‘Retrofit for the future’: reducing the carbon emissions of the UK’s housing stock

Jaryn Bradford
MA *AIEMA*
Energy Saving Trust
21 Dartmouth Street
London, SW1H 9BP
UK
0207 227 0355
jaryn.bradford@est.org.uk

Geoff Stevens
MSc *AIEMA*
Energy Saving Trust
21 Dartmouth Street
London, SW1H 9BP
UK
geoffrey.stevens@est.org.uk

Tom Byrne
Energy Saving Trust
21 Dartmouth Street
London, SW1H 9BP
UK
tom.byrne@est.org.uk

Paul Ruyssevelt
Technology Strategy Board
UK
paul.ruyssevelt@tsb.gov.uk

Keywords

retrofit, housing energy consumption, energy monitoring

Abstract

The Energy Saving Trust has undertaken an evaluation of the UK’s largest demonstration and monitoring study – *Retrofit for the Future* – of whole-house retrofits in 119 social housing properties. The objective of the study was to achieve 80 % reductions in carbon dioxide emissions compared with pre-retrofit levels. The study undertook data collection of building energy performance and the occupants’ experience of living in a retrofit home.

The paper presents the findings from qualitative social research, including in-depth interviews, with all the occupants involved in the project. The tenants assessed both the process of the retrofit and their experience using the measures installed.

A wide range of technologies, including air and ground source heat pumps; mechanical ventilation with heat recovery (MVHR); solar thermal; solar PV; solid wall insulation; smart controls; and building fabric were installed to deliver a whole-house retrofit to achieve a target carbon saving of at least 80 % compared with the UK’s Standard Assessment Procedure calculation.

An assessment of the UK supply chain, including interviews with architects, builders, installers and local housing associations, were undertaken to assess the successes and lessons learned from their particular sites as well as providing insights into the overall UK retrofit market and its potential.

In-situ monitoring was undertaken to collect detailed data from the environmental and energy performance of the properties after the retrofit. The first retrofits began in 2009 with data collection of each property’s performance taken for two years upon completion. 37 of the properties had complete one-year datasets and the results from these properties are discussed. The findings will be used as evidence to present successful solutions to achieve whole-house carbon savings in the current and future UK retrofit market.

Introduction

Employing a scientific approach has been agreed as the most appropriate method to achieve a significant reduction in energy use from the housing sector in the UK. Extensive field trials to monitor new technologies in existing buildings have been undertaken to identify the most appropriate methods to retrofit existing buildings and set design standards for new-build.

The UK government has committed to reducing greenhouse gas emissions to 80 % of 1990 level by 2050. UK buildings account for 44 % of CO_2 emissions with residential buildings amounting to 27 % of emissions (DECC, 2008). The UK has one of the oldest housing stocks in Europe with a current replacement rate of under 1 % per year. There are approximately 26 million houses in the UK and 80 % of current houses will still exist in 2050 (DCLG, 2012). An extensive energy efficiency programme for homes will be required to meet the UK CO_2 emissions reduction targets.

In 2009 the Technology Strategy Board (TSB) launched a £17 million competition called ‘Retrofit for the Future’ (TSB, 2013) to enable building and renovation companies to retrofit and refurbish social housing. The Retrofit for the Future scheme awarded grants of up to £150,000 per property to architects, builders and housing associations (the ‘applicants’) through a competitive application process with the most innovative solutions for refitting the social housing stock receiving funding. The chosen properties used the latest technologies to achieve

the highest possible standards of energy efficiency, with the objective of achieving up to 80 % reductions in CO_2 emissions and exceeding current UK Building regulations figured for thermal conductivity, air permeability, and energy consumption (HM Government, 2010). In many cases the occupants were also educated on how to improve their energy use behaviour in order to enhance efficiency.

The scheme awarded funding to 86 successful applicant organisations covering 119 occupied social housing residential properties across the UK. The aims of the Retrofit for the Future project included driving innovation through retrofitting of poor performing dwellings using a multiple systems approach; achieving reductions in CO_2 emissions by 80 % or more; and helping builders and developers to deliver more efficient, better performing buildings. The programme encouraged a whole-house approach to reduce carbon emissions including insulation, heating systems, ventilation, control systems and appliances and the effectiveness of these measures was captured through in-situ energy and environmental monitoring. The installations were taken place without cost (in terms of up-front cost or rises in rent) to the residents.

BACKGROUND: DATA COLLECTION THROUGH MONITORING AND OCCUPANCY EVALUATION

The Energy Saving Trust developed and implemented a whole-house carbon and energy evaluation protocol for the Retrofit for the Future competition to determine how the key features of designs – such as enhanced airtightness, improved fabric insulation levels, and renewable energy – contribute to the improved energy performance of the refurbished houses. This protocol captures the monitored data and enables applicants to determine whether their buildings perform as intended. In addition to energy monitoring, a supply chain evaluation was also undertaken which highlights the barriers to installing the specified measures. Project teams took different approaches to involve residents in the design process to determine the most repeatable solution in future.

A comprehensive post-occupancy evaluation exercise was undertaken to evaluate occupant experience of the retrofit measures conducted through the scheme. The occupant experiences, discussed in detail throughout this paper, are crucial to determine the wider user acceptance of the installed measures as indicated by field studies of other technologies undertaken in the UK (Bradford, et al, 2011).

