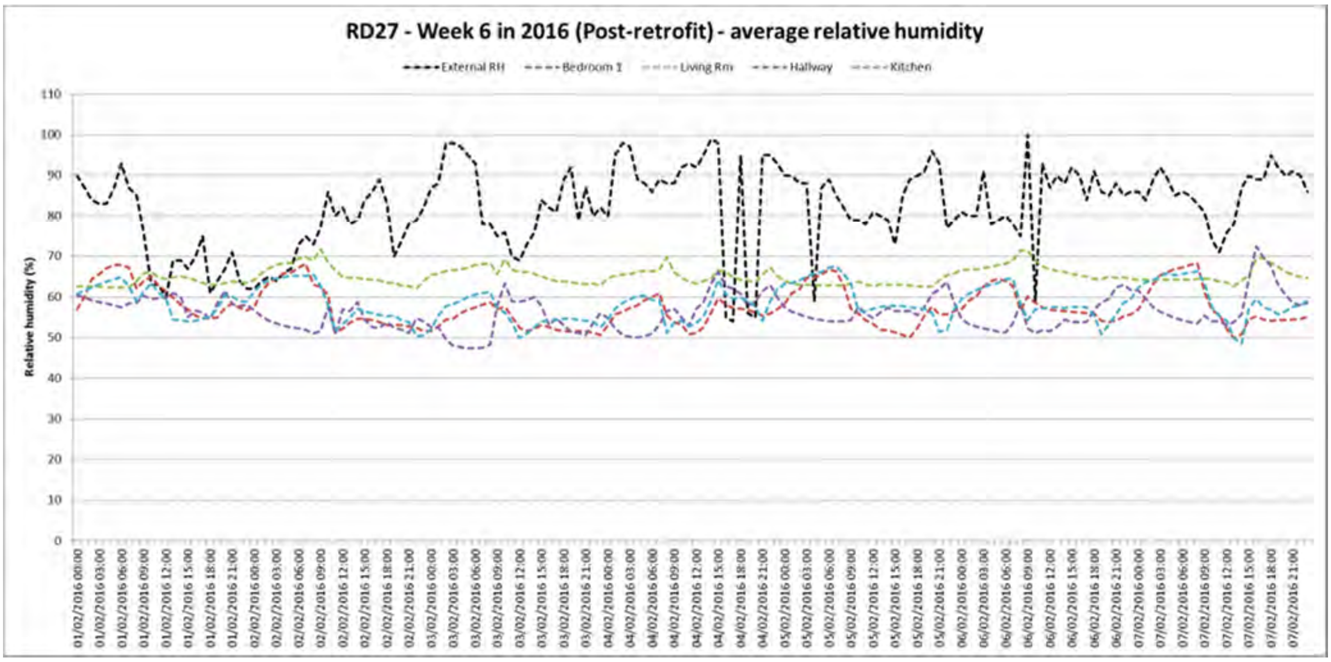
The above graphs show that there is a slight increase in the internal temperature post-retrofit (when comparing the weeks that share similar external temperature conditions). The internal temperatures post-retrofit are generally kept between 18^{o}C and 20^{o}C. This increase in internal temperature is more evident in the living room, which supports the resident's feedback following the installation of retrofit measures at their property.

Relative humidity



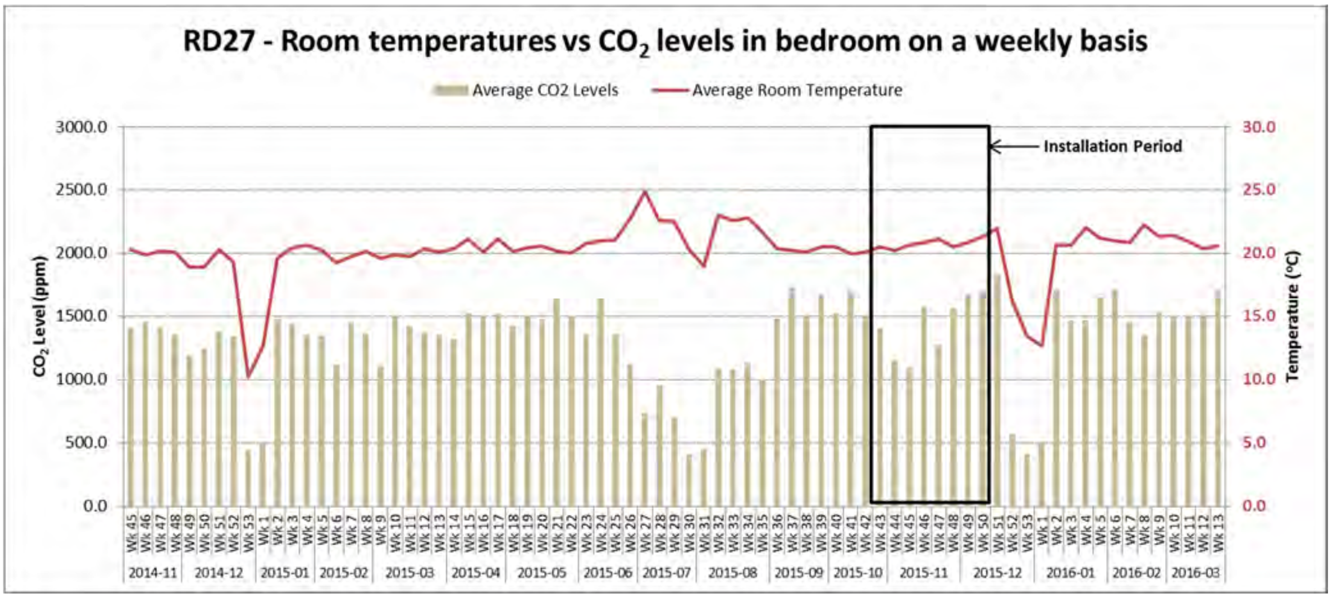




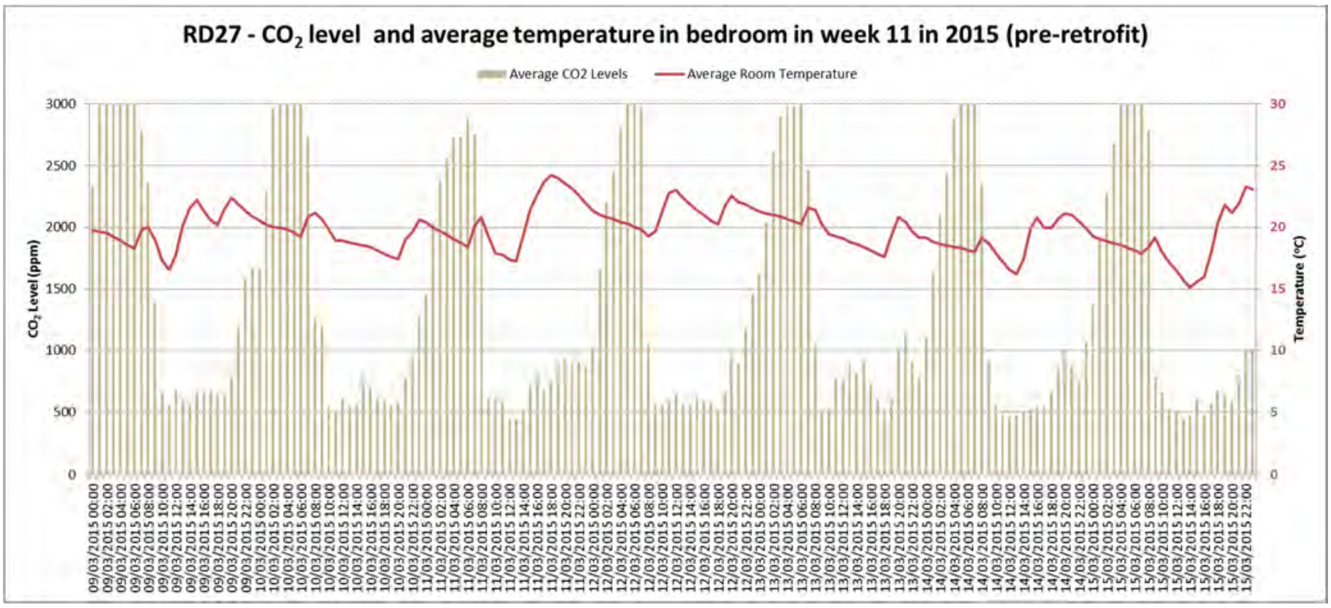


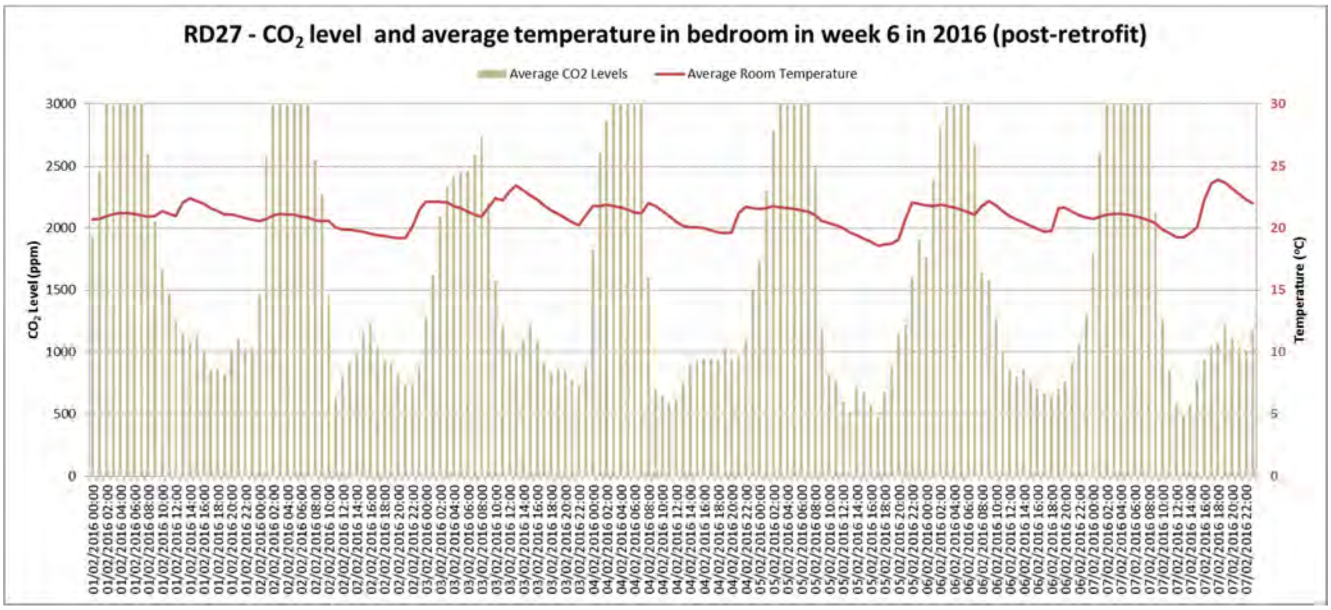
The above graphs show that the relative humidity levels remain below 80% following the installation of retrofit measures, which means that the room surfaces are very unlikely to be susceptible to the risks of condensation occurring and associated potential mould growth.

CO_2 levels in master bedroom



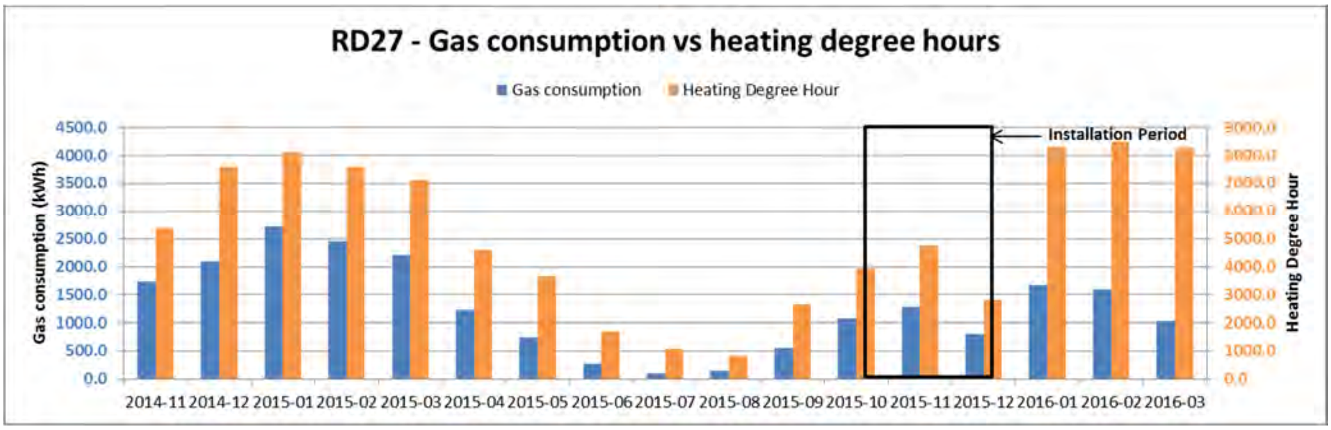
There appears to be a slight increase in the CO_2 levels post-retrofit, however, the average CO_2 level remains below 2,000ppm which is the recommended threshold for good indoor air quality.

