Programme Area: Buildings

Project: Building Supply Chain for Mass Refurbishment of Houses

Title: Synthesis report

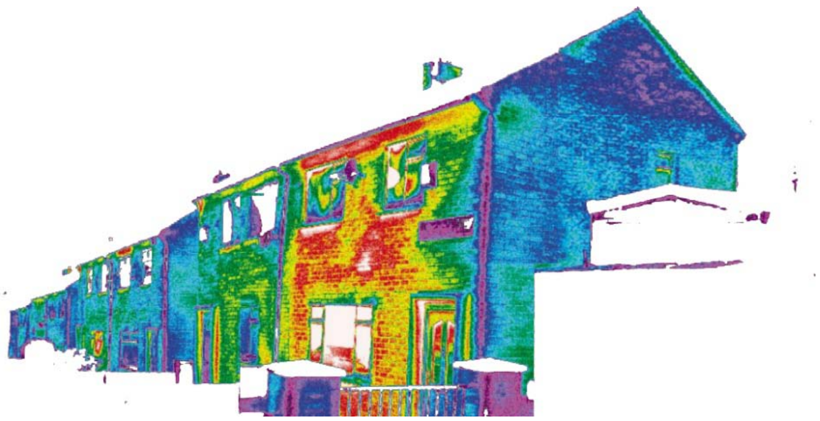
Abstract:

Please note this report was produced in 2011/2012 and its contents may be out of date. This is the final deliverable in Work Package 3. The report provide a comprehensive overview of Work Package 3 and draws out the main conclusions and findings of all the deliverables. It also recommends areas for further research and builds on the recommendations for mass roll-out as outlined in Deliverable 3.5 (Mass Implementation Plan).

Context:

This project looked at designing a supply chain solution to improve the energy efficiency of the vast majority of the 26 million UK homes which will still be in use by 2050.It looked to identify ways in which the refurbishment and retrofitting of existing residential properties can be accelerated by industrialising the processes of design, supply and implementation, while stimulating demand from householders by exploiting additional opportunities that come with extensive building refurbishment.The project developed a top-to-bottom process, using a method of analysing the most cost-effective package of measures suitable for a particular property, through to how these will be installed with the minimum disruption to the householder. This includes identifying the skills required of the people on the ground as well as the optimum material distribution networks to supply them with exactly what is required and when.

The ENERGY ZONE CONSORTIUM:



Optimising Thermal Efficiency of Existing Housing

Synthesis Report

Revised Final Report

Submitted by PRP on behalf of the
ENERGY ZONE CONSORTIUM

September 2012

Optimising Thermal Efficiency of Existing Housing

Synthesis Report

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Issue	**Revision**
Action	☐ Accepted ☐ Accepted subject to minor changes ☐ Major re-issue required ____________________ **Signature**

Contents

1 Executive Summary

This report seeks to provide a comprehensive overview of Work Package 3 and draw out the main conclusions and findings of all the deliverables. It will also recommend areas for further research and build on the recommendations for mass roll-out as outlined in Deliverable 3.5. The following headlines comprise the main themes running through all of the deliverables:

House Types

The most likely house types to target for mass retrofit should be based not only on their frequency of occurrence but also their impact on overall carbon emissions. In terms of customer types, segments should be considered according to the size of the population segment, their openness to retrofit, and their awareness of environmental issues. The most likely primary target markets for retrofit would be within the Early Entrepreneurs, Transitional Retirees and Older Established Segments. Stretched Pensioners are open to retrofit but may be limited by their ability to fund the retrofit.

Whole House Solutions

The whole house packages that emerged as a result of this project comprise solutions that scored highly across several criteria categories - solutions that made sense from a design and construction point of view, were affordable, and were relatively easy to bring to market and upscale into mass-market implementation. Solutions that were also cost-effective in terms of cost per $kgCO_2$ of carbon saved were also included, but were considered in terms of how potential improvements could be applied to both product and supply chain in order to improve scalability and deployment.

"Do it once and do it properly" was the key to the generation of these whole house packages. Incremental piecemeal improvements do yield thermal efficiency improvements, but the installation of these improvements as a whole system would yield benefits in terms of cost effectiveness (avoidance of cost duplication), enhanced performance (better thermal detailing at junctions), risk mitigation (minimise damage/decreased performance of previously installed measures), waste minimisation and disruption.

Most of the solutions that we would need for mass-scale whole house retrofit currently exist in some shape or form - the key is to work on making them better, high performing, and assembling them as an integrated systems solution that ensures that each component performs as it should instead of the piecemeal approach to retrofit that is employed today.

There are a number of factors that influence the success of a particular measure or solution - it is not simply about cost or performance. Supply chain maturity, consumer acceptance and the robustness of national and local policies all play a crucial role. These include the following:

Design and Construction	Supply Chain	Customer Acceptance	Policy	Cost
• Visual impact on the streetscape • Range of aesthetic choices • Ease of installation • Waste generation • Ease of installation	• Potential for offsite manufacture or automation • Availability of materials/Lead time • Availability of skilled installers • Robust installation methods/processes • Scalability	• Disruption potential • Ease of use • Awareness • Lifestyle impact • Desirability/Visual impact on the householder	• Carbon reduction effectiveness • Potential for provision of funding mechanisms • Quality assurance of installation and products • Health and Safety • Minimal planning or regulatory constraints	• Capital Cost • Cost of ancillary works • Cost escalation risk • Maintenance costs • Availability of funding

RetroFix packages were designed to improve the thermal efficiency to a level which would make a significant step towards the 2050 Climate Change commitments (20-50% savings) without excessive cost. These packages typically include external wall insulation, loft insulation, floor edge insulation, draught proofing, single room heat recovery, a boiler upgrade, how water tank and distribution system insulation, improved controls and airtightness. The potential for CO_2 savings is typically between 20-55% for a RetroFix whole house package, with the pre-1919 detached property (with Successful Ruralite occupants) demonstrating a considerably higher percentage of improvement than the rest of the house types modelled due to an inefficient base position in terms of carbon emissions. In contrast, the post-1980 detached property (with Elderly Established occupants) demonstrated the least benefit from the RetroFix refurbishment solution, due to its newer and therefore relatively energy-efficient fabric.

Retroplus packages include all of the solutions in the RetroFix packages plus floor insulation, replacement doors and windows, better standards of airtightness and more innovative heating systems. These packages are less cost effective on a cost per kg of CO_2 saved (new doors and windows are not cost-effective on this basis, however they do yield psychological and visible benefits that are part of the overall value proposition for the consumer), and are likely to involve a greater level of disruption than the RetroFix packages. RetroPlus packages offer up to 18% more savings in CO_2 emissions compared to the retrofit option, potentially saving between 30-65%. Again, for RetroPlus the highest percentage of improvement is demonstrated by the pre-1919 detached property (with Successful Ruralite occupants) and the lowest percentage improvement is demonstrated by the 1965-1980 low rise flat (with Young Starter occupants).