The post-occupancy evaluation was undertaken to explore the occupant experience of the installation process and identify how the occupants interact with the measures. The evaluation fulfilled the following objectives:

- Establish the improvement in amenity, comfort and control, compared either to:
  - the property pre-retrofit
  - or the occupants' prior dwelling (if they moved into the property post-retrofit).
- Performance (and perception) of measures.
- Understanding of the customer experience & hand over.
- Support the analysis of physical monitoring data.

This paper presents a further discussion of the results from the first phase of post occupancy evaluation and the supply chain evaluation.

SITE SELECTION

There are 119 sites in Retrofit for the Future, spread across England, Scotland, Wales and Northern Ireland as illustrated in Figure 1. Tables 1 and 2 illustrate the building type and age of the dwellings.

The sites are split across a variety of locations, build types and ages. All properties had two or more bedrooms. The programme's objective was to explore how retrofits succeeded in an array of different circumstances and to explore the challenges faced by each individual property[1].

TECHNOLOGIES INSTALLED

The programme focussed on deploying whole-house retrofits. A large variety of different technologies and measures were installed across the sample of properties. Table 4 includes a selection of the most popular measures and technologies utilised.

Methodology

MONITORING METHODOLOGY

A key part of the Retrofit for the Future programme was the collection of post-installation energy and environmental performance data. The sample included a wide variety of properties including build-type, age, and number of occupants, and floor area. Most properties had 2–3 residents and floor areas of 70–90 m^2, which is typical for UK residential housing. Both short- and long-term tests were undertaken. Short-term spot tests were undertaken at each property both before and after the retrofit works. These included:

- Air tightness testing.
- Thermal imagery.

These tests were organised to analyse the successes of retrofitting the envelope of the property and allowed for useful before and after comparisons. Unfortunately discussing these analyses is beyond the scope of this particular paper.

As part of the programme it was required that every property underwent building performance monitoring for at least two years after the retrofit had been completed. The monitoring is currently on-going in a number of the properties and, as such, results are not yet available. The degree of monitoring varied at each property according to the project participant and technologies present. The minimum degree of monitoring required included:

- Energy meters for main gas and electricity usage.
- Internal temperature and humidity sensors for at least 3 rooms.
- Internal CO_2 sensor at one location.

1. Statistics in Tables 1 & 2 have been obtained from the final reports delivered for each project and from the property profiles populated by project teams in the Embed database.



Figure 1. Map locating Retrofit for the Future sites.

Table 1. Build type of retrofit for the future sites.

Build type	
End terrace	24%
Mid terrace	40%
Semi detached	31%
Detached	5%

Table 2. Build age of the retrofit sites.

Build age	
Pre-1900	16%
1900–1929	20%
1930–1949	18%
1950–1966	38%
1967 +	8%

Table 3. Area of the retrofit sites.

Area (m^2)	Percentage
50–60	3%
60–70	3%
70–80	29%
80–90	43%
90–100	6%
110–120	9%
120+	3%

Table 4. Efficiency measures and technologies installed across the 119 sites.

Air source heat pump	Internal wall insulation
Ground source heat pump	External wall insulation
Gas fired boiler	Loft insulation
Biomass boiler	Under floor insulation
mCHP	Double and triple glazing
Solar Thermal	LED lighting
Solar PV	Energy efficient appliances
MVHR	Rain water harvesting
Advanced heating controls	Voltage optimisation

- External temperature and humidity sensor.

It was also desired that any on site renewable energy technology was additionally monitored to sub-meter level.

OCCUPANCY EVALUATION METHODOLOGY

Post-occupancy evaluation is a crucial part of any refurbishment programme, highlighted by evidence from previous studies (Gupta and Chandiwala, 2010) where marked variations between the intended (or 'as-designed') and actual energy performance of energy efficient dwellings have been found and explained through evaluating occupant behaviour.

Occupant interviews were organised at 80 of the sites and were conducted roughly three months after the retrofit works had finished (July–November 2011) to explore occupant profile, satisfaction (amenity comfort and control), behaviour and perceptions of retrofit process. The occupants varied in age and gender and came from a large variety of academic and economic backgrounds. As the programme only included social

housing sites none of the occupants owned their own home and the majority was dissatisfied with their previous living arrangement.

Over two-thirds (69 %) of the occupants lived in the property before the works and around half (48 %) were decanted.

Interviews were undertaken to investigate the occupants':

- Relationship with the property before the retrofit, if applicable.
- Experience of the retrofit process, if applicable.
- Relationship with the property after the retrofit.
- Knowledge and opinions of the selection of measures and technologies installed as part of the retrofit.

SUPPLY CHAIN EVALUATION METHODOLOGY

Interviews were undertaken with 40 supply chain organisations involved in delivering one or more Retrofit for the Future projects including builders, contractors, and architects. The interviews provided valuable insight from those managing the delivery of the retrofit projects to provide understanding of the drivers, barriers, and perspectives of undertaking showcase retrofits. Interaction with the supply chain identified the potential of retrofit as a business opportunity in future.

The topic guide for the interviews comprised of a series of core questions which covered the interviewee's experience undertaking the retrofit projects they were involved in; identifying barriers; and discussion of the future opportunities for the industry in the UK.

Results from Occupancy Evaluation

The interviews with occupants provide useful insight to the perceived benefits of the retrofits and the implications for the UK supply chain. Overall the occupants were very happy with their energy bills and the perceived improvements to comfort. Their interaction with the supply chain – including communication and meeting timescales – were identified as areas for improvement. A further round of post-installation occupant interviews is on-going but the results will not be available until after the summer. This research will help to identify any changes to occupant behaviour or perceptions of the installed measures.