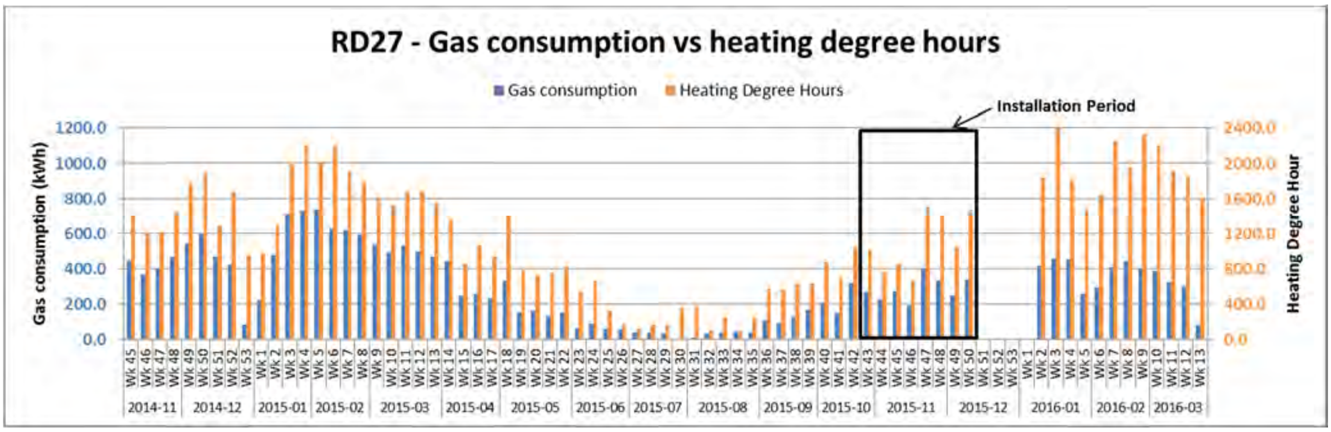




These graphs show that the pattern of CO_2 levels remains the same post-retrofit, although there's a slight increase in the CO_2 levels during the daytime hours (10am to 6pm) by approximately 200ppm to 300ppm, which could be associated with reduced air leakage in the home as a result of the retrofit works.

Gas consumption



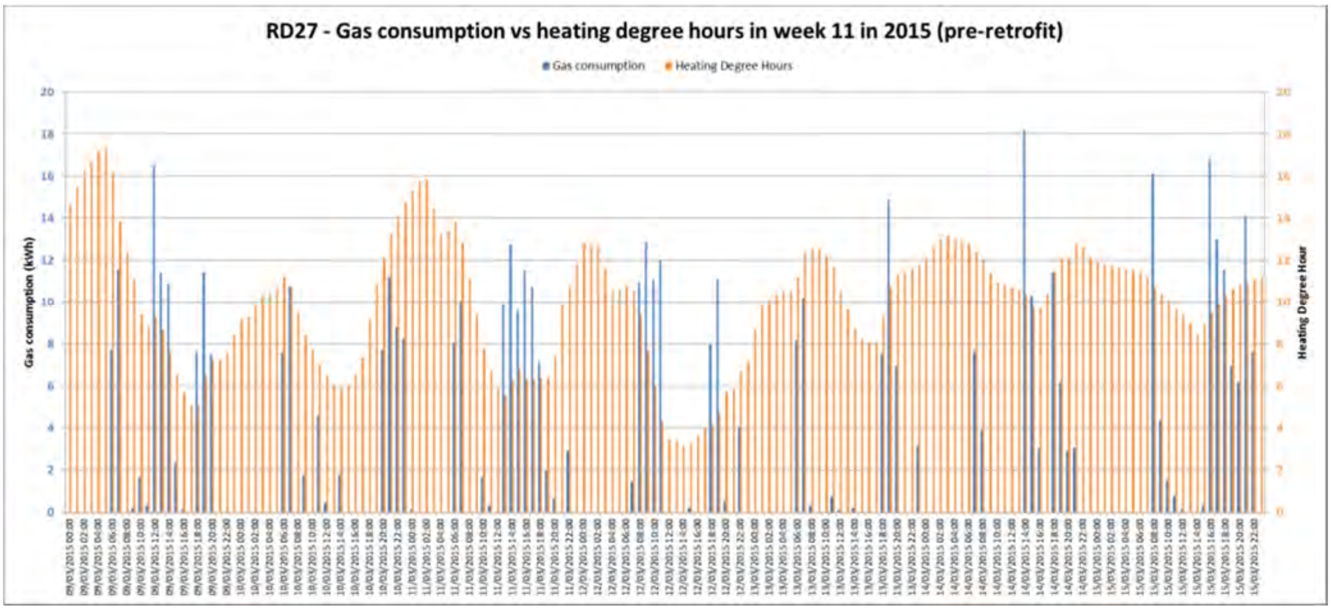


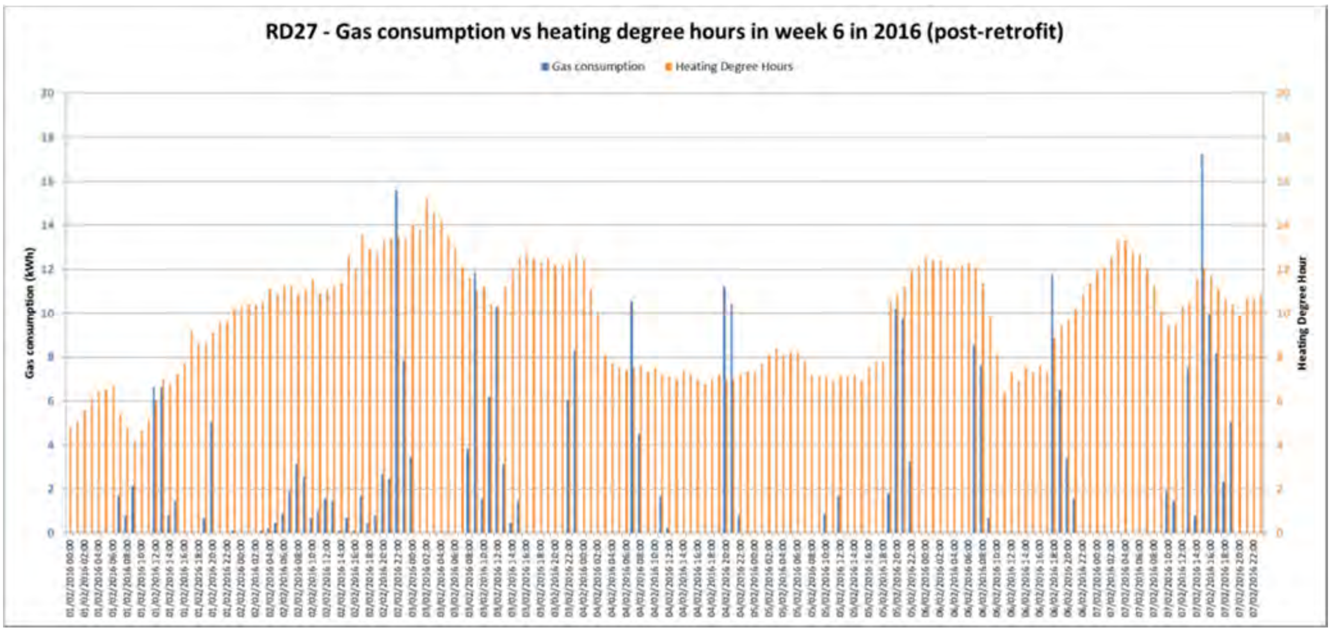
The above graphs show the total gas consumption against the heating degree hours, by month and by week respectively.

Similar to the findings from RD5, the graphs show that when like for like conditions are compared, there is a reduction in gas consumption with respect to the estimated heating required to keep the property warm. There is a significant reduction in the amount of gas consumption post-retrofit.

The total gas consumption between January 2015 and February 2015 is 5168.3kWh and the total gas consumption between January 2016 and February 2016 is 3267.8kWh.

Taking into account the total heating degree hours for these periods, the average amount of gas used per heating degree hour is 0.33kWh pre-retrofit and 0.19kWh post-retrofit, which suggests a 40% reduction in gas consumption following the installation of retrofit measures.





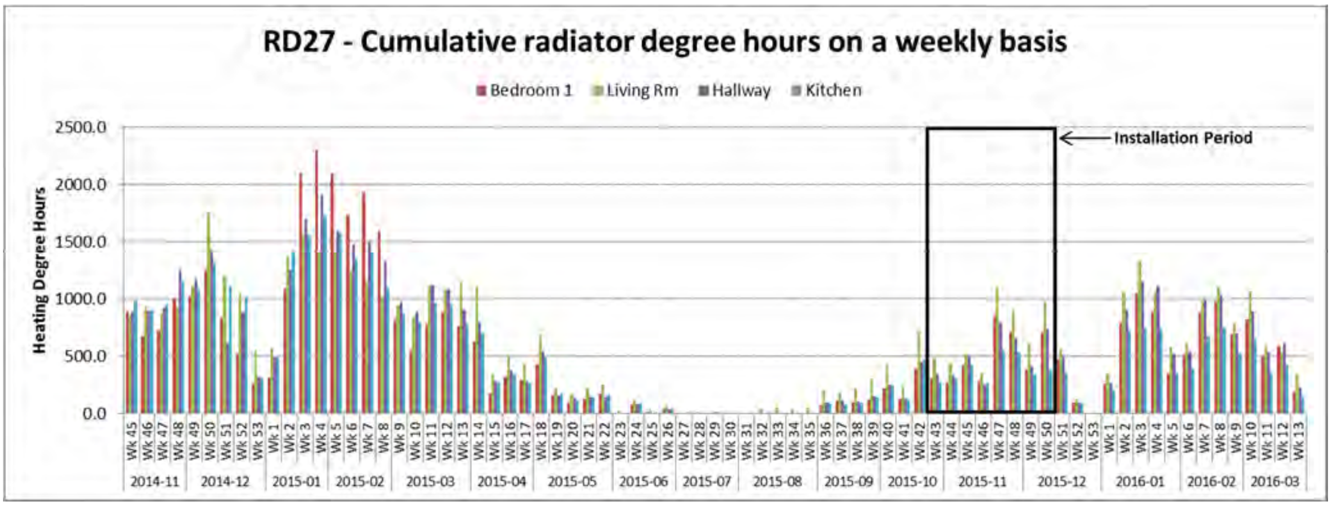
These graphs suggest that there is a reduction in gas consumption following the installation of the retrofit measures.

The total gas consumption recorded for week 11 in 2015 (pre-retrofit) is 530kWh, and the total gas consumption recorded for week 6 in 2016 (post-retrofit) is 290kWh. Further calculation shows that the amount of gas used per heating degree hour is 0.31kWh pre-retrofit, while it is 0.18kWh post-retrofit, a 42% reduction.

Underfloor Electric Heating Consumption

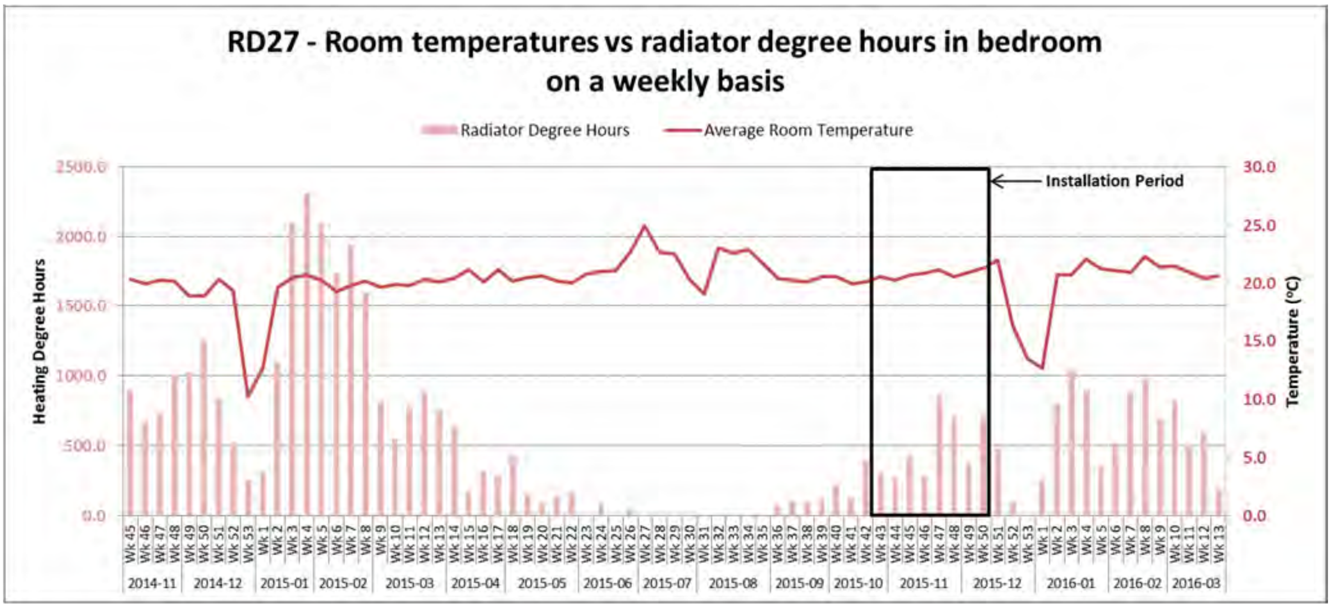
There was an underfloor electric heating system installed in one room at this house. No detailed analysis has been undertaken to assess the impact of the retrofit installation to the underfloor heating system as the resident stated that the underfloor heating system was not used after the retrofit measures were installed at the property.