The majority of dwelling/household combinations generally showed increased savings ranging from 1% to 7% for RetroFix and 5% to 12% for RetroPlus using projected carbon factors and weather data for 2030.

Cost

Current costs of retrofit are high due to the piecemeal, silo-based method that the construction industry uses for costing and for delivering the work. It is apparent that there is a lot of potential for optimising the process (of the costing itself as well as the retrofit activity) in order to bring down the costs. The costing exercises show that the low-carbon options costs over twice as much as doing a 'quick and easy' - basic thermal improvements with minimal disruption. And incentives such as a room in roof or a new kitchen and bathroom (depending on the standard of course) could cause a quadrupling of the cost. So while saying that we could offer retrofit with a free kitchen and bathroom sound like quite a romantic and inspiring notion, the reality is that it would probably be the other way around - we could target customers who are already eyeing a new kitchen/bathroom package or a loft conversion, and offer them a value proposition for a thermal upgrade at the same time.

Going for the Quick and Easy scenario is the cheapest approach but it is unlikely to achieve our carbon reduction targets. Going for Q&E means ensuring that the home is not performing badly, but for the house to reach "low carbon" or "zero carbon" it will be necessary to implement more thermal efficiency measures. The challenge is to assess how these costs can be reduced, perhaps through offsite manufacture and new technologies, or supply chain optimisation.

Mass Implementation

The major dependency for the success of a mass retrofit programme is customer acceptance. Regardless of the preparatory work to 2020, the success of any retrofit scheme will depend on customer awareness, understanding and most importantly, trust. All the activities outlined in the work package 3.7 for the four workstreams - technical solutions, supply chain, customer acceptance and policy - must work towards ensuring these conditions are met, but there is little use in developing solutions, implementing policy and training poly-competent teams if customers do not believe the retrofit process to be a worthwhile investment. Consumer engagement, in terms of mass marketing, service offerings and retrofit open days will be essential to guarantee the work in the other three work areas will have use in 2020 and beyond. Effective marketing and consumer engagement activity is therefore vital from 2012 and onwards. This will include tangible evidence of successes achieved with demonstrator projects and early adopter case studies. It will be important to engage with consumers using a range of media, targeted to specific customer types throughout the period to 2020 and beyond.

The major obstacles beyond customer demand are likely to include:

- Available funding and cost
- Heritage and aesthetic concerns
- Improved trust in the building industry
- Appropriate upskilling

Policy initiatives should be aimed to create conditions in 2020 that support both customer interest acceptance and supply chain development. The key factors that will have to be in place at the beginning of the decade are:

- Stable and supportive national and local policy
- A trustworthy and efficient supply chain
- Cost effective materials and products
- Effective and robust standard whole house packages

- Attractive marketing and value propositions

While planning post-2030 remains difficult because of a number of future uncertainties, we have identified the key variables that will likely have the greatest impact on retrofit as including customer acceptance, supply chain development, fuel mix and climate change. These are most likely to have a significant role in changing the pressures on consumers to retrofit their homes, on the supply chain to take-up the franchise business model and the individual house packages as designed in WP3.4b.

Innovation

One element which has not been included as a significant barrier, but which can contribute to the overall success of the programme is product innovation. The essential products necessary for retrofit are already available, although some will need to become more widely available and with reduced costs. Roll-out is not therefore wholly dependent on radical product innovation, although thinner insulation, easy to install materials and specialist products will be useful for hard to treat homes or dwellings with non-standard features.

While product innovation is not essential, the supply chain will require a significant step-change and a complete re-designing of supply from an end to end perspective. Key changes include reducing waste through collaboration, optimised site delivery, simplified accreditation for materials and systems, effective training for industry and transparent funding mechanisms and incentives. Without these innovations, retrofit is likely to remain costly and slow, and therefore largely unattractive to the wider UK public.

Aesthetics

External wall insulation has emerged as the key thermal element for both Retrofix and Retroplus packages, and as such the effect of a mass rollout on neighbourhood streetscapes will need to be considered. The following measures can be explored as part of the product optimisation and improvement of external wall insulation:

- integrated insulation and wall finish product that can be manufactured off-site
- varieties of wall finishes and colours to avoid monotony on a street
- the use of rapid prototyping to re-create external decorative features rapidly and cheaply
- development of design guidelines for each local area that presents a pattern book or palette of finishes, linked to a local supply chain that can provide packages that are suited to the architectural language of the area.

2 Introduction

Work Package 3 of the Optimising Thermal Efficiency of Existing Homes Project seeks to focus on the **technical solutions** of domestic retrofit.

Through numerous workshops, case study reviews and modelling exercises, the work package has created design solutions tailored to the dominant house types and the people who are likely to live in them. These designs, outlined in Deliverable 3.4b, are the result of previous work which involved stakeholder engagement, case study assessment, review of available products and areas in need of innovation and examination of the unique requirements specific to the housing stock of all four UK countries. The effectiveness of these designs in terms of carbon and energy savings, have been supported by the modelling work conducted in Work Package 2 and in light of the findings related to supply chain, policy and customer engagement.

This report seeks to provide a comprehensive overview of Work Package 3 and draw out the main conclusions and findings of all the deliverables. It will also recommend areas for further research and build on the recommendations for mass roll-out as outlined in Deliverable 3.5.

Work Package 3 Deliverable Summary

3.1 – DfX Workshop: Expert engagement workshop to address the needs and requirements from a sufficiently broad range of stakeholders in the national retrofit process, the results of which have been presented in a report;

3.2 – Retrofit and Refurbishment Case Studies: Review of a wide range of completed retrofit case studies, the issues encountered, actions taken and final outcomes and lessons learnt from each project;

3.3a – Technological Solutions Matrix: Evaluation of solutions according to established criteria which informed the development of recommendations for whole house solutions;

3.3b – Whole House Solutions: Development of a generic approach to whole house solutions for a set of representative house types;

3.4a – Virtual Refurbishment: A critical look at implementing whole house solutions for the UK's four countries and identify any gaps to be addressed when formulating the single dwelling implementation plan;

3.4b – Single Dwelling Implementation Plan: Outlines the development of individualised improvement scenarios to the customer segments and house types identified previously by the consortium;

3.5 – Mass Implementation Plan: An overview document that can be used to plan the mass rollout of retrofit in the UK;

3.7 – Synthesis Report: A consolidating report summarising key research insights and providing recommendations for creating robust technical solutions.

2.1 Report Objectives

- Provide an overall summary and recap of the findings from Work package 3;
- Detail each deliverable in terms of methodology and conclusions;
- Present a comprehensive review of the key findings across the Work Package and their wider applicability; and
- Identify remaining knowledge gaps and suggest areas for further exploration.