The interviews determined that a majority of the occupants were unsatisfied with the quality of their property's comfort energy performance before the retrofit. Only 28 % of the occupants were positive about their original property and only 21 % of respondents felt that their accommodation was comfortable prior to living in the retrofitted home. Figure 2[2] clearly demonstrates that the occupants' opinions of their properties' comfort vastly improved after the retrofit had been completed. This finding shows that the majority of retrofits had been successful in at least making the properties perceivably more comfortable to live in.

Data also suggests that, in addition to perceiving greater levels of comfort after the retrofit, occupants also had a higher general opinion of their dwelling as well. Figure 3 shows that before the retrofit less than 25 % of the occupants had a positive opinion of their home. After the retrofit this improved to nearly 85 % and very few stated that they had a negative opinion of the home.

These results indicate that, from the perspective of the occupants, the majority of retrofit projects in the programme were a success. It also appears that the positive opinions went further than purely feeling comfortable in the property. The question regarding general opinions of the dwelling returned a higher percentage of 'very positive' responses than the question just discussing comfort.

A number of responses provide insight into why the occupants' general opinion of the retrofitted dwellings was so high. Not only did the occupants feel warmer and more comfortable they also felt special. In some cases the treatment of damp has brought health benefits to the occupants and some tenants even feel safer as a result of the retrofit works:

> As a family we were more susceptible to colds and coughs because of the damp, but since the retrofit we're much happier and feel much healthier.

> I was burgled in 2008 – the windows did not lock. I tried not to let it bother me but it did play on my mind. Now, I feel very secure, the locks on the (double glazed) windows and doors are very secure.

Of course another important indicator of retrofit success and occupant happiness is the impact the works has had on their energy bills. Across many interviews the occupants had stated that they had seen a noticeable reduction in their energy bills, even after just a couple of months:

> The house is so much warmer and our bills are a much lower; for Jan–March 2010 (before works) energy bill was £360; For Jan–March 2011 (after works) energy bill was only £120.

> We used to pay £126 per month for gas and electric. It's now £55 per month for both, and the house is much warmer and less draughty.[3]

OCCUPANT CHALLENGES

Even with the reported positive feedback regarding comfort and fuel costs, there were some parts of the programme that occupants felt could be improved including the timescales for work and the explanation of how to use a variety of the technologies and measures installed.

A good majority (62 %) of occupants responded they received a decent explanation of the retrofit process and the time it would take. In retrospect the satisfaction levels were much lower however, as presented in Figure 4. The majority of occupants (nearly 70 %) felt dissatisfied or very dissatisfied with the length of time required to complete the works. There was also a lot of dissatisfaction with the level of disruption caused during the process.

2. All graphs and tables within the result section have been produced from raw data collected by the project team.

3. Please note that energy bills are dependent on other factors such as external weather conditions and comfort and may have impacted on the difference in energy bills. Please also note that during this time (2010–2011) energy prices in the UK rose by an average of 10–15 %.

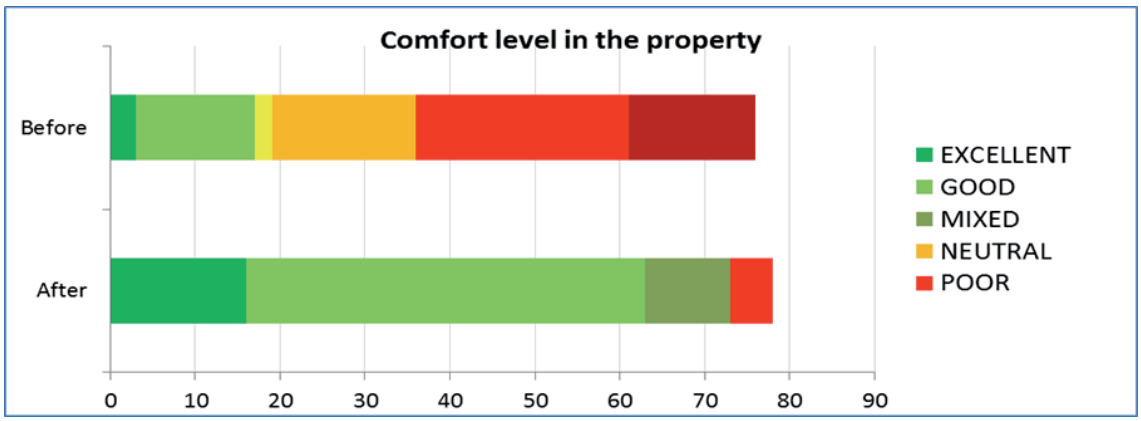


Figure 2. Opinions on comfort level of the property before and after retrofit.