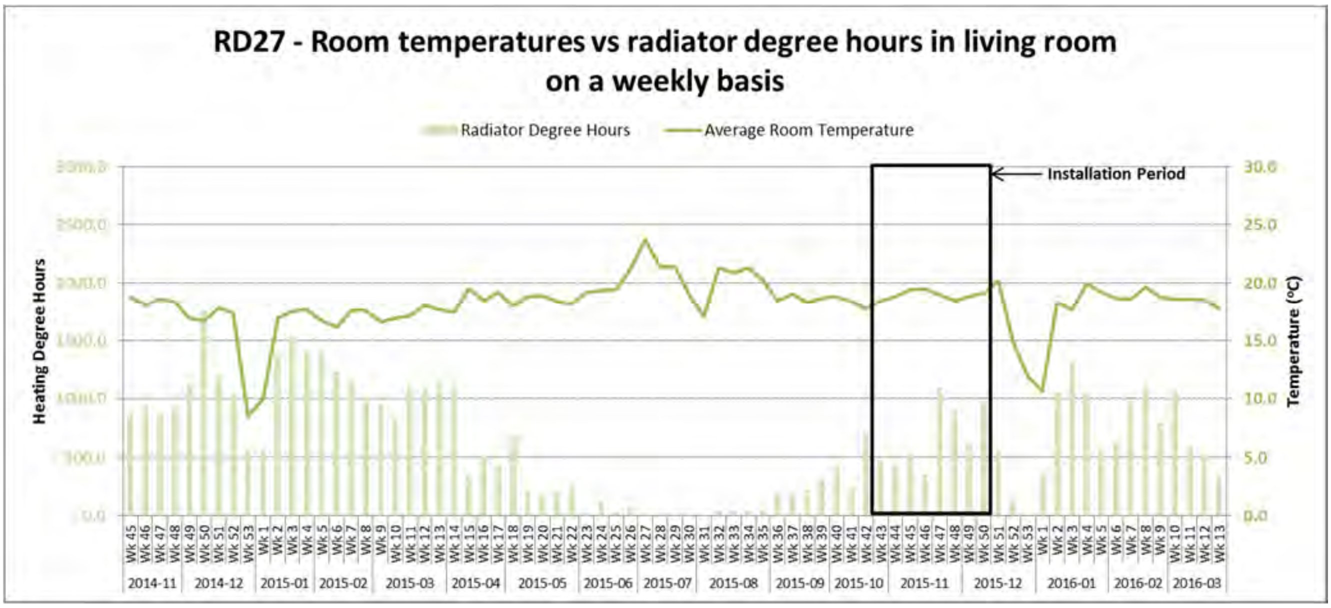
Heating usage



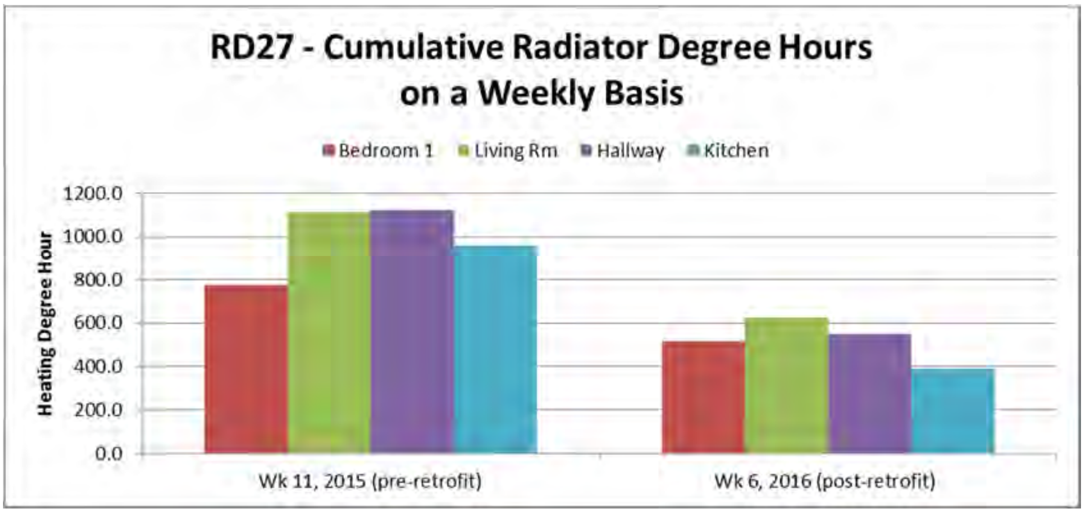
The above graph shows the heating degree hours calculated based on the radiator and the room temperature that are collected from the data loggers. When compared with the graphs on the previous page, it can be deduced that it required less heat energy to heat the property.

The following two graphs further confirm that the internal room temperature is maintained the same (if not warmer) while less heat energy has been used.





The graph below further confirms that less heating is required post-retrofit to maintain the same internal temperature (during the weeks that share similar external temperature conditions).



In use heat balance test

		1st test	
Property Reference	**Pre-Retrofit Total HTC (W/K)**	**Post-Retrofit Total HTC (W/K)**	**Fabric thermal performance of the house due to retrofit (%)**
RD27 (Post-1980 semi-detached)	223	172	+23%

Air permeability test

Property Reference	**Target Air Permeability ($m^3/h.m^2$)**	**Air Permeability Pre-Retrofit ($m^3/h.m^2$)**	**Air Permeability Post-Retrofit ($m^3/h.m^2$)**	**Changes Due to Retrofit (%)**
RD27 (Post-1980 semi-detached)	6.0	30.96	First test 19.1	-38.3%
			Second test after further air sealing 11.95	-61.4%

It should be noted that the RD27 pre retrofit air test was undertaken when the original garage door was in place. This was removed and the opening blocked up by the resident prior to the retrofit work. The first post retrofit test (result 19.1) identified the primary air loss route to be the plasterboard on dabs finish to all rooms, a finish not found on older homes unless they have been refurbished with plasterboard, the void behind which allows air to leak into the roof space, cavity wall at the first floor junction and probably the party cavity wall. The pre-retrofit test was not thorough enough to highlight this air loss due to so many other air loss routes. Additional air sealing work had to be undertaken to improve the air permeability to 11.95 (minimum in current Building Regulations for a new build house is 10.0), further reduction would have been very intrusive, disruptive and likely not cost effective.

Summary of Findings - RD27

- Rooms are generally warmer post-retrofit and can be maintained at a temperature that the resident desired without using more space heating.
- There is a reduction of 40% in gas consumption post-retrofit for the weeks analysed, although the in use heat balance test is only showing an improvement of 25%.

4. Post Install Problems/Warranties

4.1. Resolution and analysis of technical problems post-completion

There have been no reported serious technical problems or failures since the retrofit works have been completed. There were a number of snagging items (defective or missing works) at each house following the completion and prior to the formal handover of the project sites back to the residents. These snagging items were largely related to finishing or sealing around perimeters or penetrations, a full list of the snagging items are listed below including some non-project repair works undertaken at the same time as the main installation work.

Table 1: Snagging stage defects

Snagging stage defects			
RD1	**RD5**	**RD9**	**RD27**
EWI perimeter/penetration sealing missing (part)	EWI perimeter/penetration sealing missing (part)	EWI perimeter/penetration sealing missing (part)	EWI perimeter/penetration sealing missing (part)
Draught stripping to basement door	Rear window not closing properly – to be eased	EWI below dpc insulation missing (200m length)	EWI pointing missing (few places)
Insulation to underside of stairs coming away	Expansion joint not painted (side wall)	Draft stripping to front door/porch missing	Fascia cover strip missing
Paint missing from render stop-bead (rear)	Poor duct taping of insulation on boiler condensate pipe	Base of below dpc EWI to have mastic seal where render is defective (junction of front bay to porch)	Internal window cills not level
Seal all internal reveals to windows and doors where needed		Mastic seals around two waste pipes from bathroom to be finished	Plaster skim finish quality
Seal skirting in main bedroom		Gate stop to be installed to prevent render damage	Fan extract embedded into wall insulation
		Render to be finished adjacent to external tap as mesh showing	Paint splash to be cleaned from curtain
		Air leakage from consumer unit on upstairs landing (into loft) sealed	

Table 2: Repairs/Upgrades outside Retrofit Demonstration project scope

Repairs/Upgrades outside of the Retrofit Demonstration project		
RD1	**RD5**	**RD9**
Master bedroom bay window sealed/waterproofed	Rear window adjusted as not closing properly	Hot water tank room sealed
Rear roof end flashing (right corner) sealed	Damp in entrance	
Rear chimney repointed	New entrance doors	
Crack in dining room wall repaired	Additional fencing and external lighting	
Cracking to ceiling in kitchen / 2nd bedroom repaired		
Kitchen tiles near door sealed		

Since the completion of the work at the houses, the residents of one home have reported problems with the heat recovery fans. An engineer from the fan manufacturer visited in May 2016 and concluded that the wrong length of fan had been installed in the bathroom and kitchen. These were replaced, as a consequence of the wrong length; the heat recovery system was not working to its full potential. This error was caused by the contractor ordering a fan for a standard cavity wall width without considering the external wall insulation and brick slip thickness. As such, a much longer fan was required than the standard cavity wall version. The electrician then installed the fans which were too short and it was the cooler air blowing from these fans which suggested to the resident that there may be a problem and consequently PRP asked the supplier to visit the site.

In future the fan size should be added to the drawings/specifications rather than just the product reference but the buying process needs to be more considered, with perhaps such items being bought directly by the team leader on site or by him/her via the central buyer. Alternatively the builder's merchant who supplies the materials through on time deliveries, could ensure that the correct fans where delivered to site. With greater volumes of work, whoever orders the fans would come to learn what standard lengths are required for a solid wall and cavity wall house. The electricians will also need educating with regard to the fan types and sizes.

The snagging works were rectified by the two contractor's and approved by Peabody/PRP as being acceptable. Largely the snagging items were those which commonly happen in refurbishment projects, but greater adherence to quality at the time of work could prevent many of them occurring. Snags were identified by the installation team leader, contractor site manager, the EWI supplier technical inspector, Peabody's clerk of works or PRP's technical team undertaking observation on site. The owner of a private house would typically only encounter the team leader and the EWI supplier technical inspector during retrofit work to their house (possibly also the contractor site manager, depending on the size of the contractor organisation and the building regulations inspector if the works were not being certified under a competent person scheme). Only one person is required to undertake quality checks, not the many that were involved in this demonstration project but without adequate training and experience that one person may not identify all the defects. This could potentially lead to underperformance of the retrofit works and cause physical or aesthetic damage to the home and ultimately cost the homeowner more money to rectify the consequential problems in the future.

Substandard installation quality is largely down to operatives not being clear of the quality and detail requirements of the works, either assuming that previous standards used are sufficient or a lack of understanding of what certain details are aiming to achieve. The installation teams need improved awareness of the acceptable level of quality, from both a technical performance and aesthetic finish perspective. Training is required across all those we have worked with and we expect that the majority of other retrofit industry operatives will require it too. The training would include the reasons why the substandard quality is not acceptable (customer acceptance, brand damage, repair costs etc.) and the level of quality that is acceptable (training through desk top case study examples and physical on-site training). Over time the team members would undertake installation to higher quality levels but it would still take the team leader or a roving quality inspector to enforce quality through regular on-site checks to ensure quality standards are being adhered to.

It is believed that rectification of problems during the work, and repairing typical snagging items cost contractors on average 5% of the contract price (total cost of the works) equating to approximately £1,400 of the cost of the work to each home. This is supported by our on -site observations, on this and other projects, and from this we deem that with greater attention to quality at the time of installation and checking of work as it proceeds rather than post completion of the full works this percentage could be reduced to 1% or less.

This saving is achieved through minimising on site and travel time, material costs and expenses associated with returning to site to undertake the repair works. A right first time approach would also promote greater consumer confidence in the delivery team and retrofit organisations. There have been no other problems since the handover of the homes.

4.2. Commercial considerations

The use of proven products with long warranty periods from trusted manufacturers will reduce the potential for the retrofit installation company to incur costs post completion of the work. These costs will be associated with customer service, admin and possibly removal of faulty products and installation of the replacement products. Such costs will add to the companies' overheads and in turn will be passed back to customers via the price they pay for retrofit solutions to be installed. Faulty products may also damage the brand of the manufacturer and the retrofit installation company.

The project team has experienced cheap ventilation fans breaking outside of this project after short installation periods and the residents of the house not reporting this or getting replacements (latter private homes). Problems with surface condensation, mould and poor indoor air quality are often then experienced.