3 Work Package Summaries

3.1 Work Package Structure

The work conducted in Work Package 3 was aimed at developing individualised design solutions for the dominant house types in the UK, as well as a mass implementation plan that would enable to establishment of a UK-wide retrofit programme by 2020.

3.2 DfX Workshop

The Optimising Thermal Efficiency in Existing Housing "DfX" Workshop was held in mid-July 2010 in central London, and was attended by over 45 participants from 32 different organisations representing a wide range of stakeholder groups and interests. The objectives of the workshop were to better understand the various barriers and obstacles to the success of a national retrofit implementation plan and to translate the outputs of the workshop into a framework for future deliverables to use as measures of success

Summary of Methodology

The day long workshop included a variety of sessions to address policy, design and development, supply chain delivery, stakeholder values and future planning. In smaller teams, all of the attendees were asked to critically assess the issues presented and report their key results back to the larger group in order to effectively capture views from the participants. These findings were recorded in detail and presented in the 3.1 report.

Key findings

The following issues emerged as being the top key issues and variables that need to be looked at in relation to the development of a roadmap for the delivery of mass retrofit in the UK.

Cost - The issue of cost may well be used as a measure of success for the proposed roadmap. This includes the cost of improvements, cost of implementation, cost per unit of carbon saved, cost distribution among the different stakeholders, financing and funding options and profitability will all affect the degree of achievability of the solutions as well as the degree of support from all stakeholders involved.

Time - The aspect of time is a variable that needs to be considered carefully - the roadmap needs to be able to set out phases of implementation as well as the impacts of any changes over time that may affect implementation. Consideration of speed of implementation is also essential - gradual changes, step changes and radical changes in the construction sector, supply chain and consumer awareness can form the basis of different scenarios for the plan.

Stakeholder Value - An understanding of each stakeholder's motivations and barriers is essential in order to determine the best strategy for incentivisation. The main stakeholder in most people's minds is obviously the owner-occupier, but we shouldn't forget all the businesses and companies that have to deliver all of these retrofits - how do we create value for them in terms of business sustainability?

Public Acceptance - acceptance from the householders is key to ease of implementation. Understanding their motivations and building trust between the householders and the other stakeholders in terms of quality, standards, information and support should help to inform the plan.

Scalability - early demonstrators of retrofit have helped us gain a better understanding of the technical issues involved in retrofitting individual properties. What roles do economies of scale and new technologies play in 'scaling up' this retrofit process? Is it a simple matter of adding materials and skilled workers into the supply chain, or is a radically new approach required?

Future Proofing - the visioning exercise highlighted various societal, environmental, economic and technological changes that may emerge within the next twenty years. How do we manage these changes and create a roadmap that is adaptable to various scenarios that may arise due to changing demographics, climate change, societal attitudes and fuel sources? Assumptions for these changes need to be developed and considered.

Skills - 'up-skilling', 'de-skilling', 'knowledge transfer' and the concept of a 'one stop shop' are all variables that need to be tweaked in the development of the retrofit plan, particularly in terms of its effect on the supply chain. What magnitude of upskilling is required and is this deliverable?

Dissemination - The role of dissemination is closely related to the achievement of stakeholder value - how do we engage the media and marketing promotion to make the prospect of retrofit more appealing - is carbon reduction really the right approach, or is 'pimp my house' a more effective way to reach out to householders? Consistency of messaging is also critical - what are the targets? Is there a clear strategy for achieving them?

Mitigating Risk - Most of the barriers to implementation are related to perceived risk - financial, reputational, and environmental. How will these risks be identified and managed throughout the process in order to provide stakeholders with a level of confidence in the process? How would we manage design risks, such as unintended consequences of our proposed solutions, such as overheating, loss of space, decreased ventilation and air quality, etc?

3.3 Retrofit and Refurbishment Case Studies

This report presents the findings from completed retrofit case studies by outlining the interventions of each case study and common problems in retrofitting projects, including costs, supply and installation issues. Other issues such as skill, supply and process gaps that should have been addressed are presented. Overall, this report appraises the results of different refurbishment projects and provides commentary and analysis of general successes and failures which can be applied to both small and large refurbishment projects in the future.

The selected case studies cover a wide range of building types. Each retrofit project is presented in sufficient detail to highlight the pre- and post- refurbishment condition of the dwellings as well as the issues encountered, actions taken and final outcomes of each project.

Summary of Methodology

Several case studies were selected from the wide range of examples to which the Energy Zone Consortium had access. These have been classified according to the following segments:

Age Band

- pre-1900s
- 1900s-1930s
- 1940s-1950s
- post-1960s

Geographic Location

- England
- Northern Ireland
- Wales
- International (Germany, France)

Information for all the case studies was gathered through a questionnaire survey which was conducted among the consortium partners and led by PRP. The partners directly involved with the present case studies, or had contacts with the relevant case study delivery team were responsible for answering a set of questions in order to provide valuable technical information on each project.

Key findings

The case studies examined in this report have similar experiences in terms of common obstacles, successes and failures, and lessons learned. The most common trends are outlined below in order to provide guidance for future retrofitting projects.

Most Effective Intervention(s) - The majority of the projects experienced the greatest success in improved thermal efficiency through the use of wall insulation and improvements to the building's envelope. The use of internal and external insulation will also vary widely, depending on the individual dwelling, heritage constraints and the occupancy of the building.

However, there were varying degrees of success depending on the type of insulation used. For example, aerogel insulation proved difficult to use and significant lead-in times resulted from the limited number of suppliers.

Least Effective Intervention(s) - Despite playing a role in a building's envelope, the replacement of windows proved often to be the least effective and the most difficult intervention during the retrofit process. Overall, windows have a relatively low impact on energy saving and were the most common issue according to those involved in the case studies.

New Technology Difficulties - Given the relatively new nature of a number of interventions and products, difficulties were anticipated by those involved and should be expected in future retrofit projects.

New insulation products, such as Aerogel, also presented unique problems because of difficulties in transport and installation. Those who Aerogel during their retrofit projects explained their hesitation in using this type of insulation again in future projects.

New technologies also often lack warranties because they are considered experimental products, which should be considered by the project team.

Customer Acceptance - Most home owners and tenants were excited about the projects, though their overall knowledge of the retrofit process and expectations varied greatly.

Projects also tended to proceed more smoothly and with less stress if the properties were empty or the residents were decanted during the retrofit process.

There must also be a sufficient level of communication between parties, including the resident so expectations are realistic from the beginning of the project. User manuals and improved 'toolbox talks' are especially important for present and future occupants and will help reach efficiency goals.

Level of Expertise - Given the fact that many of the interventions are relatively new experienced trades people tend to be few or in need of additional training. In some cases, where there was a high degree of construction team inexperience, important details were missed, such as the lack of thorough insulation and sealing which led to detrimental cold bridging.