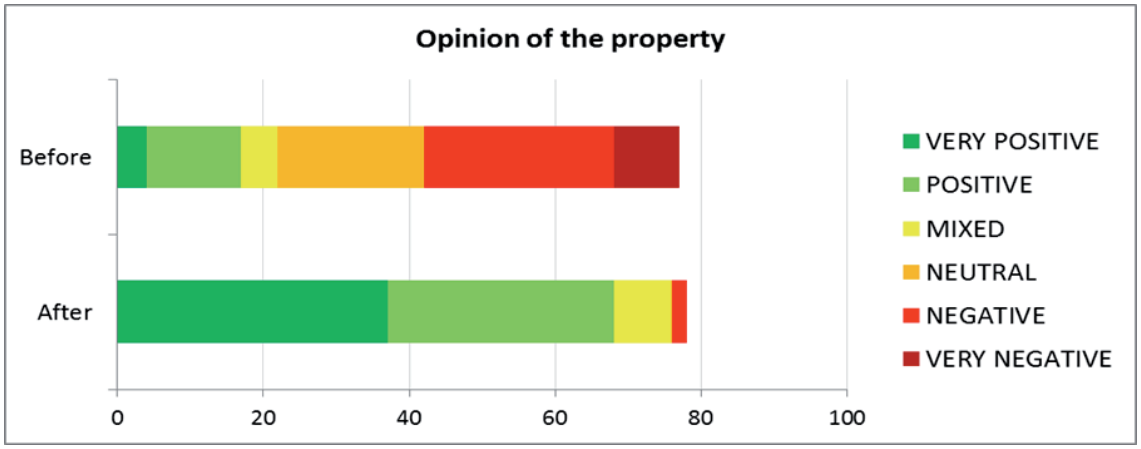


Figure 3. General opinions of the property before and after retrofit.

These levels of dissatisfaction remained similar whether the occupants remained in situ or were decanted. This indicates that to the occupants it doesn't matter whether they are asked to leave the property for the duration of the works or not, they will still felt disrupted.

The interviews with occupants identified that the most dissatisfying aspect of the retrofit process was the length of time it took to complete the works. This varied greatly across the project ranging from four months to two years. There also appears to be some confusion between the occupant and project manager when completion was actually achieved. These are key implications for the UK supply to consider when undertaking future retrofit schemes.

> We were told it would take just over a month, the works started 4 or 5 months after they were supposed to. Works started in late November 2010, and the property still isn't finished as far as I am concerned.

> The works started in January 2011, and as far as I am concerned they haven't finished yet – we were told it would take 4–5 months.

These responses highlight the issues of time taken to complete the works but it also indicates that some occupants felt the property wasn't completed even though the project management had signed off on it.

The handover of the completed property to the tenants was also as a challenge the occupants felt strongly about. Over half of occupants stated that they received a 'poor' explanation of how the measures installed as part of the retrofit work. The majority of interviewees reported that they had a decent understanding of the purpose of the measures (74 %) but less so on what actions would affect measure performance (40 %). These findings are similar to those found from other UK field trials of new technologies installed in homes (Bradford, et al, 2011).

PERCEPTIONS OF DIFFERENT TECHNOLOGIES:

Occupant perceptions (80 responses) differed for certain measures and Table 5 indicates how different measures are perceived – in a positive, neutral or negative way.

The occupants largely have a neutral opinion of the majority of the technologies that were widely installed in the programme. This suggests that occupants either cannot differentiate between the measures or they do not understand how they work. Not only do occupants appear to not understand the majority of specific technologies and measures installed in their homes they also appear confused by the heating controls they have been provided.

MVHR was the only technology that received negative opinions. This may be due to the fact that not only do people not understand how MVHR works but they are also aware of its

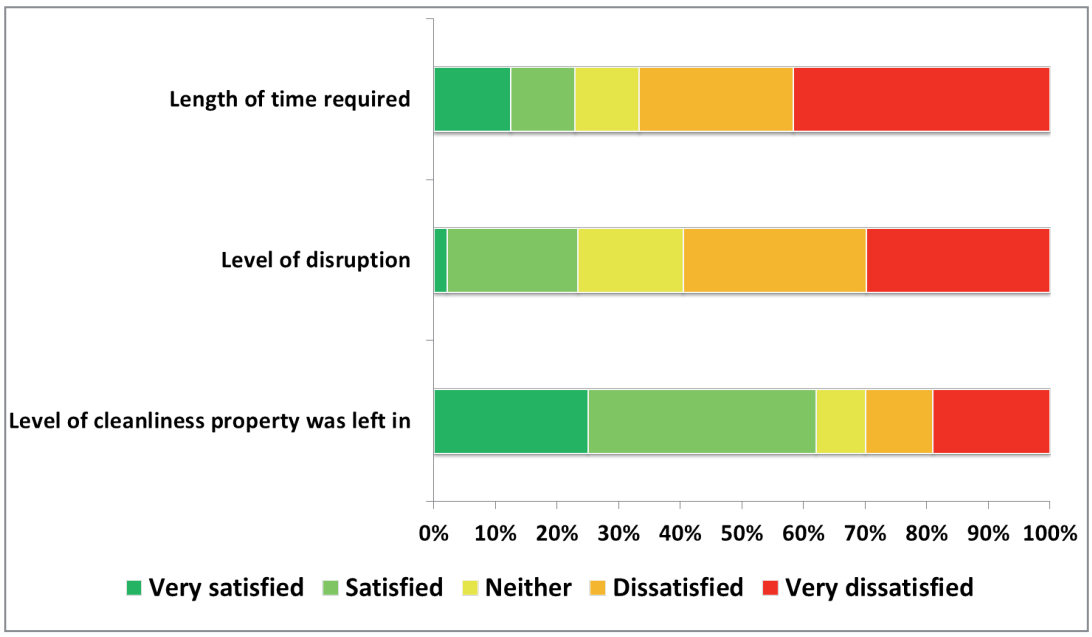


Figure 4. Satisfaction of the retrofit process.

Table 5. Occupant perceptions of different measures (n=80).