It is common in the retrofit and domestic building industry for the cheapest, most familiar or readily available product to be installed, sometimes despite what the design specification states. This can save the installer or builder money but can leave the customer with a product which may have a reduced life or performance. Often the customer will not understand that the product is of a reduced quality, and they may have paid for a more expensive better quality product. A more robust product may have a higher capital cost than the alternative cheaper product but it could ultimately save money for the retrofit installer and reduce additional impacts on the residents and building fabric.

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5. Costs and Process

This section covers the analysis of retrofit costs and drivers of such costs.

The first sub-section lists the cost drivers for retrofit to give an overall summary of the aspects which influence the out-turn costs of retrofit programmes. The next three sub-sections split the total cost of retrofit into three categories.

- Material costs
- Labour costs
- Survey, design and other overheads

This is followed by the Final Installation Cost sub-section which contrasts out-turn costs from the four property retrofits with the cost models, plans and expected outcomes established at the outset of the project. In addition the project team have revised the expected costs of the Retrofit Approach for each of the four properties based on proposed product and process improvements and this is presented in Report 2.

The final sub-section considers the overall Target Cost of Retrofit.

5.1. Cost Drivers for the Retrofit Approach

- Direct Material
    - External Wall Insulation (EWI) System
    - EWI Ancillaries
    - Internal Wall Insulation (IWI)
    - Ventilation and Heat Recovery
    - Chimney Treatment
- Direct Labour
- Survey, Design & Quality Assurance
- Overhead
    - Scaffolding & Access
    - Welfare Van
    - Other Plant
    - Site Management
    - Waste Management
    - Insurance, Administration and Profit
- Risk
    - Building Condition
    - Disputed Costs
    - Additional Works

5.2. Direct Material Costs

The core material costs are the EWI System (insulation / adhesive / render and brick slips) and the ancillary items (fixings, base-track, tape etc.). All materials, including the EWI insulation that was used on this project, are subject to list pricing which may be heavily discounted based predominantly on volume and the profile of projects on which it is used.

In this section we summarise the build-up of costs at list prices, then discuss the opportunities for discount.

Table 3 shows the cost build-up of External Wall Insulation systems including fixings and other ancillary items.

Table 3: EWI List Pricing

External Wall Insulation System			**Rendered**	**Brick Slips**
	Insulation (80-120mm)		£25.93/m^2	£25.93/m^2
	Standard & rapid set adhesive (30bags≡ 90m^2)	£42.90 / bag	£14.30/m^2	£28.60/m^2
	Mesh Coat (20 Bags) Primer Top Coat	£25.03 / bag £25.03 / bag	£ 5.56/m^2 £ 0.78/m^2 £ 6.70/m^2	
	Brick Slips Joint Mortar (30bags≡ 90m^2)	 £35.50 / bag		£53.77/m^2 £11.83/m^2
			£ 50.74/m^2	**£120.13/m^2**
EWI Ancillaries				
	Base Track	(averaged /m^2)	£ 5.87/m^2	£ 5.87/m^2
	Fixings - base-track @ £0.05 each + Clips - 120mm insulation @ £0.94 each	(averaged /m^2) (averaged /m^2)	£ 0.50/m^2 £12.50/m^2	£ 0.50/m^2 £12.50/m^2
	Others: Mesh / Beads / Sealing Taps	(averaged /m^2)	£ 2.50/m^2	£ 3.00/m^2
		Total Material	**£ 72.11/m^2**	**£141.00/m^2**
Benchmark Costs				
	RD9	80/m^2	£5,769	£11,281
	RD1 (rear elevation only = 65% of property)	66/m^2	£4,759	£9,307
	RD5	87/m^2	£6,274	£12,268
	RD27	90/m^2	£6,490	£12,691

This shows the cost challenge at list pricing where the rendered system materials account for over 60% of the Retrofit Approach target cost (£10,000) excluding labour, ventilation & draught-proofing, access & welfare, survey, overheads and profit. When brick slips are included the cost of materials alone is above the target cost for a 3-bed semi-detached house. This is in itself does not mean the target cost is ultimately unachievable just that the material costs have to be lowered though volume purchasing and the installation process adapted to reduce the installation programme length.

At scale suppliers are able to commit to significant discounts and, anecdotally from experienced installers, dramatic savings against the list price can be achieved as shown below. The 75% discount rate is suggested by installers working at mass scale on the CERT (Carbon Emissions Reduction Target) Programme which at its peak was accounting for 22,000 EWI interventions per year.

The retrofit of multiple hundreds of homes per year would encourage manufacturers to engage in the development of an improved supply chain and potentially working on a Design for Target Cost solution with designers, installers and logistics organisations.

Table 4: Discount levels for EWI

Benchmark Costs			Render Finish			Brick Slips		
			List	26%	75%	List	26%	75%
	Per square metre Cost		£72	£53	£18	£141	£104	**£35***
	RD9	$80/m^2$	£5,769	£4,269	£1,442	£11,281	£8,348	£2,820
	RD1	$66/m^2$	£4,759	£3,522	£1,190	£9,307	£6,887	£2,327
	RD5	$87/m^2$	£6,274	£4,643	£1,568	£12,268	£9,078	£3,067
	RD27	$90/m^2$	£6,490	£4,803	£1,623	£12,691	£9,391	£3,173

***Clay** brick slips (face cut from a standard clay brick) are currently in very short supply due to the high demand for bricks in the UK and unlikely to offer such substantial discounts. There may be potential in future. Alternatively synthetic slips have many cost and installation advantages including speed of installation, much reduced wastage of material compared to cutting clay bricks, reduced cost per slip over clay slips.

The target cost for rendered finish in the project plan was between £16.88/m^2 and £22.50/m^2. This shows that if the reported volume discounts of 75% are achievable, the target material cost is close to achievable on rendered systems.

For brick slips the cost uplift is almost 100% and there is an additional impact on installation time with current processes. There may be a market at this premium price (even with discount), but the brick slip finish really requires a step-change innovation with cost effective panels supplied with pre-applied slips.

It should be noted that the brick slips quoted above are clay slips. Acrylic slips or a rendered brick effect are cheaper alternatives but may not provide the same aesthetic quality as clay brick and may not be acceptable to customers if being proposed as a replacement finish for existing clay bricks.

EWI Material Opportunities

When pricing for EWI installers account for all building elevation area, irrespective of windows, this takes into account the specification requirement for ‘L-Shape’ insulation around all openings to avoid stress cracking of the external finish.

This leads to levels of high off-cuts and an 18%-23% material wastage of good product which cannot be used.

No piece smaller than 200mm x 200mm can be used and to achieve the ‘brick overlap’ requirement off-cuts smaller than 400mm x 200mm can rarely be used. Around kitchen and bathroom windows with drainage under as well as meter cupboards (as in the photo) there is a mental challenge to get as close as possible to achieving the specification. For speed installers also tend to reach for a new board rather than use off-cuts and / or ignore the requirements. Suppliers will recycle off-cuts but there is an additional charge for collection, even in bulk.

One supplier is looking at providing a photographic optimisation application for use on site. Other opportunities to improve material usage would be to supply some pre-cut 500mm x 500mm L-pieces for use around windows. Better still is on option to pre-cut an optimised façade.

Table 5: IWI System Cost

Internal Wall Insulation System				
	Phenolic Insulation with Plasterboard (90mm)		£24.74/m^2	
	IWI Ancillaries - Adhesive - Battening - Fixings - Mesh & bead (estd.) - Plaster skim (estd.)		£ 1.00/m^2 £ 0.20/m^2 £ 0.40/m^2 £ 0.50/m^2 £ 0.75/m^2	
		Total Material	**£ 27.59/m^2**	
		Render Finish	Discount	
		List	26%	75%*
	IWI System with Discount	**£27.59**	**£20.42**	**£6.90**
	* 75% Discount Levels have not been confirmed for IWI materials at volume			

For IWI it can be seen that the dominant material cost is in the plasterboard faced insulation board. Labour costs for fixing, plaster skim and painting are another important aspect. If a Tape and Jointed dry lining system in lieu of skim finish can be used there will be a significant improvement in time and cost. The Internal Wall Insulation system used on the project required both adhesive and mechanical fixings adding to the installation time and cost. Developing and proving a product that requires only one means to secure will be a significant advantage.

Ventilation & Heat Recovery Systems

The ventilation strategy for the Retrofit Approach is to use single room heat recovery fans in kitchens and bathrooms to minimise disruption that would be incurred installing whole house ventilation heat recovery, whilst giving a clear means of reducing wet-room humidity and condensation risk.

Single Room Heat Recovery products are still a niche purchase and as a result currently attract a higher price than might be expected from their product costing. Product performance and pricing have both improved during the course of this project but there should be scope to reduce to the target cost with volume based discounts as shown in the table below. List price reductions of 60% are achievable but there may be further potential in larger quantity, after discussion with the manufacturers.

Table 6: Ventilation Heat recovery unit costs

Single Room Ventilation Heat Recovery Benchmark Costs 2 required - kitchen & bathroom			BAU Cost: £250 each.			Target Cost: £125 each.		
			Timer Only			Humidistat		
			List	26%	60%	List	26%	60%
	Envirovent HeatSava					£275	£203.50	£110.00
	Vent Axia Low Carbon Tempra		£145			£220		

	Lunos e					£300		
	Manrose Vent Axia HR25		£250	£185.00	£100.00	£275	£203.50	£110.00

Chimney Treatment

Heat loss via air movement is controlled in chimneys using a Chimney Sheep as a plug, high in the flue at first floor ceiling level. This product is a good example of niche products becoming mainstream and the cost reducing dramatically as a result. At the outset of the project the 'new' Chimney Sheep product was for sale at £19. Now the same product is widely available for less than £13 as a wider market, consumer installable solution.

Table 7: Chimney insulation costs

Chimney Sheep Benchmark Costs	BAU Cost:	2 @ £19 = £38		Target Cost:	**£22.80**	
	List		26%		60%	
10" Round Chimney Sheep	2@ £12.50	**£25**	2@ £9.25	**£18.50**	2 @ £5.00	**£10**

5.3. Direct Labour

There is a wide range of day rates paid to individuals across the retrofit supply chain. Variability is based on region (London confirmed as being 20% higher cost than Midlands / North of England), type and professionalism of the supplying organisation.

The project team has identified some organisations effectively paying below the legal minimum wage. As a starting point for analysis we have taken the Living Wage[1] benchmark for labourers and researched market rates benchmarked with a trade database[2] for tradesmen and team leaders. This equates to:

o	Team Leader:	£19.23/hr,	£155/day,	£40,000/yr
o	Tradesman:	£10.57/hr,	£ 85/day,	£21,970/yr
o	Labourer:	£ 8.25/hr,	£ 66/day,	£18,495/yr

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[1] http://www.livingwage.org.uk/what-living-wage

[2] http://www.payscale.com/

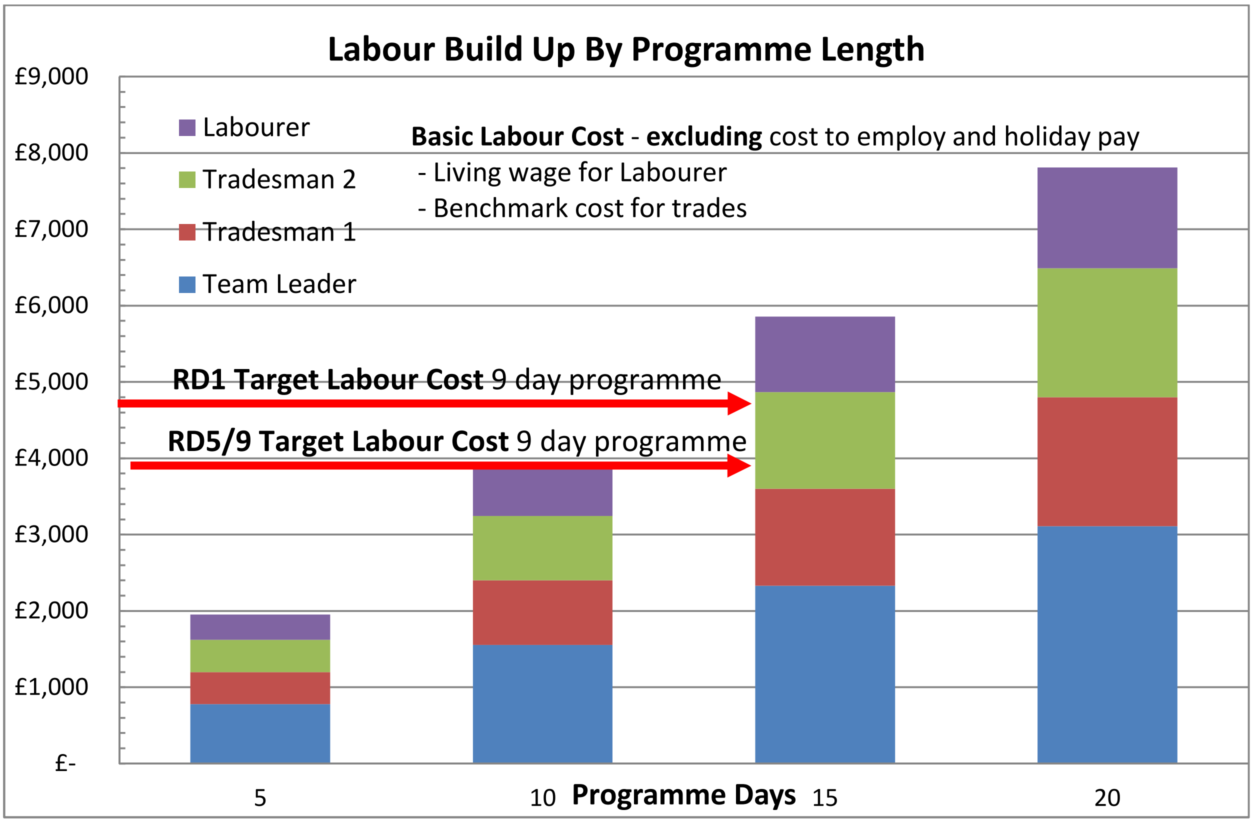


Figure 1: Poly-competent team Labour costs - Salary only

When the basic labour cost is presented it highlights the need to reduce the on-site delivery programme for the Retrofit Approach to the 9/10 day target if the overall target cost is to be achieved. The uncertainty/ variability of programme (RD9 24d / RD1 25d / RD5 41d / RD27 35d including snagging) shows the need for greater control of programme through a more industrialised process: Anything significantly above a 10d programme exceeds the target labour cost for all but the deeper RetroPlus^{TM} specification for RD27.