As a result, a good site manager is essential to a project. Such an individual would be helpful in maintaining communication between parties and addressing any concerns or problems in the early stages of the project.

Availability of Materials - Remaining flexible in terms of potential long lead-in times for the ordering and delivery of materials is especially important, and the potential for delay should be considered into the project plan. Such problems may include few product manufacturers, distance between project site and manufacturer and long lead-in times for popular products. However, if no new innovative products are used and products are readily available 'on shelf', minimal delays can be expected.

Cost implications - Most of cases which had conclusive data on post-refurbishment emission reductions achieve either satisfactory (40% - 70%) or large carbon emission reductions (>70%).

The total cost of refurbishment is highly dependent on the scale of repair works. For example, two case studies achieved over an 80% CO_2 reduction, due to environmental measures. However, this comes at a significant trade-off in terms of cost as such large reductions can only be achieved with significant investment.

Interventions that were the most cost-effective appear to be case studies that were large projects that included a number of dwellings or flats and significant floor area (m^2). These projects were able to achieve the greatest percentage of carbon emissions with the least investment.

However, the cost for non-thermal improvements such as general repairs or replacement of old structural elements dramatically raised the cost of refurbishment and accounts for almost a third of the total cost.

3.4 TECHNOLOGICAL SOLUTIONS MATRIX

This report relates to the deliverable 3.3a, a "Technical Solutions Matrix" which will form the basis for recommendations on whole house solutions for the various house types. The aim of the report was to undertake a comprehensive sweep of what is currently available, as well as emerging developments related to thermal efficiency.

This matrix consists of an infographic that investigates the various solutions that can be used to improve thermal efficiency in our existing housing stock. It sets each solution out against a range of criteria related to design, construction, supply chain, customer acceptance and policy. The original intent was to relate these criteria to the range of house types that will be covered in the study, but as the stock segmentation was still in its early stages we have modified the deliverable slightly to come up with a more modular approach to analysing the technical solutions.

Summary of Methodology

In order to arrive at a simple technical solutions matrix, we examined the problems and issues with existing housing from a stakeholder point of view. This generated a list of solutions that formed the final matrix, which was based on issues that could catalyse the retrofit process.

This non-house type specific approach is a slight variation from the original intent of the deliverable, but this modular approach enabled the creation of a toolset for evaluating technical solutions. This has proved more valuable than the original deliverable itself, as the various components can be adapted to investigate a wide range of house types.

Key findings

Evaluation Matrices - The final Evaluation Matrix shows that the "Top 5" interventions are the ones that are already widely accepted and have been partially implemented across the housing stock - loft insulation, cavity wall insulation, tank and pipe insulation, high efficiency boiler installation, draught proofing and repair of doors and windows. Of interest are the thermal interventions that follow - improvement of building control systems, smart meters, airtightness, internal wall insulation and external wall insulation complete the "Top 10".

In terms of opportunities to add value to the retrofit exercise, the most highly rated non-thermal add-ons were new fitted wardrobes and shelves, which could potentially be used as a "hook" for customers to encourage them to undertake retrofits. This is followed by interior redecoration, new kitchens and bathrooms, rooflights/solar pipes and garden landscaping. The lowest indicative values for the "hooks" were for grey water recycling systems and conservatory/sunrooms.

The lowest indicative values for thermal improvements were received by ground floor insulation, room in roof, rebuilding external walls, MVHR, under floor heating, and heat pumps.

Synergy Matrices -Based on our "Top 10" likely interventions, the following synergies are recommended for each of the fabric-related interventions:

- Loft Insulation - best done in conjunction with re-roofing, room in roof and roof light/ solar pipe installation
- Tank and pipe insulation - best done in conjunction with boiler installation
- New high-efficiency boiler installation - best done in conjunction with tank and pipe insulation, solar hot water system installation
- Draught proofing - best done in conjunction with replacement doors and windows, repair of doors and windows, airtightness improvements
- Repair/improvement of doors and windows - best done in conjunction with draught proofing, thermal bridging and condensation solutions, and airtightness improvements
- Airtightness improvements - best done in conjunction with re-roofing, room in roof, replacement doors and windows, draught proofing, repair of doors and windows, cavity wall insulation, internal wall insulation, thermal bridging and condensation improvements, MVHR installation and new kitchen/bathroom.
- External Wall Insulation - best done in conjunction with replacement doors and windows, insulation for tunnels and passages
- Internal Wall Insulation - best done in conjunction with replacement doors and windows, airtightness improvements, thermal improvement of existing extensions, new kitchen/bathroom, and new fitted wardrobes and shelves.

It is worth noting that these synergies are two-way - for example if the Top 10 item is the primary intervention it would be worth considering accelerating the programme for the synergetic interventions so that they are done within the same retrofit exercise. However, of course if the synergetic intervention is one that is not likely to ever be implemented on the property then it should not be considered. From the opposite perspective, if the homeowner is planning to install a new kitchen or bathroom in the near future then it is a perfect opportunity to pitch the argument for internal wall insulation.

3.5 WHOLE HOUSE SOLUTIONS

Introduction

The Whole House Solutions Report (WP3.3b) builds on the research carried out for the Technical Solutions Matrix (WP 3.3a). Using the matrices as a decision guide, this report tackles the challenge of developing generic whole house solutions for a set of representative house types.

The objective of the report was to consider the issues related to deliverability, quality, cost, performance, scalability, replicability, adaptability and flexibility for a representative set of house types

Summary of Methodology

Building on from the work done previously, the Whole House Solutions Report started with an in-depth look at the most likely technical solutions that would be involved in a whole house retrofit. These include the following:

1. Wall insulation
2. Roof insulation
3. Floor insulation
4. Window and door upgrades
5. Heating system upgrades

Each technical solution was discussed in terms of target U-values (in the case of fabric elements) and specifications, as well the unique constraints associated with the inclusion of each element into a suite of measures. This report introduced the idea of 'decision trees' - a concept that would emerge as a critical element of the project going forward, and a basic decision-making flowchart is presented for each technical solution.

The key findings from the Technical Solutions Report were taken on board during the process of determining whole house solutions. Due to the range of house types available, four types that are distinctly different from each other were selected, in order to work through the range of unique constraints posed by each type. The four types are as follows:

1. Three bed semi detached house (57.5% of the total UK housing stock)
2. Mid-rise block of flats (13.8% of the total UK housing stock)
3. High-rise tower block (1.5% of the total UK housing stock)
4. Hard to Treat property (up to 41% of the total UK housing stock - defined as being solid wall, off gas, no loft space)

Each of these types was analysed in terms of the following framework:

1. Existing condition - what might you find in a property of this type?
2. Issues and Risks - what are the challenges and unknowns?
3. Improvement Options - what can you do to make the property more thermally efficient?
4. Innovation Options - solutions that are not in the mainstream yet but have the potential to solve difficult problems at the critical building junctions. These take on board the findings from a Retrofit Innovations workshop that was held as part of this work package.