Measure	Savings	Average cost	Average opinion of measure
Glazing	Medium	Medium	Good
Loft insulation top up	Low	Low	Good
External wall insulation	High	High	Neutral
Internal wall insulation	High	High	Neutral
Floor insulation	Low	High	Neutral
Solar PV	Medium	High	Good
Solar hot water	Medium	High	Neutral
Ground source heat pump	High	High	Neutral
Air source heat pump	High	High	Neutral
Energy saving light bulbs	Low	Low	Neutral
MVHR	Low	High	Negative

operation. Interviews with the occupants indicate that they generally feel that it is noisy and it costs electricity.

Figure 5 depicts the occupants' understanding of the heating controls in their previous property compared to the heating controls provided in the retrofitted home. The majority (nearly 85 %) of interviewees indicated that they had a good or excellent understanding of their heating controls in their original property. This figure diminishes to roughly 60 % for the retrofitted property. There are also no instances of occupants stating they had an excellent understanding of the controls post retrofit.

This is an interesting finding as previously the data suggested that the properties were perceived as much more comfortable (see Figure 2). This indicates that despite the poor understanding of controls the properties are still perceived as much warmer. This could be attributed to the impact of the enhanced insulation apparent at every property in the programme.

Results from supply chain interviews

This section presents the key findings from the supply chain interviews conducted with architects, builders, and contractors involved with the installation of energy efficiency and micro-generation technologies as part of the Retrofit for the Future programme. Interviews were undertaken to identify the per-

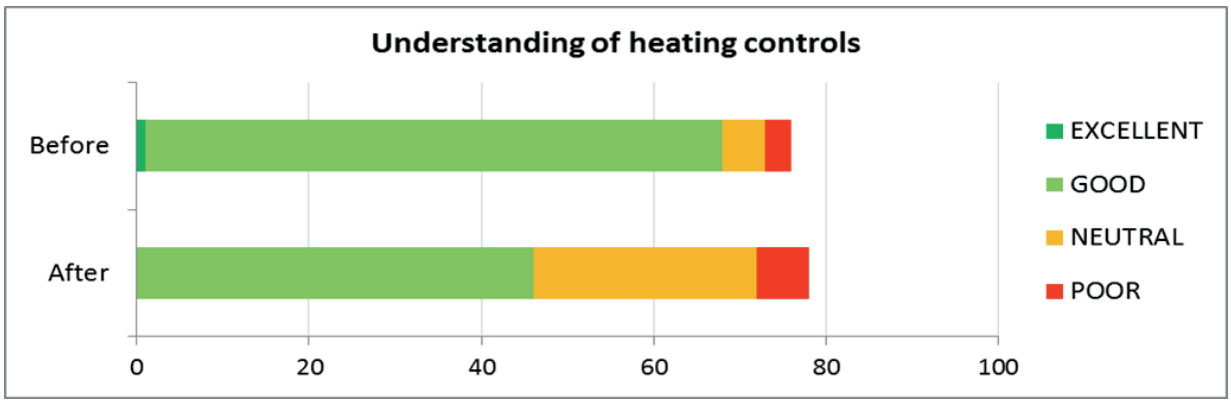


Figure 5. Understanding of heating control before and after retrofit.

ceptions of members of the supply chain to installing measures and interacting with the occupants and highlight lessons learnt.

INTERVIEWS WITH ARCHITECTS

20 architects who were questioned were generally very positive about their experiences with the retrofit progress. In many cases the success of projects surpassed their expectations and most of them claimed they coped well with integrating new technologies into design.

According to the architects interviewed, the social housing market is seen as the most significant opportunity for large scale retrofits in the UK. There is a large number of houses that require retrofitting as the social housing stock is currently largely inefficient and there are a number of incentive programmes to improve the building stock. A number of similar dwellings can also be grouped (a row of terraced houses for example) allowing for similar approaches to be replicated in one area. This means a number of homes can be retrofit at once, leading to improving economies of scale.

The owner-occupier housing sector is also seen as a growing market for extensive energy retrofits. However, architects felt that the average private homeowner customer is deterred by the cost of energy efficient retrofits. This may change in the future however as the UK market grows, reducing the costs of certain methods and technologies.

The majority of architects responded that many contractors did not grasp sustainable low carbon practises and some contractors delivered poor workmanship in their project(s). This is largely due to the perceived inexperience of contractors carrying out such large scale retrofit projects – especially including new technologies and measures – rather than their general skill level. A number of architects however had very good experiences with contractors and have developed a useful network of partners to use in future projects. All architects mentioned that a useful method of assessing supplier and contractor quality, expertise and reliability would be beneficial in planning retrofit projects.

Architects stated that the success of projects and project management was largely affected by whether the occupants were in situ during the works. If the occupants remained in the property during a large scale retrofit it negatively impacted the project delivery, for example occupants do not want to be disturbed, which affected the amount of time spent on site and the associated costs.

INTERVIEWS WITH BUILDERS AND CONTRACTORS

20 builders and contractors who were interviewed identified good project management as one of the keys to successful retrofit projects. Part of this project management is the requirement for decent communication throughout the project team and the entire project process. Contractors believed that project management could be improved if they were involved in the early design stage. Issues such as the time taken to install certain measures were sometimes short-sighted by project managers and some were unaware of what impacts the installation of certain measures or technologies might have. For example, external wall insulation cannot be applied in very cold conditions as the render cannot set. This wasn't always factored into the management of project delivery.