The RetroPlus^{TM} solution offers increased insulation levels, upgraded windows and even greater attention to detail on draught-proofing, air-tightness and moisture control. This extends the target programme by 50% to 15days for a typical mid-sized property.

Reviewing the programmes and 10day target with installation teams revealed their assessment of the potential to achieve a 10day programme for the Retrofit Approach.

- Rendered system: Achievable in 10 days with an experienced team provided:
  - No weather delay to render system application (rain and low temperature).
  - Site prepared with a correctly installed scaffold or alternative access provision.
  - Straightforward drainage relocation (Challenges on RD9 & RD1).
  - Improved eaves detail (to avoid thermal bridge) from an ease of installation perspective
  - No delays from existing building condition or additional works.
  - Continuous supply of material.

Render drying times (typically 24hrs depending on weather) present a challenge to the programme duration. To complete the work within the 10 working day period the basecoat render drying period needs to be:

  - During the middle weekend (challenging to get all boarding and basecoat in 5 days)
  - At a point where the full team can be usefully used on other works for a full day. This will require some very tight programming.

- Alternatively the works may cover 10 weekday days over 3 weeks to give a later weekend for render drying which may be possible if multiple homes are being undertaken by the installation company and the team can be used elsewhere e.g. Enabling works on next house in the programme.

Render cannot be applied when there is precipitation or cold temperatures (generally below 5ºC) and as such application in winter months is not possible and during the rest of the year is dependant on dry weather and such the risk of delay to the programme is high. Ideally EWI systems will be developed which eliminate the need for on-site curing time: a dry-fix panel or factory completed wet finish system with no weather dependency.

The previous chart shows basic labour cost based on regional hourly rate alone. Figure 2 incudes comparisons between:

- Basic pay
- Full employment cost (National Insurance, holiday pay, pension and other employers' costs)
- Main contractors costs (Subcontracted rates with' contractor's margin)
- Contrast across 2 regions (North England County and London).

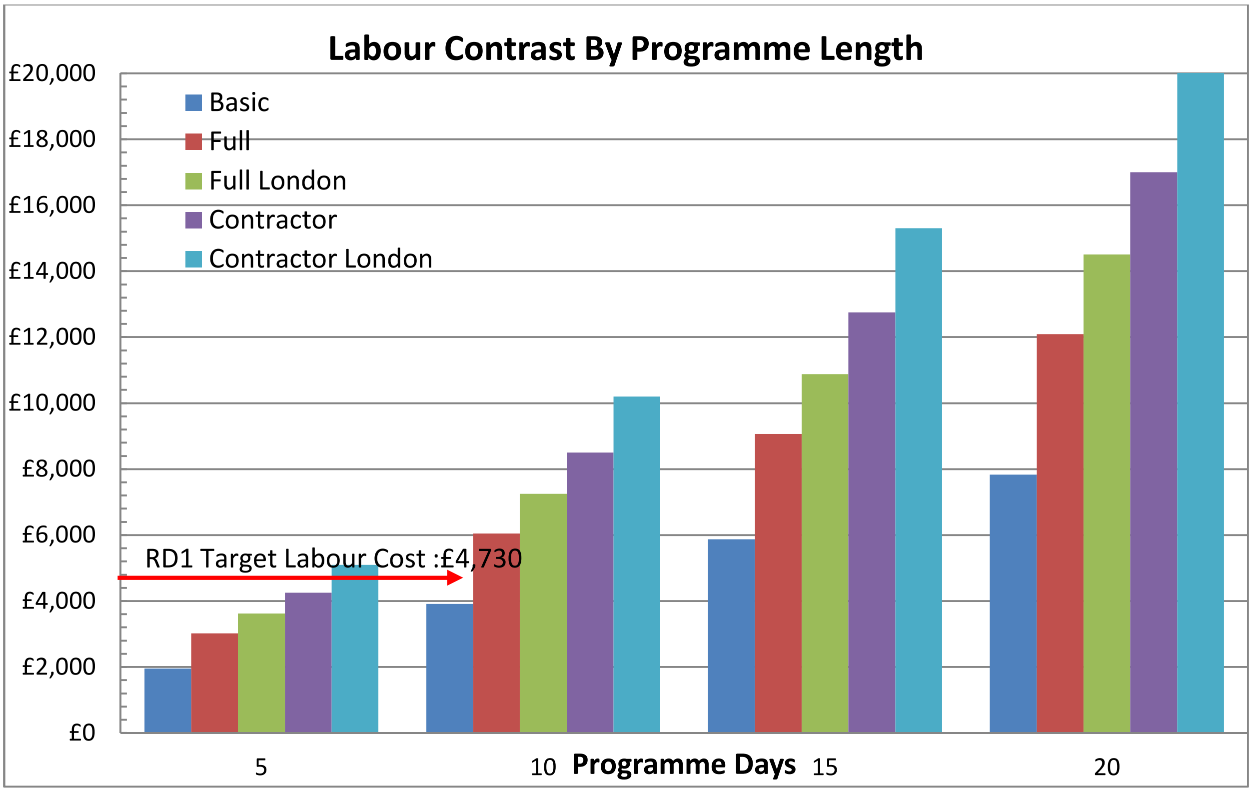


Figure 2: Poly-competent team Labour costs - Build up

Once the full costs of employment and regional variations are included the challenge to achieve the target labour cost is accentuated. Here it becomes clear that the Contractors' margin on labour is a block to cost effective delivery of the Retrofit Approach. Even with a directly employed model (full) a sustainably paid team is nearly 30% above target labour cost, more the 50% above for London for a 10-day installation programme.

To get within 5% of the £4,730 RD1 target cost would involve paying the team leader the same as the tradesmen (£22,000) or reducing all staff pro rata.

Table 8: Benchmark Labour Costs

Benchmark Labour Costs		Basic Pay			Day Rates			
		Hour	Day	Annual	Full Cost	London	Contr-actor	Lon Cont'r
	Team Leader	£19.43	£155	£40k	£243	£292	£290	£348
	Tradesman	£10.57	£85	£22k	£132	£158	£210	£252
	Labourer	£ 8.25	£66	£18.5k	£98	£118	£140	£168
	Full Team	**£48.81**	**£390**	**£88.5k**	**£604**	**£725**	**£850**	**£1,020**
	Contrast:							
	Gas Engineer	£13.22	£106	£27.5k	£165	£199	£280	£336
	Electrician	£11.74	£94	£24.4k	£146	£175	£250	£300

Assuming the Labour costs above are the lowest sustainable only two alternatives for getting closer to the target cost can be identified:

- Pro-rata reduction in material cost.
- Step change in installation time: Eliminating the wet-trade render with a dry fix panelised system. Reducing to a one week programme would allow for an additional £1,000 spend on materials offset by the labour reduction. Such a five day programme would be a considerable step forward, both technically and for the consumer proposition.

5.4. Survey, Design and Overhead Costs

5.4.1. Survey, Design & Quality Assurance

Three options for survey and design have been developed and costed (based on a repeated and refined process):

- **Option 1: BAU** (thermal bridging not considered)
    - Basic measured and visual survey – 0.25 day
    - Draw up existing plans and elevations – 0.75 day (if planning application required)
    - Produce proposed plans and elevations – 0.5 days (if planning application required)

  Total 1.5 days = £450.00 (assumes lower skill requirements and therefore lower day rate)

- **Option 2: Full Retrofit Approach** (current with thermal bridging considered)
    - Enhanced basic measured and visual survey – 0.5 day
    - Draw up existing plans and elevations – 0.75 day
    - Design time including specification and material selection – 1 day
    - Submit Planning or Lawful Development application – 0.25
    - Produce proposed plans and elevations – 0.5 days
    - Production of junction/thermal bridging/finishing details – 2 days

  Total 5.0 days = £2,500.00 (assumes greater skill requirements and therefore higher day rate) This figure could be reduced through repetition of homes and reuse of the thermal bridging details

- **Option 3: Streamlined Retrofit Approach** (potential future model – requires new survey app and new same day online planning/lawful development application)
    - Photogrammetry survey – 0.35 day
    - Specification and material selection using photogrammetry app – 0.25 day

- o Submit online Planning or Lawful Development application – 0.15 day
- o Production of bespoke junction/thermal bridging/finishing details – 1 day (assumes common thermal bridging details become industry standard)

Total 1.75 days = £875.00 (at higher skilled day rate)

For costing purposes **Option 3** has been used for the Revised Retrofit Approach as a thorough, but not cost prohibitive, assessment and costing of the Retrofit packages.

5.4.2. Overhead

- **Scaffolding & Access**
  As material cost and programme improvements are made, the cost of scaffolding installation becomes relatively more significant. Work at two of the four properties was delayed starting as a result of unavailable scaffolding installation crews. Scaffold erection took 2 days for all properties bar RD1 where the team worked sporadically over the first two days and as a result completed on the third day.

  It can be seen from the following table that the contractor's requirement for design scaffold adds significantly to the access cost.

Table 9: Scaffold Costs

	Description	Base	Additions	Design / Drawing	Total	Detail
RD9	Design scaffold & wrap	£1,748	£1,678	£420.00	£ 3,846	Additional calcs drawings & inspection. Build error.
	Winter scaffold with Monoflex wind-screen. Also required additional wind bracing and massive weights for stabilisation.					
RD1	Design scaffold	£2,668	£1,146	£275	£ 4,089	Rear elevation only. Includes chimney access. Not built to design dwg.
RD5	Design Scaffold	£2,898	£4,332	£670	£ 7,900	Minor modifications on site. [Extra for duration]
RD27	Complex bridge scaffold local design	£2,500	N/A	N/A	£ 2,500	Practical solution rapid erection. Good value.
Other	Contrast: Local design without chimney access	£1,275	Included	N/A	£ 1,475	All safety equipment & certification included.
	Minimal EWI solution	£ 890*	Included	N/A	£ 890	All safety equipment & certification included.

The winter scaffold with weather shielding for RD9 was not wholly successful to protect the workface, but the cost is comparable with RD1 and RD5 where chimney works were required. The directly procured RD27 cost was at least as complex as any other solution with a bridge across the property from front to rear. It did not have to be a designed scaffold and it demonstrates good value. The contrast with other EWI projects using traditional scaffold (without chimney access) shows that considerable saving can be made by keeping heights low. The *£890 cost is a fixed price per property based on semi-detached properties being insulated on a localised rolling programme. The minimal EWI Solution in larger quantity (£890) is used in the cost evaluation which follows for all properties except RD27 where the nature of the property requires a complex design (£2,500).

- **Welfare Van**
  Despite revised regulations for site welfare facilities contractors had little experience of using team welfare vans: As a result prices quoted were higher than market rates and so were a significant cost burden on the extended programme.
  - RD9: £700/wk – cleaning as extra cost @ £50/wk
  - RD1: £700/wk – including cleaning
  - RD5: £ - Longer term negotiated rental details not shared
  - RD27:£600/wk including cleaning
  - Purchased vehicle cost £223/wk
    (Based on £28,000 purchase, £1,200/yr insurance, £100/wk cleaning & maintenance, £13,000 residual 3yrs)

- **Other Plant**
  Other plant hired during the demonstration project included a petrol generator, but generally tenants preferred to offer the use of electrical supply to avoid the noise of the generator (unless access could not be given). Costs quoted by contractors were higher than anticipated; likely to include significant mark-up on price paid. No hire costs were included in the initial project pricing.
- **Site Management**
  For RD9 and RD1 the site team leader took the role of external co-ordinator and on-site contact point with limited hands-on work. With the learning curve of new techniques and supply challenges this addition was necessary to keep the programme progressing. Once the solution details and processes are stabilised the role could be as a hands-on team leader (as achieved on RD5 – but at some expense of productivity with supply & design distractions). Full costs for prelims are **£1,400/week** which should include site management, welfare van, plant hire & waste removal.
  For the RD27 contractor the site supervision quoted cost was £11,000 **(£2,750/week**), 50% more than the cost of the poly-competent team and double the prelims for the National Contractor. The individual was neither a working team leader nor fully successful as material supply co-ordinator or for quality assurance. With an experienced team and standard process this supervision could be spread over multiple sites, or a more productive poly-competent team leader as per the Retrofit Approach. For the cost review in Section 0 we assume a 15% mark-up on material and overhead which is between £700 and £900/week as a minimal cost.