Costing exercises were also carried out on the three-bed semi detached option to explore the relative cost between different levels of intervention. The estimates were based on a 1919-1944 semi detached property with a bay window, and reflect current supply chain pricing methodology - a piecemeal, non-integrated approach that is in no way industrialised or streamlined.

Key findings

Bespoking Mechanism required - Every property is different. And while it is possible to propose a suite of measures that would deliver a significant improvement in thermal performance, the inconsistencies in the housing stock mean that once the overall approach has been decided, an efficient method of delivering the solutions would have to include a risk-managed and robust methodology for dealing with the myriad of unique constraints that each property would have. One solution would be a regularly updated decision tree tool that would assess which of the many available solutions would be the closest fit to the property being retrofitted, given the property's unique characteristics.

Current High Cost - Current costs of retrofit are high due to the piecemeal, silo-based method that the construction industry uses for costing and for delivering the work. It is apparent that there is a lot of potential for optimising the process (of the costing itself as well as the retrofit activity) in order to bring down the costs. The costing exercises show that the low-carbon option costs over twice as much as doing a 'quick and easy' - basic thermal improvements with minimal disruption. And incentives such as a room in roof or a new kitchen and bathroom (depending on the standard of course) could cause a quadrupling of the cost. So while saying that we could offer retrofit with a free kitchen and bathroom sound like quite a romantic and inspiring notion, the reality is that it would probably be the other way around - we could target customers who are already eyeing a new kitchen/bathroom package or a loft conversion, and offer them a value proposition for a thermal upgrade at the same time.

Going for the Quick and Easy scenario is the cheapest approach but it is unlikely to achieve our carbon reduction targets. Going for Q&E means ensuring that the home is not performing badly, but for the house to reach "low carbon" or "zero carbon" it will be necessary to implement more thermal efficiency measures. The challenge is to assess how these costs can be reduced, perhaps through offsite manufacture and new technologies, or supply chain optimisation.

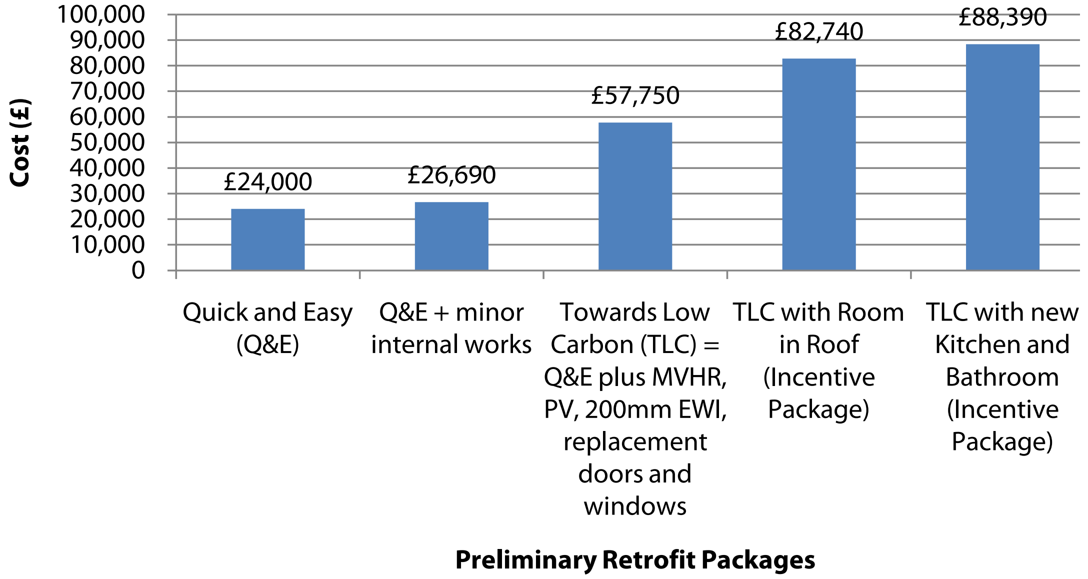


Figure 1. Preliminary retrofit packages and associated costs for a 1919-1944 semi detached property with a bay window.[1]

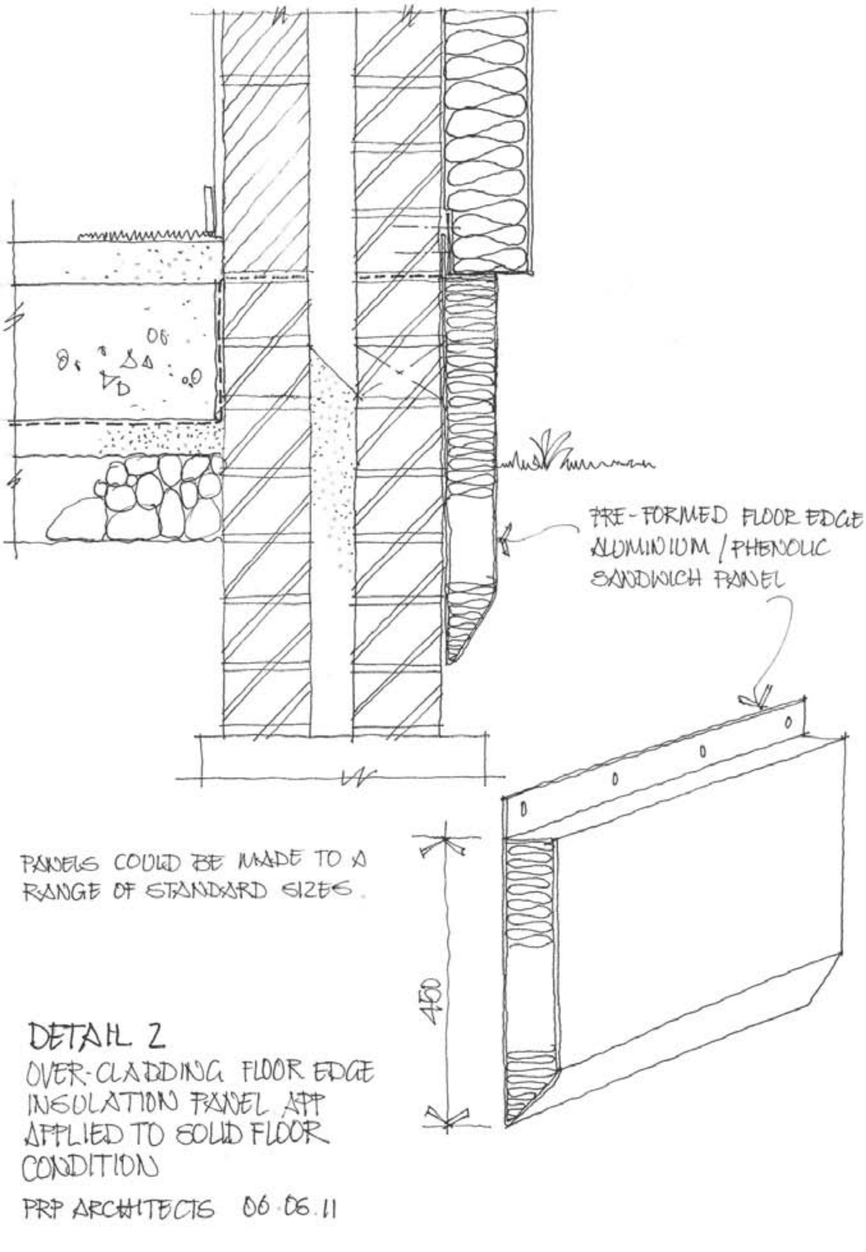
Necessary Innovation- One of the last sections of report investigated the concept of mass-producing junction detail elements - ideas for products that address problematic thermal junctions. These products are presented as complete, easy-install assemblies that clip or slide into place, as thermally broken fixings, or as enabling products which make "mass bespoking" easier. Some of these details may already exist but have not been brought into the mainstream, possibly due to the production volume, lack of marketing, lack of knowledge of the design industry, or lack of skilled installers. An example is provided below while more detailed information can be found in the original report.