The builders and contractors interviewed believed that improving knowledge and awareness of sustainable technologies and practises to be very important in increasing the size of their market. There is a low level of experience with installing certain technologies and practises such as mechanical ventilation with heat recovery, heat pumps and reducing thermal bridging. Interviewees believe that increasing this level of experience within the sector will promote good practice, good results and more business.

Again, the social housing market is seen as an attractive opportunity to many builders and contractors. They feel that as fuel poverty is a priority for social landlords there is an increasing demand for insulation and affordable warmth. They also see the benefit is dealing with just one client, a housing association, to carry out a lot of work on multiple homes. This opinion was also shared by a number of architects questioned who feel marketing to housing associations more cost effective.

Results from monitoring and data collection

The objective of the Retrofit for the Future programme was to achieve an 80 % reduction in CO_2 emissions compared to the average 1990 UK residential dwellings in terms of energy consumption in kWh per m^2. This section presents the reductions in energy consumption and concomitant CO_2 emissions from the monitored dwellings and presents a discussion of the results.

Building performance, energy, and environmental data was collected from 119 properties across the project as per the above methodology. Air-tightness results were taken before

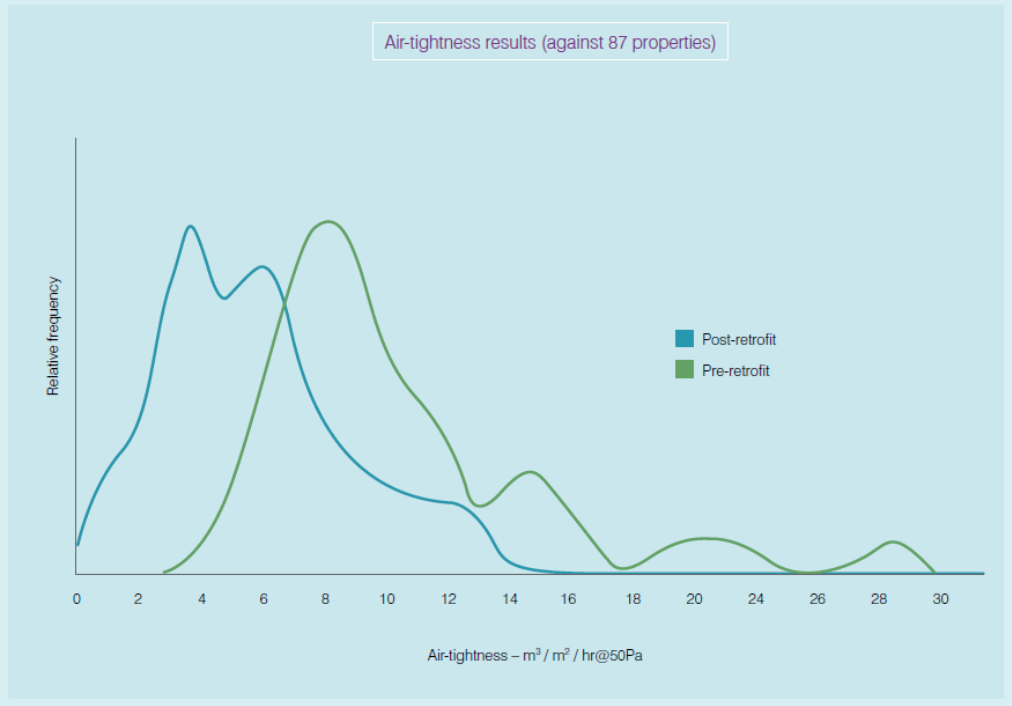


Figure 6. Measured airtightness across the sample of properties: pre- and post-retrofit (n=87). (Source: TSB, 2013.)

and after the retrofits and the results from 87 properties are presented below. Analysis of energy performance and energy costs from 37 dwellings was undertaken from dwellings which have complete and continuous energy & environmental conditions data for a minimum of 12 months.

A number of factors including: technical problems, continuity of data collection, on-going data collection, and incomplete information received from project teams throughout the length of the programme (e.g. staff turnover and other problems encountered throughout the project inhibited data collection) meant that complete data sets are not yet available for all dwellings. Data continues to be collected from a number of sites and is collected, along with data from all dwellings in the project, in the Energy Saving Trust's EMBED database which is open for all users to view the data. For the purpose of this research, only homes with complete one-year data have been analysed and presented.

AIR-TIGHTNESS

All new residential buildings are required to meet certain levels of air tightness in an effort to improve the energy efficiency by minimising uncontrolled ventilation losses. Compliance with UK Building Regulations (HM Government, 2010) requires an air permeability result better than 10.0 m^3/m^2h at 50 Pa in new dwellings. Air tightness measurements were undertaken pre- and post-retrofit and results are available for 87 dwellings. It was anticipated that the properties would be much worse than current regulations however most achieved better. This means that the potential to improve CO_2 emissions from ventilation losses was less than expected. Figure 6 illustrates the improvements made to airtightness across the sample of properties. The most frequent pre-improvement air-tightness result was a value of ~8 $m^3/m^2/hr@50$ Pa which improved to a post-retrofit value of ~4 $m^3/m^2/hr@50$ Pa (TSB, 2013).

OVERVIEW OF CO_2 EMISSION SAVINGS

Energy data from each property prior to retrofit was not available. To identify each property's energy demand, the Energy Saving Trust calculated a proxy target for baseline household energy demand for an average three-bedroom house based upon 1990 levels. This target was normalised for each property type by using the average gross internal floor areas. An 80 % reduction from these figures led to an energy consumption target for heating, hot water, and electricity usage of 115 kWh/m^2 per year and an emissions target of 17 kg/CO_2 per year.