- **Waste Management**
  Site waste collection was variable by site. For the national contractor led properties a specialist collection was made once (or occasionally twice) per week. To minimise disruption, particularly on the constrained RD1 site, waste removal should have occurred daily – preferably removal in the welfare van but difficult with dusty and wet waste without consideration of containment of waste. The National Contractor's waste removal costs are covered in the prelims.

  For RD27, waste was removed approximately weekly and the total cost was set at £200. As with the other sites more regular removal would have improved the resident experience. Specialist window contractors were used for the RetroPlus^{TM} triple glazing and they removed all waste from site on the day as they worked in their own van – a much better solution.

- **Insurance, Administration & Profit**
  For the National Contractor these costs are set at 6.5% of project costs. At budget cost this was £1,500 for RD5, but in the final account £8,641 as a result of the project technical challenges. Where a contractor receives increased profit for project over-run, additional work or delay, there is an incentive to look for additional work. A fixed, but appropriate, profit would incentivise a focus on short programmes whilst keeping costs to a minimum. For RD27 the costs were a fixed £2,000 which equates to 4.6% of the total cost for the works to this house.

5.4.3. Risk

Management of risk is significant learning point from the four demonstration properties. Despite a disproportionate amount of time spent planning, detailing and optimising the works only the RD27 programme, as a modern property, was not notably affected by problems with its condition. At RD5 the process of inserting insulation fixings into the external walls of the house from the outside through the insulation boards, caused the external bricks to be pushed into the cavity as the mortar was not strong enough to bond the bricks together while resisting the force from the driving in of the fixings. The mortar had previously been repointed but to a substandard depth which could not have been identified via a visual survey. The interpretation of permitted development rights relating to EWI in planning policy is a risk that must be considered, some local authorities have requested full planning applications for EWI even where the proposed materials are the same as existing and should be allowed under permitted development. One local authority would not allow a change from a bricks finish to render even though other houses in the street had render. It is also unlikely that homes in Conservation Areas can have EWI installed, certainly at the front of the house, and often these home types have small internal rooms due to the period in which they were built and installing IWI would reduce the room size to potentially unacceptable levels.

- **Uncertainty – Building Condition**
  Building condition was identified as a key driver of risk and unexpected cost at the conception of the project. The expectation was that older properties would have increased risk and so pricing should include greater contingency.

  - **RD9** (major items only)

Damp-proof course reinstatement	£ 680
Renew fascias and soffits	£ 242
Bathroom internal pipework& ceiling	£ 383
Replace original Soil/Vent Pipe	£ 264
Other (garden & roof)	£ 128
	Total: £ 1,728

  - **RD1** (major items only)

Dri-zone chemical wall damp-proofing	£ 951
Repair roof tiles, chimney pots and eaves	£ 836
Cast iron drainage & plumbing replacement	£ 521
Asbestos removal	£ 500
Break paving to prevent damp	£ 372
Porch wall repair	£ 330
Structural inspection	£ 316
Additional insulation (loft undetected at survey)	£ 213
Repair stone sills	£ 191
Fence repair (not additional)	£ 177
Cellar access for insulation (corrugated sheet)	£ 150
Hidden chimney-breast void (insulate & decorate)	£ 106
Other kitchen and bathroom renewal	£ 82
	Total: £ 4,245

  - **RD5**

Remedial work for failing wall construction	£ 15,088*
Additional scaffold duration	£ 4,800*
Dri-zone chemical wall damp-proofing	£ 1,902
Other damp-proof works	£ 1,143
Fascias, soffits & guttering replacement	£ 1,250
Chimney & roof tile works	£ 575
Bathroom, kitchen and drainage pipework	£ 350
	Total: £ 25,108

* RD5 remedial works for the walls should have been identified either at survey stage through an enhanced EWI survey or early in EWI installation. Had this been the case the building condition costs could have been reduced to approximately £5,000 for repointing or affixing EML mesh at the outset.

  - **RD27**
    None raised from this late 1980s property.

- **Disputed Costs**
  In addition to agreed changes in scope there is potential for claims of increased costs which were contested in the final reckoning.

  - **RD9**

Works considered 'in scope' of fixed price contract	£ 6,958	
Excessive charges for time	£ 1,774	
Items unclear on specification (internal insulation)	£ 717	
Items claimed with no evidence of completion	£ 265	
Total:	**£ 9,714**	(≈50% renegotiated)

  - **RD1**

Additional EWI costs above quoted	£ 7,934	
Furniture removal cleaning etc. – excessive cost	£ 2,425	
Chimney access & works (part of scope)	£ 1,571	
Items claimed with no evidence of completion	£ 746	
Plumbing works 'in scope' of fixed price contract	£ 626	
Insulation works expected in contract	£ 414	
Total:	**£ 13,716**	(≈50% renegotiated)

  - **RD5**

Additional charge for brick slips above contract	£ 26,680*	
Works considered 'in scope' of fixed price contract	£ 1,221	
Excessive charges for time	£ 1,100	
Items claimed with no evidence of completion	£ 150	
Total:	**£ 29,151**	(≈50% renegotiated)

    *The poor quality and errors of the initial EWI specialists within the poly-competent team led to the replacement of the team on the rework and completion of EWI. However the contractor was only willing to do so on a day rate basis – over and above the original contract sum. Quality of finished works was high, but the costs disproportionate (hence in the disputed category rather than building condition).

  - **RD27**
    None.
    Some errors on installation (leading to rework) were covered by the contractor from within their contingency and profit. No claims made.

The range and level of the claims for additional cost (due to condition and disputed) are both notable; with the finally agreed total cost for three of the properties being more than double the budget. This level of uncertainty is intolerable to any prospective retrofit market and property owners will not invest on this basis. There are multiple underlying reasons for this underperformance although the balance of weight between them is uncertain.

- Incapable assessment of building condition: With a fully detailed and costly survey more of the potential condition issues could be identified: The RD5 wall collapse in particular. This is the dominant condition impact accounting for more than £31,000 of additional costs, but the impact could have been avoided with improved installation process capability.
- Operator capability & engagement: A marked difference in attitude and capability between team members. Had the insulation on RD5 been installed with more care (sharper drills, screw rather than hammer fixings) the wall failure would not have occurred and the EWI would have added to the strength of walls which had already survived 60 years.
- Contracting model and behaviour: The fixed price contract chosen passes risk on to the contractor and, when problems occur, the reaction is often to try and identify mechanisms for reclaiming cost as a variation.
- Weather conditions & programme pressure: With projects underway in December, February and November weather delays are almost certain. When teams are paid by the results, not time on the job there is frustration and a temptation to cut corners.

Rather than a knee-jerk reaction to add cost with more detailed survey and tighter contracting the project team proposes a more collaborative approach with shared risk and a common goal to make retrofit more productive across the value chain.

5.4.4. Additional Works

In addition to unplanned costs there is an opportunity for discretionary work to be added at the request of the property owner. For the social tenure properties there was also an influence from the tenant requesting improvements; perhaps granted by the landlord as 'compensation' for programme delay and disruption in some cases. This cost data is useful for identifying the opportunity for 'upsell' of services during the works – or as offerings to include as options at the outset.

- **RD9**

Removable window reveals	£ 391
Bathroom improvement	£ 348
Loft clearance (initial claim £960)	£ 300
Furniture moving (initial claim £1,100)	£ 250
Garden clearance & fence repair	£ 131
Clean gutters	£ 100
External tap extension for EWI	£ 75
Porch improvements	£ 73
	Total: £ 1,667

- **RD1**

Built in wardrobes/shelving units x2 supply & fix	£ 2,625
Additional Box gutter	£ 528
Internal works & protection (skirting, pipe lagging)	£ 315
Fencing additions	£ 287
Remove gas fire and replace fire surround	£ 237
New window	£ 182
Renew 5 electrical sockets	£ 132
Additional internal door locks & other hardware	£ 59
Additional moisture sensors	£ 160
	Total: £ 4,525

- **RD5**

New doors	£ 1,950
Additional eaves insulation detail (should be in scope)	£ 840
Tenant requests external light & fencing	£ 481
Chimney extras	£ 405
Electrical	£ 362
Gas fire removal	£ 179
Addition to gullies	£ 175
Internal repair to poorly fitted windows	£ 145
	Total: £ 4,537

- **RD27**

Second access door to garage	**Total: £ 583**

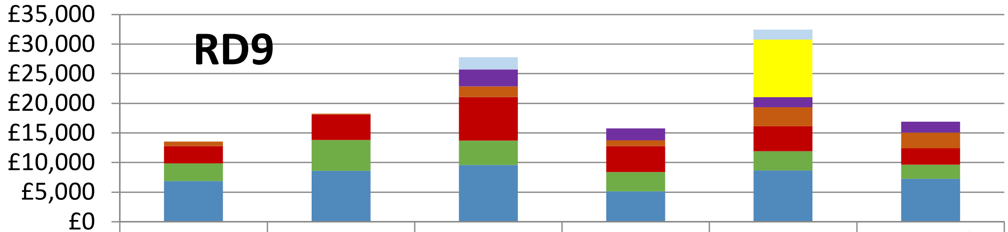
5.5. Final Installation Cost Report

This section considers comparison of the following costs:

- Costs developed in the ETI's Optimising Thermal Efficiency of Existing Homes (OTEoEH) project
- Business As Usual (BAU) Costs – contrasted with 2014/15 traditional EWI projects.
- Stage Gate 1 Quoted Project Costs by the National Contractor
- Actual costs RD9, RD1 & RD5 (London weighting) by the National Contractor
  Actual Costs RD27 by the Regional Contractor
- Retrofit Approach Original Expected Cost
- Retrofit Approach Revised Expected Cost – Future forecast.

In the following graphs, additional works covers one-off project costs and also client requested additional specification. Disputed costs are the value of the contractual disagreements described in section 5.4.3 above. Condition contingency is the estimated / actual costs for unexpected additional costs arising from deteriorated buildings; with older properties having higher estimated values.

5.5.1. RD9 - 1919-1944 Semi-Detached

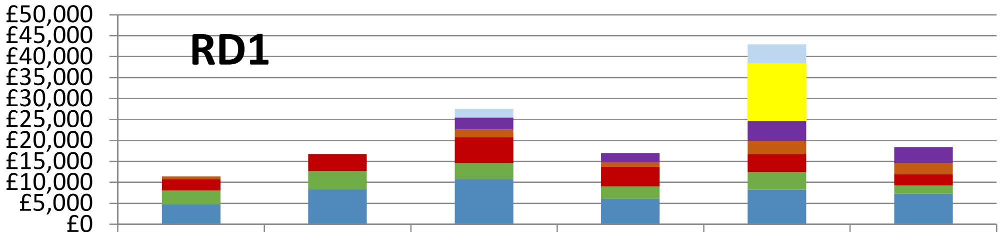


	OTEoEH	BAU	National Contractor	Retrofit Approach	Out-Turn	Revised Retrofit Approach
⬜ Additional Works		-	2,087	-	1,667	-
🟨 Disputed		-	-	-	9,713	-
🟪 Condition Contingency		-	2,841	2,000	1,728	1,875
🟧 O/H & P	740	125	1,820	1,000	3,214	2,625
🟥 Prelims	2,961	4,309	7,346	4,406	4,200	2,781
🟩 Material	2,976	5,189	4,129	3,220	3,243	2,382
🟦 Labour	6,871	8,611	9,590	5,161	8,688	7,253
Total	13,549	18,234	27,812	15,787	32,453	16,917

Key points from RD9 costs:

- Condition related costs were below those estimated and this has been reflected in the Revised Retrofit Approach.
- Significant disputed costs as discussed in 5.4.3 this is likely to be a result of the contractor looking to recover R&D costs associated with the works (this also applies to RD1 & RD5).
- The original Retrofit Approach labour cost was overly optimistic based on low team costs (non-London & minimum wage rates).
  Achieving the £5,161 target cost would require a 7-day programme. (8.5 outside London)
- Material and scaffold costs for Revised Retrofit Approach require significant scale and a rolling programme to achieve heavily discounted pricing.
- Revised Retrofit Approach expected costs for a straightforward semi-detached property are 70% above the £10,000 goal in London. 55% above in North England county and other regions.
- Further cost reductions would require a step change in programme to 1 week, or greatly reduced scaffold, welfare van and material costs.