Floor edge insulation panel

It is generally accepted that EWI over-cladding should not be taken below DPC level to insulate a concrete slab edge, either fully exposed or set behind a cavity wall as drawn. Both Sto and Permarock have separate details for insulating below DPC using EPS wrapped in a membrane.

This proposal suggests that a pre-formed, aluminium-faced insulated sandwich panel could be used in conjunction with any cladding system, installed with the base starter track at the beginning of a project. A bespoke panel would be quicker and simpler to install, and would eliminate inconsistencies that might occur when working in the ground. Size, thickness, depth and colour would need to be determined, and a range of options may be required.

[1] For further information regarding these preliminary packages and how these costs were calculated, please see report *3.3b Whole House Solutions*, 30 June 2011.


PRE-FORMED FLOOR EDGE
ALUMINIUM / PHENOLIC
SANDWICH PANEL
450
PANELS COULD BE MADE TO A
RANGE OF STANDARD SIZES.
DETAIL 2
OVER-CLADDING FLOOR EDGE
INSULATION PANEL APP
APPLIED TO SOLID FLOOR
CONDITION
PRP ARCHITECTS 06.06.11

3.6 VIRTUAL REFURBISHMENT

Introduction

The Virtual Refurbishment Report builds on the research carried out for the Technical Solutions Matrix (WP 3.3a) and Whole House Solutions (WP 3.3b) reports. Taking the solutions proposed in WP3.3b, we took a critical look at implementing these solutions for the UK's four countries - England, Scotland, Northern Ireland and Wales, looking at the differences in the housing stock and the unique constraints on thermal efficiency improvements that exist in each country. The overall objective was to investigate the robustness of the solutions for housing outside of England - and to enrich our anecdotal evidence of the differences in housing stock across the four countries with actual case study visits and interview with local experts.

In addition to the case study visits, we also started testing house types using the single dwelling model from work packages 1 and 2 in order to start looking at comparative energy and carbon reduction potential.

Summary of Methodology

In order to test the solutions, we came up with simplified packages to test against at least three different house types for each country. These house types were selected based on frequency of occurrence, contribution to the CO_2 emissions of the UK's existing housing stock and geographical spread. Some house types that were ultimately included in the final report may not have a high frequency across the UK, or be the biggest contributor to housing stock CO_2 emissions. However, our aim is to take a holistic approach that examines the wide range of housing types and ages across the UK. For example, a flat tends to have very a different construction than other housing types and although not a major presence in all the countries in the UK, its unique features could not be overlooked. The chosen house types are the following:

1. E19M English pre-1919 mid-terrace house
2. E44S English 1919-1944 semi-detached house
3. E64S English 1945-1964 semi-detached house
4. S19F Scottish pre-1919 low-rise flats (ground, mid and top floors)
5. S44F Scottish 1919-1944 low-rise flats (ground, mid and top floors)
6. S19D Scottish pre-1919 detached house
7. S80D Scottish post-1980 detached house
8. W19M Welsh pre-1919 mid-terrace house
9. W64S Welsh 1945-1964 semi-detached house
10. W80D Welsh post-1980 detached house
11. NI80S Northern Irish post-1980 semi-detached house
12. NI80D Northern Irish 1965-1980 detached house
13. NI19D Northern Irish pre-1919 detached house

For each house type, we decided on three retrofit packages. These packages of energy efficiency measures and improvements were decided upon based on that which was set out in Work Package 3.3 and grouped based on the degree of disruption for the measures. We then ran the three packages through the ETI TE model in order to determine fuel savings, construction costs, CO_2 emissions reduction and energy savings.

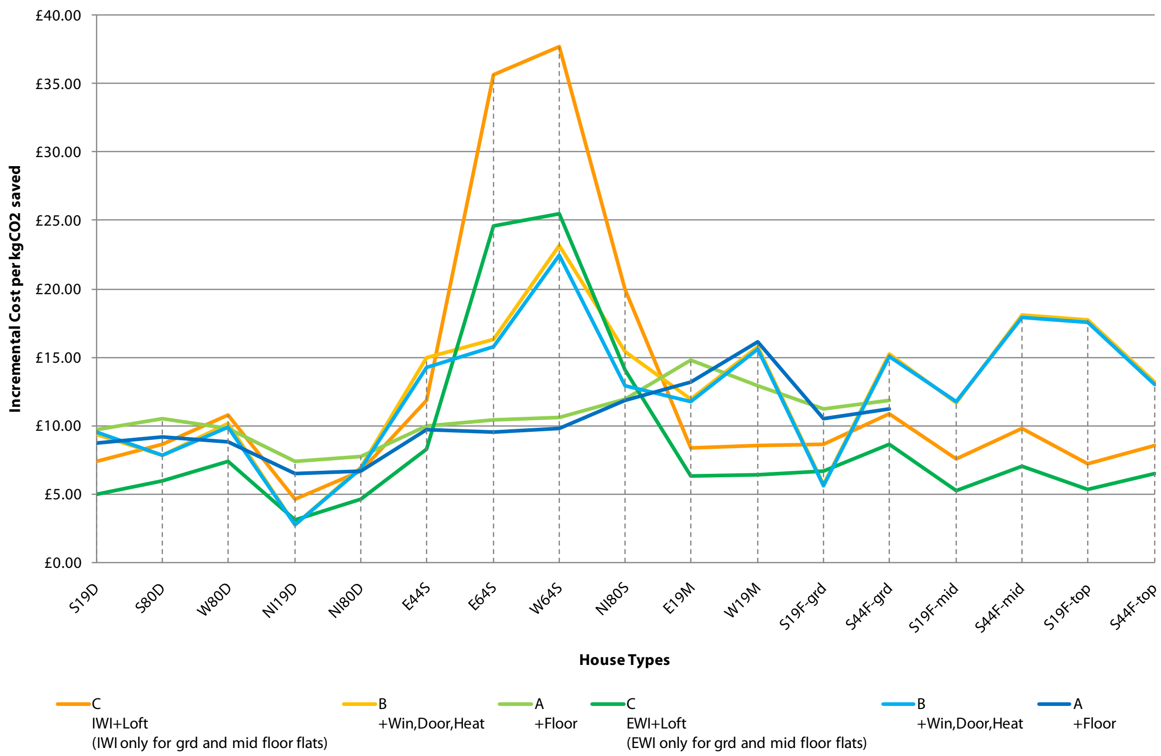
Package C - Wall insulation (IWI or EWI as appropriate) + Loft Insulation