Of the 37 properties with complete data, three achieved an 80 % reduction in household CO2 emissions measured in kg/CO_2 per year. A further 10 properties achieved CO_2 reductions equivalent to 70–80 % kg/CO_2 per year. 13 achieved reductions between 50–70 %. Figure 7 illustrates the distribution of measured CO_2 emissions and energy consumed from the 37 properties split between gas and electricity usage. The analysis of performance data from these 37 dwellings shows a strong correlation between good levels of air-tightness and lower CO_2 emissions. Further, analysis of data indicates that increased air-tightness (and the associated deductions in emissions) were achieved without negatively impacting the residents' comfort levels.

ENERGY COSTS

In addition to measuring the energy use and CO_2 emissions from the dwellings it was important to determine the running cost of these energy-efficient homes. Energy costs were not available from the period before the retrofit but an estimation of the post-retrofit running costs was calculated based upon average UK retail energy prices[4]. Figure 8 illustrates the estimated

4. Calculations of energy costs have been based upon unit costs of 14.48 pence per kWh of electricity and 4.43 pence per kWh of gas.



Figure 7. Distribution of measured CO_2 emissions from the 37 properties split between gas and electricity usage. Source: TSB, 2013.

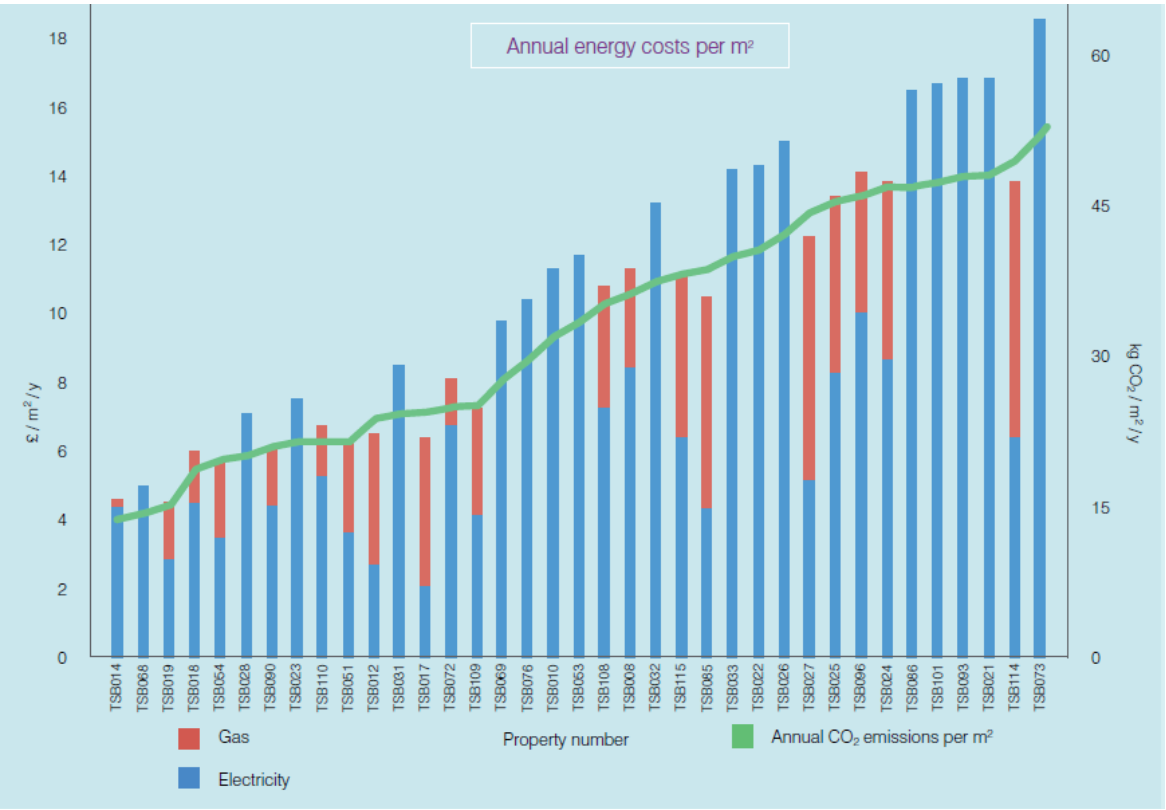


Figure 8. Estimated annual running costs for the 37 properties with a comparison against CO_2 emissions (per square metre). Source: TSB, 2013.

annual running costs for the 37 properties (per square metre) with a comparison against CO_2 emissions. The properties with the lowest fuel bills also had the lowest levels of emissions. The property with the lowest estimated annual fuel costs was £374 per annum.

CASE STUDY: THE TOP ACHIEVING PROPERTY

The best reduction in CO_2 emissions compared to the modelled pre-retrofit energy demand was 80.7 %. This property was a typical two-bed Victorian terraced property with solid brick walls. The technologies installed include: internal & external solid wall insulation; loft insulation; sunpipe; mechanical ventilation with heat recovery; an A-rated gas boiler; solar water heating and solar PV panels. Annual fuel bills after the retrofit totalled £450. The property with the lowest estimated annual fuel costs was £374 per annum.