5.5.2. RD1 - Pre-1919 Mid-terrace

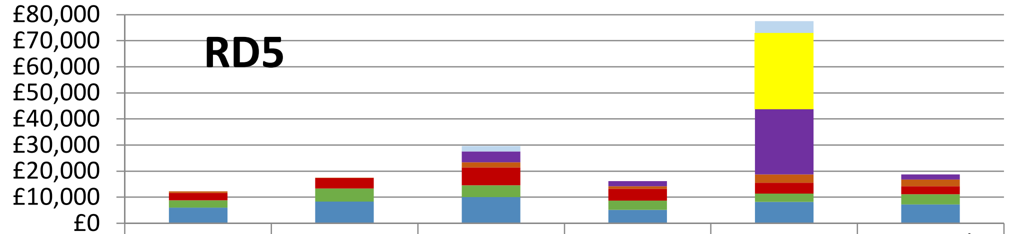


	OTEoEH	BAU	National Contractor	Retrofit Approach	Out-Turn	Revised Retrofit Approach
🟦 Additional Works		-	2,087	-	4,527	-
🟨 Disputed		-		-	13,717	-
🟪 Condition Contingency		-	2,927	2,200	4,744	3,750
🟧 O/H & P	671	125	1,804	1,063	3,241	2,625
🟥 Prelims	2,683	3,923	6,172	4,713	4,200	2,722
🟩 Material	3,242	4,365	3,822	2,933	4,205	1,983
🟦 Labour	4,772	8,366	10,763	6,081	8,273	7,253
Total	11,368	16,779	27,574	16,989	42,907	18,333

Key points from RD1 costs:

- Condition related costs were above those estimated; with the Dri-zone damp-proof injection being the most significant cost (20%). Many items relate to the older building fabric of a pre-1919 property. The increased condition contingency arising from these accounts for the difference between the Original and Revised Retrofit Approach costs.
- Significant claims for furniture removal, cleaning and protection of carpets etc., although disputed need to be considered carefully for properties with significant internal work. Claims were not linked to the weather related programme delay, but this will have had some impact.
- Additional works costs were also high – this may, in part, be a result of the landlord offering improvements to offset the tenants ‘fatigue’ from an extended programme.
- Revised material costs are very low based on a low square meterage for a terraced property and a rendered / IWI solution rather than brick slips.
- Total Revised Retrofit Approach costs of £18,300 are 83% above the goal. Costs could reduce to £17,000 outside London.

5.5.3. RD5 - 1945-1964 Semi-Detached

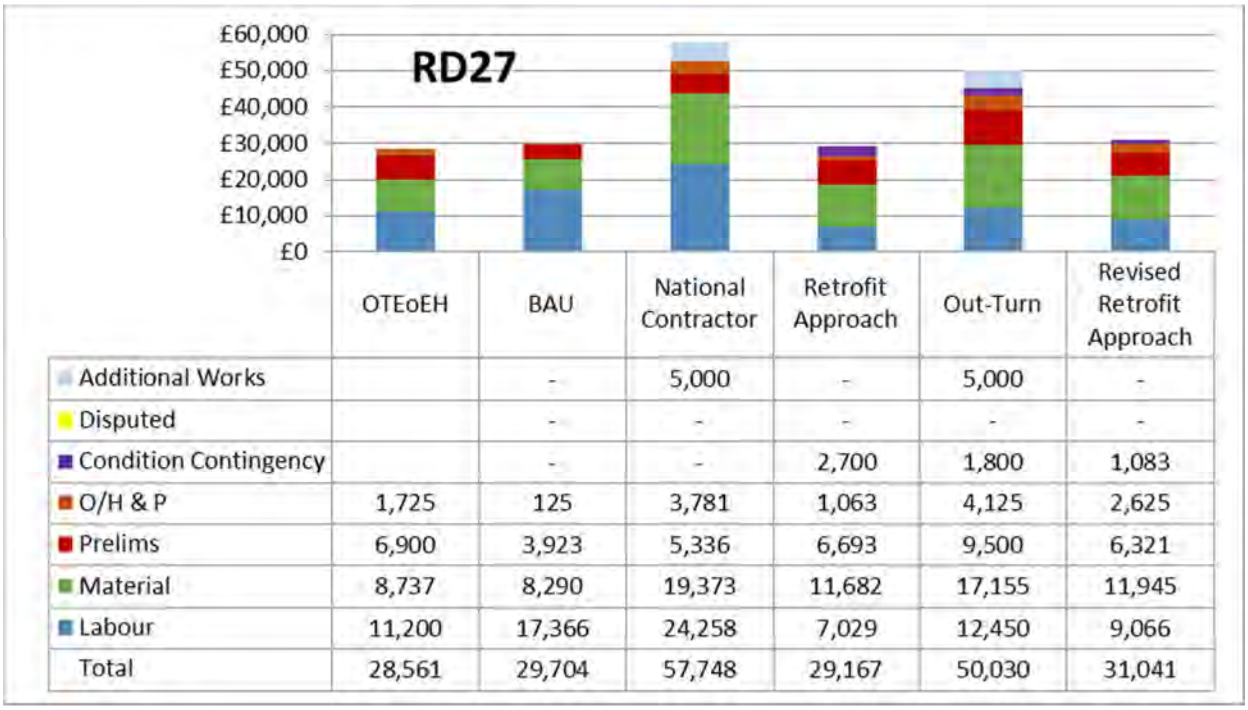


	OTEoEH	BAU	National Contractor	Retrofit Approach	Out-Turn	Revised Retrofit Approach
🟦 Additional Works		-	2,087	-	4,537	-
🟨 Disputed		-	-	-	29,151	-
🟪 Condition Contingency		-	4,152	2,000	25,109	1,875
🟧 O/H & P	682.84	125	1,940	1,000	3,174	2,625
🟥 Prelims	2,731.36	3,923	6,902	4,460	4,200	3,013
🟩 Material	2,871	5,040	4,579	3,609	3,124	3,925
🟦 Labour	6,001	8,366	9,993	5,135	8,237	7,253
Total	12,286	17,454	29,653	16,204	77,532	18,691

Key points from RD5 costs:

- Out-turn costs dominated by the rectification of weak walls which were at risk of collapse. Had the problem been spotted earlier, the condition costs could have been limited to £5,000.
- Brick slip application costs of £26,000 disputed as heavily inflated by day rate charging. The quality of work was high but only at half the rate of slips applied and grouting completed per man per day compared to the RD27 experienced team.
- Retrofit Approach Revised labour costs are based on an achievable 10 day programme and London rate vs. previous version. Outside London project labour costs reduce by £1,200.
- Total Retrofit Approach Revised costs of £18,700 are 87% above goal, but may reduce to £17,300 outside London.

5.5.4. RD27 - 1980's Semi-Detached



	OTEoEH	BAU	National Contractor	Retrofit Approach	Out-Turn	Revised Retrofit Approach
■ Additional Works		-	5,000	-	5,000	-
■ Disputed		-	-	-	-	-
■ Condition Contingency		-	-	2,700	1,800	1,083
■ O/H & P	1,725	125	3,781	1,063	4,125	2,625
■ Prelims	6,900	3,923	5,336	6,693	9,500	6,321
■ Material	8,737	8,290	19,373	11,682	17,155	11,945
■ Labour	11,200	17,366	24,258	7,029	12,450	9,066
Total	28,561	29,704	57,748	29,167	50,030	31,041

Key points from RD27 costs:

- The Regional Contractor's out-turn costs are 14% below the National Contractor's budget based on like for like additional costs for project specific site management.
- Significant saving on EWI labour via specialist contractor, despite inflated costs for specialist Electrical and Gas tradesmen.
- Labour increased by 20% London weighting would still be £4,500 or 23% below the National Contractor's estimate.
- Triple glazing costs reduced by 45% from budget pricing as products become mainstream and without the main contractors' margin (material costs also include window fitting labour).
- No disputed costs – contingency included and EWI and brick slip application much faster than previously seen on RD5 but without compromising quality.
- Retrofit Approach Revised material costs require a further reduction in glazing costs.
- Retrofit Approach Revised labour costs set based on an achievable 15 day programme and regional rate vs. previous version. For London labour costs increase by £1,800.
- Total Retrofit Approach Revised costs of £31,000 are 50% above RetroPlus^{TM} goal of £20,000.

5.6. Target Cost Summary

Reviewing the four properties and exploring the options for material and labour it is apparent that the original **Target Cost** of £10,000 per property offering is beyond the capability of the current cost base and product and process improvements identified by the project team and suppliers.

With a regional installation (lower labour cost) and the most straightforward (3 bed-.semi with rendered finish) and elimination of **all** contingency for building condition; the lowest cost currently envisaged is:

- **£13,600** for a property similar to **RD9** with 95m^2 of external wall**.**

Based on the current cost model the **£10,000** target could be achieved for:

- A mid-20th century terraced property with 65m^2 of rendered EWI, a 6 day programme and no contingency for condition.

Cost sensitivity and Opportunities for Retrofit:

- **Labour**
  The labour costs used in the above analysis are based on
  - Living Wage level for the poly-competent team labourer @ £17,000/yr; £20,000/yr in London
  - Tradesmen earning median trade wages @ £22,000/yr, £26,000/yr in London.
  - Team Leader earning £40,000/ year, £48,500 in London.

  There may be opportunities to keep salaries pegged below these levels, but as seen during the demonstration projects the quality of the team and their level of engagement makes a significant impact on the quality of work and the overall project.
  Total costs have been linked to duration of the works measured in full weeks of 5 days. This sets a challenging target for **RetroFix**TM in 10 days, particularly when brick slips are specified
  For **RetroPlus**TM this is a more easily achievable 15 day target (where triple glazed windows are installed by specialists) and the additional time is focused on improving airtightness and thermal bridging details.

- **Materials**
  Cost reductions for materials based on high volumes have not been confirmed formally by manufacturers, but have been cross referenced with contractors working on major programmes.
  In addition to the discount rates an emphasis needs to be put on material optimisation (EWI insulation) to reduce off-cut waste and improved logistics to optimise delivery.
  For newer products (e.g. Single room heat recovery fans) there is potential to industrialise manufacturing further to achieve a lower target prices.
  Brick slip costs on RD5 or RD9 add over £1,800 (10% of total cost) and this is only possible if they are installed faster than current best practice; using as little site labour as rendered systems.
  Materials which can enable step change programme reduction to achieve a 1 week (5-6day) programme will make a significant impact on cost and the **RetroFix**TM proposition.

- **Site Management and Prelims**
  The key elements of this category are:
  - Scaffolding / access platforms for which the project team have not found a viable alternative, but which would improve the proposition if it were included in the team.
  - Welfare van which assumes a single van per team. It may be possible for 2 teams to share such a van for rolling programmes in a locality. This would have a positive impact on cost.
  - Management of the works is set at 15% of labour and material cost to cover back-office costs.

- **Overhead and Profit**
  The only areas of overhead covered in this this category are:
  - Fixed fee design solution at only £250.
  - A Retrofit Approach detailed survey at £875
  - Costs for planning / building control set at £750

  Profit is set at a fixed level of £750 to encourage rapid installation programmes.
  These costs are set low with very little corporate overhead or contingency.

- **Condition Contingency**
  The building owner needs to be aware of the variability of works costs based on age and condition and should also have a stake in the risk – unless they are willing to accept pricing where the risk is fully added to the installers pricing.
  The Project Team’s proposal remains to split the contingency risk 33% for the client, 67% for the installer: The logic being that this incentivises the installer to minimise costs whilst enabling them to recover some overspend from the client – to reduce the risk of ‘hiding’ underlying defects.
  Both elements are included in the graphs above and so the offered **RetroFix**TM price would be the total less 1/3 of the contingency.

- **Disputed Costs**
  The level of disputed costs came as a surprise and disappointment to the project team. Whilst there were certainly grounds for additional costs in many areas, the value of claim was at odds with the intent at the outset.

The disputed costs accounted for 25% of the total costs across three properties and in the end the agreement was reached with a 12.5% reduction still leaving out-turn costs more than double the budget.

Although an R&D project, in which all parties could have improved performance, there is a clear sense that if the contracting team put as much effort into mitigating costs as they put into claiming additional cost, the end result would have been better for all concerned.

Whilst alternative commercial models discussed in this report should minimise the risk of disputed cost; the experience on this project demonstrates the need for very clear expectations of performance and clarity of instructions to installers.

- **Additional Works**
  Additional works can be seen as an opportunity for installers to up-sell from the core retrofit products. Additional works that can be done cost-effectively whilst the team is on-site may be an opportunity for additional revenue and good levels of margin. Some may be related to the works:
  - Replacing fascias and soffits to improve aesthetic
  - Adding security lighting, hanging baskets, satellite dishes etc.
  - Upgrading doors and windows.

  These and similar items may be part of an extras menu at the time of planning the retrofit. Broader internal / external construction work is unlikely to be linked but if the team demonstrate capability and are trusted by the end clients the model could be stretched to include:
  - Kitchen & Bathroom replacement
  - Loft conversions
  - Extensions
  - Landscaping

6. Co-Benefits

This section summarises the benefits to the householder and landlord beyond the energy saving objectives of the retrofit works. The three subsections are:

- Impact on property value
- Spin-off benefits: Valued improvements as part of the works without additional cost.
- Additional Cost Benefits: Opportunities to upgrade at lower cost than if completed in isolation.