Package B - Package C plus replacement windows and doors and upgrade of heating system

Package A - Package C and B plus ground floor insulation and MVHR and other airtightness measures

Key findings

The graph starts at the leftmost side with detached properties and then moves towards the right hand side in terms of reduced area of exposure - semi-detached properties, then mid-terraces, then flats.



There is a noticeable difference in the cost-effectiveness of wall insulation for properties built ca. 1964 (E64S and W64S) because of the fact that the existing fabric is already comparatively thermally efficient therefore any additional insulation does not have as significant an effect as it would if it were being applied to an older construction.

For mid and top floor flats, the most cost effective measures are replacement windows, doors and heating systems (S44F and S19F mid and top)

For most of the detached houses, EWI+Loft insulation is the most cost effective measure, and with the exception of W80D, floor insulation is the most cost inefficient measure. For the semi-detached houses, the most cost effective measure is floor insulation, and with the exception of N180S and E44S, the least cost effective measure is IWI+Loft insulation.

The mid-terraces behave similarly to the detached houses - wall insulation is the most cost-effective and floor insulation is the least cost effective.

Acceptance and Applicability - While external wall insulation is likely to be the most cost effective in improving energy efficiency and reducing CO_2 emissions, it is likely to be difficult to install both from a planning perspective as well as the actual installation itself (due to the wide variety of façade detailing variations), and disruptive. Few people are likely to elect to have internal wall insulation measures done, given the scale of disruption and concern over personal belongings, valuables and pets. Cavity wall insulation will be the least invasive, though there are differing views on the process across the UK, most noticeably in Scotland. As such, wall insulation methods will need to be considered on a country-by-country basis which will then need to be subdivided by area based on age, tenure and aesthetics.

Loft insulation is the other most cost effective measure in reducing carbon emissions and energy demand. However, unlike wall insulation, the installation of loft insulation is widely accepted by the general public as a typical building measure. There tend to be similar feelings toward the replacement of windows, doors and boilers. Approximately half of the housing stock will most likely already have this installed, however (double glazing has roughly the same percentage of occurrence) and for significant thermal improvement to happen, wall insulation is typically the next big 'bang for buck' in terms of heat loss.

Convincing the public to undertake package A is likely to be difficult. The level of disruption is comparable to internal wall insulation with regard to expected mess, inconvenience and duration of works, as well as the need to move resident belongings. However, underfloor heating is an attractive consideration for many people and coordination with ground floor installation may improve the uptake of this measure.

Supply Chain - As suggested previously, there are significant differences between the current state of the supply chain for different solutions. Loft insulation and the replacement of windows, doors and boilers have well established supply chains which would enable an easy roll out of these measures. However, effective internal and external wall insulation (which would need to include internal and external decoration following installation. This is the case for ground floor installation and as such, the only way to improve acceptance and implementation would be to improve overall efficiency in the supply chain.

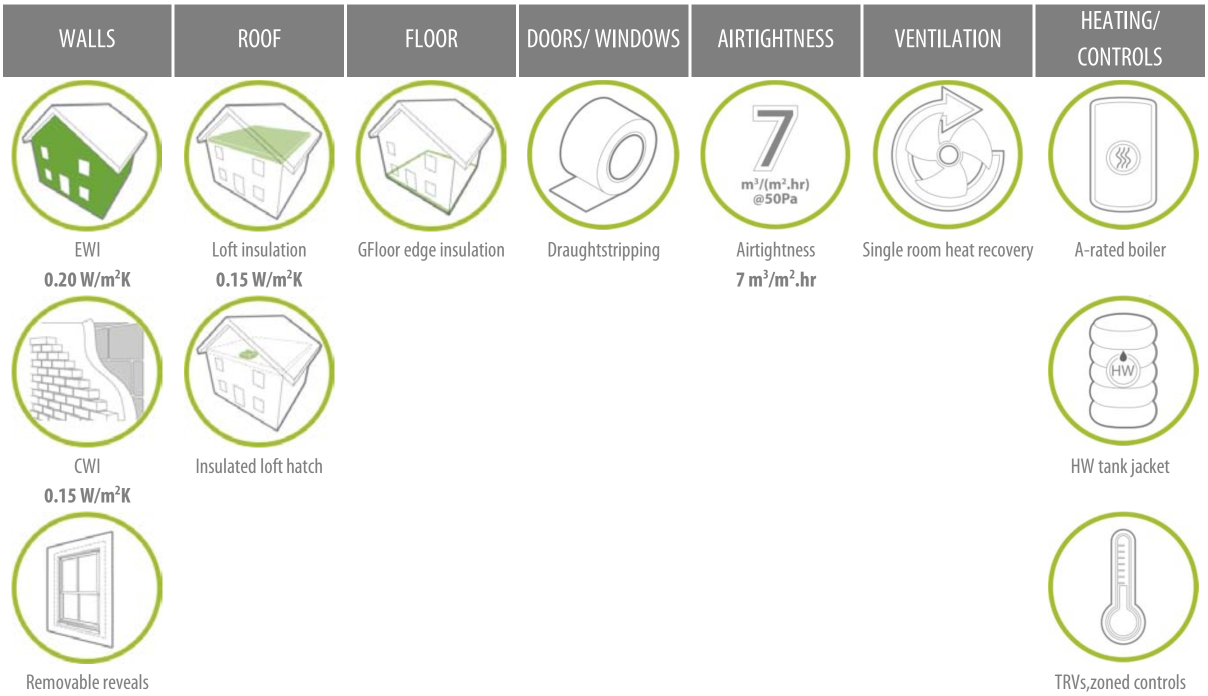
Costs- The model used to achieve the results for the three packages for each of the house types is reflective of the supply chain as it presently stands. As such, the cost of installation remains high and is unlikely to be attractive to the majority of the population in the UK. If overall efficiency is improved within the supply chain, it is expected that costs would be cut in half. Effective coordination with Government funding will also be essential and would greatly improve the attractiveness of all three packages. This remains the biggest obstacle for achieving a UK wide retrofit programme.