Key Findings

The study's key findings provide useful guidance to inform additional research into large-scale whole-house retrofit in the UK. Key lessons have been learnt through interaction with both the supply chain and the occupants of the 100-plus retrofit homes which should be considered as the UK moves to retrofit a high proportion of its existing building stock. Monitored building performance data illustrates a good potential to achieve reductions in terms of energy and CO_2 emissions compared with dwellings' modelled energy demand before the retrofit. Analysis of qualitative interviews with the supply chain and the occupants and interpretation of building energy performance data has identified the following key findings:

- Occupants' overwhelmingly responded that the retrofitted properties are much more comfortable than their original dwellings and their general opinion of the dwelling is much higher too. Tenants reportedly feel safer, healthier and had noticed a reduction in their energy bills.
- The majority of occupants however was dissatisfied with the length of time taken to complete the retrofits and was also unhappy with the disruption caused.
- Some occupants felt the level of workmanship to be poor and did not have a good relationship with the contractors and project teams.
- The handover of the properties was generally poor which resulted in many occupants not understanding the measures and technologies installed. Confusion over new heating controls was especially apparent.
- Supply chain interviews indicate that many builders and contractors are inexperienced in sustainable retrofits. Contractors believed that up-skilling their sector will help improve their market.
- Architects, builders and contractors unanimously agreed that the social housing market provided the biggest opportunity for sustainable retrofits in the UK.
- Of the 37 sites with a complete data set, 3 achieved the target of 80 % reduction in CO_2 emissions. A further 23 achieved reductions in CO_2 emissions between 50–80 %.
- Pre-retrofit air tightness of the properties was better than expected. This left less scope for reduction in CO_2 emissions than originally anticipated in many properties.
- Energy costs as low as approximately £4 per square metre per annum were achieved in the top 3 properties.

Conclusions

The UK Climate Change Act (2008) requires that annual CO_2 emissions should be reduced by 80 % compared to their 1990 levels by 2050. As household energy use is responsible for over a quarter of these emissions, the UK has committed to reduce CO_2 emissions from all dwellings by 80 % as part of the long term emissions reduction targets. If this is to be realised, all existing dwellings will need to achieve significant improvements in energy performance.

The Retrofit for the Future programme, sponsored by the Technology Strategy Board and UK Government, sought to undertake showcase refurbishment projects to 119 social housing properties across the country to better understand the social, economic, and environmental impacts of retrofitting the country's most inefficient building stock.

The programme's key findings provide useful insight into the experiences encountered by residents and the supply chain through the undertaking comprehensive retrofits. Key lessons have been identified by the participating architects, builders, and contractors which will help the supply chain to improve best practice as larger-scale refurbishments become more common. The feedback of residents provides invaluable insight into their perceptions of the retrofit process and their experience using new technologies in their home. From the discussions with the supply chain and occupants involved it can be concluded that the majority of retrofits were successes, however further training of the supply chain is necessary. Occupants will also require further education as unfamiliar measures and technologies are introduced into their homes. Interviews with occupants and the supply chain indicate retrofit projects can be successful, however, engagement from every stakeholder involved is required to ensure consistent results can be achieved.

Monitored data illustrates that 3 of the 37 dwellings with complete data sets achieved the target 80 % reduction in CO_2 emissions per square metre. A further 23 dwellings achieved reductions in CO_2 emissions between 50–80 %, which illustrates that there is a good potential to achieve significant energy efficiency improvements to the UK ageing building stock through retrofits. Data suggests a number of reasons why more properties did not reach the 80 % target, ranging from lack of customer understanding to properly control the installed measures to imperfections in the way energy use in UK buildings is modelled. This study will help to surmount these challenges as energy efficiency becomes more commonplace in the UK retrofit market. Further, more properties from the study will be analysed once complete one-year performance data becomes available, which could identify more homes that have achieved 80 % reductions. The UK supply chain has overcome numerous barriers to achieving these reductions and is now in a better position to understand the implications of whole-house retrofit on their targets for achieving energy efficient homes.

The Retrofit for the Future programme aims to learn from 119 retrofit projects from across the UK, involving a variety of occupants and members of the supply chain. The lessons learned from this programme can help pave the way for thousands of successful retrofits to be completed in the UK by 2050.

References

Bradford, J, Bean, F, and Carmichael, E. London, UK 2011. The Energy Saving Trust Heat Pump Field Trial, Proceedings from the ECEEE 2011 Summer Study.

The Department of Communities and Local Government (DCLG), London UK 2012. English Housing Survey: Headline report 2010–11. Office of National Statistics, London.

The Department of Energy and Climate Change (DECC), London UK, 2008. The Climate Change Act. Online [http://www.decc.gov.uk/en/content/cms/legislation/en/content/cms/legislation/cc_act_08/cc_act_08.aspx].

The Energy Saving Trust, London UK, 2008. Emission Impossible. Online [http://www.energysavingtrust.org.uk/Global-Data/Publications/Emission-impossible-a-vision-for-a-low-carbon-lifestyle-by-2050].

Gupta, R and Chandiwala, S. 2010. Understanding occupants: feedback techniques for large scale low-carbon domestic refurbishments. Building Research and Information, 38(5), pp. 530–548.

HM Government, London, UK. 2010. The Building Regulations 2010, Part L1B: Conservation of Fuel and Power. 2010 Edition. Online [http://www.planningportal.gov.uk/uploads/br/BR_PDF_ADL1B_2010.pdf].

The Technology Strategy Board (TSB), Swindon, UK 2013. Retrofit Revealed – The Retrofit for the Future Projects – data analysis report. Online [http://www.retrofitanalysis.org/retrofit-revealed-by-technology-strategy-board.pdf].