Property Value:

The uplift in market value as a result of retrofit additions has been determined by the project real estate subcontractor to be nil and attributed to the lack of market experience in valuing retrofit homes although this is expected to change with increased volume of retrofit projects. Properties are valued based on local precedent at the time and in a period previous to the valuation, based on what purchasers have paid for similar properties. Where there are no local retrofitted homes to act as a precedent then surveyors may look to other UK regions for precedents or to published research. There is very little evidence of how house values are affected by retrofit and as such surveyors are not willing it seems to reflect that retrofit work has been undertaken in a valuation. The retrofit should improve the overall look of the house, reduce future expenditure on maintenance, minimise energy bills, improve indoor air quality and comfort as well as offer other benefits, all of which should increase the house's value. Further work needs to be undertaken outside this project to establish how real estate agents can value retrofit work and what will enable buyers to understand the benefits and how they relate to an increased purchase price.

The Spin-off and Additional Cost Benefits demonstrate a broad range of improvements for the building owner and the householder. This gives additional weight to the value proposition for both landlords and owner occupiers.

6.1. Spin-off benefits

Spin off benefits are improvements above the intended energy saving, which arise from the RetroFix^{TM} or RetroPlus^{TM} works without additional cost. The items listed below have been either suggested by, or confirmed by the householders of the four demonstration properties as benefits of the completed work on their house.

It would be desirable to have an assessment of value of these benefits, but householders found putting a cash value on them very difficult and said that despite the benefit; in most instances they wouldn't have spent any money on the spin-off improvements unless the timing was precisely right. The figures added here are therefore purely estimates of the lowest cost to have similar tasks completed in isolation.

The following spin-off benefits can be considerable in terms of both monetary and quality of life value. However, the challenge is to identify who will pay for that value. More wealthy householders can and will pay as part of an aesthetic and value adding (to property) project.

Health & wellbeing:

The health implications of not addressing condensation and air quality issues could be significant; the level of risk is dependent of the current health of the householders. Any cost impact assessment would therefore be entirely speculative on behalf of the project team and so no values have been used here.

- Internal surface condensation reduction
- Internal mould minimisation
- Improved indoor air quality
- Comfort improvement – draft sealing and higher internal temperatures achieved in cold weather.

Aesthetics

IWI – opportunity to refresh/update wall colours	to decorate 2 rooms	£300
EWI – improve external appearance	paint external render	£900
EWI to rear – improve rear courtyard/garden, appears lighter and more welcoming	paint rear brickwork	£500
EWI – remove redundant cabling/aerials on façade		£50

Preventative maintenance

EWI at eaves level – gutter clean out	£75
Boiler flues checked and maintained	£50
Re-Secured external goods: Hanging baskets, lighting, porch, etc.	£50
Kitchen and bathroom drainage maintenance	£50
Window seal & lock checks / maintenance	£50

Other improvements

Clear loft of possessions/redundant water tank (with loft insulation)	£50
Easier access loft hatch	£50
Windows/doors – improved security (RetroPlus™)	£50/ window
'Amazing' reduction in noise transfer - Triple Glazing (RetroPlus™)	No alternative approach
Increased window sill space (EWI - RetroPlus™ & IWI - RetroFix™)	No alternative approach

6.2. Additional cost co-benefits

Co-benefits which arise, but with additional cost, may be delivered more cost-effectively as part of the retrofit works. Those items which require scaffold or other roof access are particularly beneficial as the cost of access is already included. Small electrical or plumbing tasks can also be added at marginal cost when scheduled with the works – whereas the call-out or minimum charge for a tradesman may be prohibitive. The valuation assessments here are an indication of the saving vs. the cost in isolation.

Preventative maintenance and repairs:

EWI – opportunity to service boiler when flue extended	50%		£50
Roof insulation – install new roof covering	Dependent on area but	50%	
Asbestos removal/sealed	Marginal saving		
Drainage cleaning / repairs	Rodding / cleaning	50%	£40
Chemical Damp-Proof (expensive)	Marginal saving if any		

Valued Additions

Renewed fascia/soffits/rainwater goods with EWI	50% reduction from scaffold	£800
Cooker hood with heat recovery	(requires new products)	
External lighting – particularly PIR security	30% reduction from scaffold	£75
New, relocated or upgraded satellite dish	(supplier may not offer saving)	
Additional or relocated TV / broadband entry points	(supplier may not offer saving)	
Install more or relocate electrical sockets with IWI		
Thermostatic radiator valves	Marginal saving unless system drained.	
Loft boarding for additional storage	25% reduction with insulation	£30
Laundry drying area in bathroom (to prevent moisture build up elsewhere)		
Upgraded storage / wardrobes (particularly with IWI)	30% reduction with installation	£100
Tidied / landscaped garden (if neglected as experienced on 3 of 4 properties)	Marginal cost benefit	
Carpet replacement (Particularly IWI)	Marginal cost benefit	
External gravel / paving	30% saving dependent on area	

Significant Home Improvements

New kitchen and bathroom linked to IWI	5-10% saving	£250
New window/doors	Marginal cost benefit	
Internal layout alterations	Marginal cost benefit	
Extension to home	Marginal cost benefit (£10,000+ niche)	
Renewable energy system install	Net saving adapting scaffold	£700
Loft conversion	Net saving adapting scaffold	£700
Light pipe installed through roof	Net saving adapting scaffold	£700

Electrical Upgrade

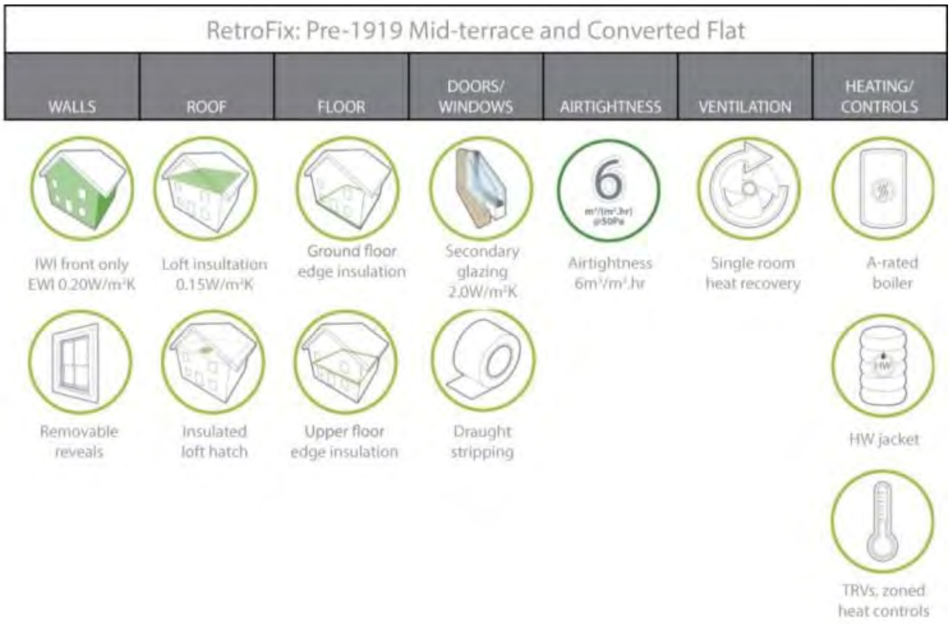
New consumer unit to replace old fuse box	Marginal cost benefit	
Rewire	Marginal cost benefit unless full IWI	
Smart meter installation	Specialist install	
Electric car charging point	Specialist install	
Voltage optimisation	Quick install	£50
Loft lighting	Quick install	£50

Gas, Heating and Plumbing Upgrade

Heating system renewal or upgrade – if planned ahead of works		£250
External (insulated) tap	Quick install	£50
Additional, replaced (slimline) or relocated radiators.	Saving per radiator	£10
Gas fire replacement or removal. Quick install	Quick removal	£50

Appendix A - Retrofit Approach Package, performance targets and actual installed measures

Retrofit Approach RetroFix^{TM} package of measures:



RD1 Actual installed measures in demonstration trial:

Performance targets:

Level of retrofit: RetroFix ™

Targeted primary energy consumption reduction: 25%-40%

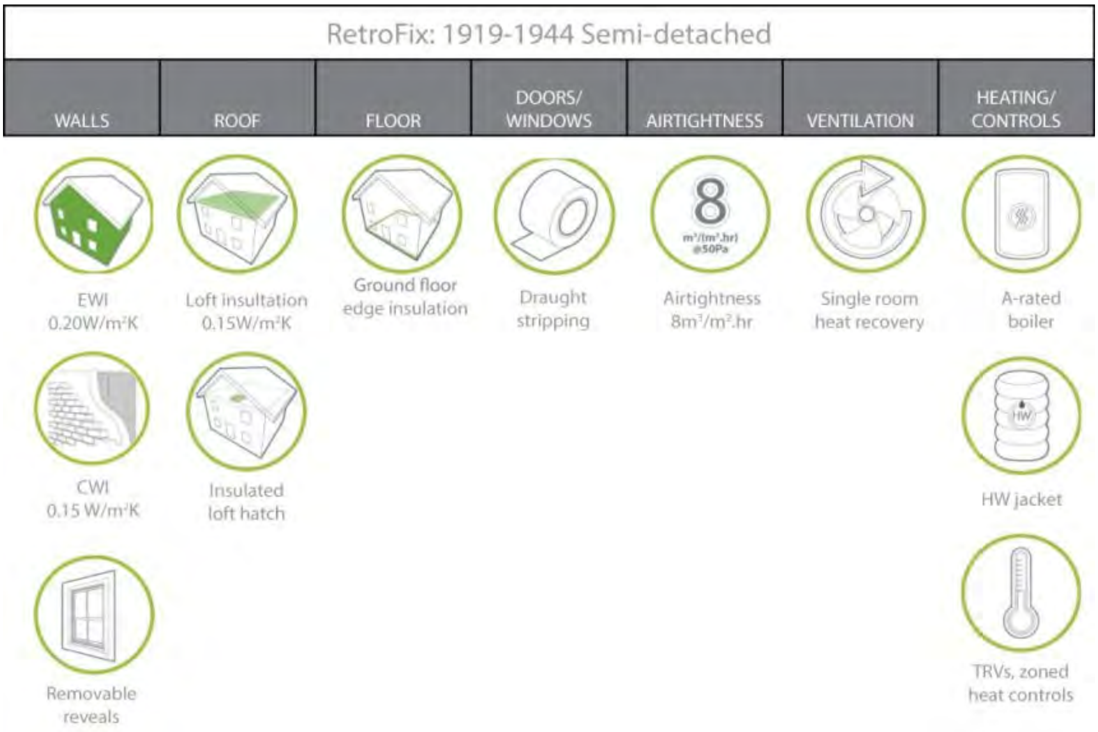
Installation Process (time): Maximum 2 weeks

Capital Cost: £10,000

Pre Retrofit

Post Retrofit

Retrofit Approach RetroFix^{TM} package of measures:



RetroFix: 1919-1944 Semi-detached

WALLS	ROOF	FLOOR	DOORS/ WINDOWS	AIRTIGHTNESS	VENTILATION	HEATING/ CONTROLS
EWI 0.20W/m^2K	Loft insultation 0.15W/m^2K	Ground floor edge insulation	Draught stripping	Airtightness 8m^3/m^2.hr	Single room heat recovery	A-rated boiler
CWI 0.15 W/m^2K	Insulated loft hatch					HW jacket
Removable reveals						TRVs, zoned heat controls

RD9 Actual installed measures in demonstration trial:

Performance targets:

Level of retrofit: RetroFix ™

Targeted primary energy consumption reduction: 25%-40%

Installation Process (time): Maximum 2 weeks

Capital Cost: £10,000

Pre Retrofit

Post Retrofit

Retrofit Approach RetroFix^{TM} package of measures:

RetroFix: 1945-1964 Semi-detached

WALLS	ROOF	FLOOR	DOORS/ WINDOWS	AIRTIGHTNESS	VENTILATION	HEATING/ CONTROLS
EWI 0.20W/m²K	Loft insultation 0.15W/m²K	Ground floor edge insulation	Draught stripping	Airtightness 7m³/m².hr	Single room heat recovery	A-rated boiler
CWI 0.15 W/m²K	Insulated loft hatch					HW jacket
Removable reveals						TRVs, zoned heat controls

RD5 Actual installed measures in demonstration trial:

Performance targets:

Level of retrofit: RetroFix ™

Targeted primary energy consumption reduction: 25%-40%

Installation Process (time): Maximum 2 weeks

Capital Cost: £10,000

Pre Retrofit

Post Retrofit

Retrofit Approach RetroPlus^{TM} package of measures:

RD27 Actual installed measures in demonstration trial:

Performance targets:

Level of retrofit: RetroPlus^{TM}

Targeted primary energy consumption reduction: 40%-60%

Installation Process (time): Maximum 3 weeks

Capital Cost: £15,000-£20,000

Pre Retrofit

Post Retrofit

Appendix B - Health and Safety Files and Warranties Claims

The table below shows which installed items are covered by warranties and the duration of the warranty.

Table 10: Warranty periods

Home	Measure		
	EWI	**HR Ventilation fans**	**Windows/external doors**
RD1	Yes - 10 years	Yes - 5 years	N/A
RD5	Yes - 10 years	Yes - 5 years	N/A
RD9	Yes - 10 years	Yes - 5 years	N/A
RD27	Yes - 10 years	Yes - 5 years	Yes - 10 years

There have been no warranty claims during the period between the completion of the retrofit work at each house and the completion of this report.

The Health and Safety files for each house are provided as separate files.

Appendix C - Monitoring Datasets

Provided as separate files.