3.7 Single Dwelling Implementation Plan

Introduction

This Single Dwelling Implementation Plan report outlines 24 whole house package variations for the most promising customer segments and associated house types in terms of uptake and frequency.

RetroFix. The first section of the Whole House Packages begins with the basic or "RetroFix" packages, which are considered to be interventions that would improve a property's thermal efficiency by 20-50%. These are improvements on the "Quick and Easy" packages which were a feature of the previous work packages.



Enhanced, or "RetroPlus" packages include what were considered as "Good Practice" measures coupled with added-value options that would be tailored to the customers living within them. Hence there are 8 main variations on the RetroFix Packages, while there are 20 variations on the RetroPlus Packages. The RetroPlus packages are more sensitively tailored to the customer segment occupying them.

Enhanced packages take the basic package as a starting point and then further improve thermal efficiency using floor insulation, replacement doors and windows, better airtightness and more innovative heating systems.

RetroPlus - Finally, as a theoretical exercise in pushing the boundaries of current technical solutions, we also modelled the results of a Passivhaus-like option, which was based on the Passivhaus for retrofit, or EnerPHit standard, which has much higher U-values for the individual components, solar thermal hot water systems, MVHR, and an airtightness of $1.0m^3/(m^2.hr)@50Pa$. This was mainly an exercise in finding out if going for a very high standard would be more effective in getting significant reductions in energy consumption, and by how much. However, current costs for this magnitude of intervention would be prohibitive if done on a mass scale, as well as issues related to availability of materials and skilled installers. As such, costing was not modelled because the modelling would not be able to account for the increased cost of higher-standard thermal and airtightness detailing, solar thermal systems and MVHR, therefore modelling the costs of the Passivhaus option would not yield meaningful results.

Summary of Methodology

Chosen house types were determined according to the typology in which the highest percentage of the customer segment live, and the house types which emit the most CO_2 emissions per segment. Customer profiles have dictated aspirations, values, motivations and energy consumption behaviour, which were then used to develop design solutions and delivery programmes.

The pivotal exercise of WP3.4 was the Single Dwelling Implementation Plan workshop which drew on the practical expertise of consortium partners and PRP's own in-house retrofit specialists to develop design solution for each house types. This included not only architectural and construction considerations but the customer segment most likely to reside in each house type and their attitudes toward thermal refurbishment.

The design workshop also helped to identify gaps in materials and process which may lead to a demand for particular product innovations that will facilitate the retrofit process. 'Dream' products that would help improve the retrofit process in terms of cost, efficiency and overall attractiveness to the general public were also taken into account. These products have been analysed by project partners at BASF and have been also been utilised by WP4.

Key findings

Cost Efficiency - Post-1980 properties are not cost effective to retrofit at our basic level, all Pre-1980 properties reasonably demonstrate cost effectiveness in terms of retrofit. While Post-1980 homes show benefits at enhanced level for carbon emissions reduction and fuel savings, but it is not very cost effective because of the high cost of minimal carbon reductions. However, some pre-1919 properties experience a reduction in carbon emissions by up to 50% for the basic packages, and up to 58% for the enhanced packages. Achieving RetroPlus standards can result in reductions of up to 75%.

Occupant Behaviour - Occupant behaviour is a factor that should not be ignored, particularly when predicting energy savings - we have demonstrated that for the same house type and same set of solutions different types of occupants greatly influence fuel savings and CO_2 emissions reductions. For example, despite reductions in lighting, appliance and hot water use, given the same house type, Greener Graduates use up more energy overall - spending around £100 more per annum than the Young Starters, living in the same type of property but heating to a 1°C higher set temperature.

Required Innovation- If we want to hit more ambitious "low carbon" targets, relying on current construction methods and materials is not enough. We can only hit these targets if we aspire to meet Passivhaus-type standards, and promote the development of solutions that will enable us to hit the high performance U-values that are required.

Cost- If we set £10,000 as a threshold value for the basic package, we find that nearly all of our basic and enhanced packages for the low income groups to not fall within this zone. Some of the basic packages for the higher income groups come close to this threshold, but presumably even with a slightly higher cost they may decide it is worth it if they can be convinced that the retrofit is of value. In any case it is clear that costs must come down, financial enablers must be made available to make whole house retrofit available to our target customer groups, or that a consumer engagement exercise is undertaken such that the threshold for spending increases, or a combination of all three.

Added Value- Loft conversions are generally not viable in terms of cost effectiveness and thermal benefits. We need to explore other ways of adding value by creating habitable/storage space. Major works, such as these loft conversions and kitchen and bathroom renovations, could be an opportunity or a trigger for retrofit instead, and we should explore the concept of piggybacking onto these works as opposed to offering them as incentives. Retrofitting could perhaps be the incentive instead of the other way around.

3.8 MASS IMPLEMENTATION PLAN

Introduction

The aim of report 3.5 was to explore and detail the necessary actions along the trajectory from 2012 to 2050 for retrofit across the UK. It was envisioned that this period should be divided into three distinct phases: Preparation to 2020, Retrofit Rollout 2020-2030 and Future Scenarios 2030-2050. These sections further detail the key tasks and initiatives necessary across all work streams to launch a mass retrofit programme and identified the likely remaining obstacles to programme success in 2020. A future planning workshop helped to develop plans for post-2030 based on key variables related to supply chain development, customer acceptance and changes in climate, and analysing their impact on retrofit.

The report is intended as an overview document that can be used to plan the mass rollout of retrofit in the UK. It is also meant to flag potential obstacles and areas of opportunity which should be considered when developing the strategy for mass implementation of retrofit.

Summary of Methodology

Preparation to 2020- This first section examines the preparations required for the deployment of the first wave of mass retrofit in 2020. These actions were decided upon following an extensive workshop with consortium partners, which concluded with a completed comprehensive timeline. Each task was then detailed in terms of what needs to happen, when and where it needs to take place, who will be involved and how to engage these stakeholders.

Retrofit Rollout 2020-2030- This second section assumes that the preparatory tasks to 2020 have taken place and a mass retrofit programme is set to begin. Assuming everything is in place by 2020, there are still potential challenges to consumer uptake, the foremost of which will be customer acceptance. Other major obstacles, including available funding, heritage concerns, and appropriate upskilling are identified and their impact on retrofit examined.

Future Scenarios 2020-2030- The last part major part of the report is the result of an exercise in future planning. Consortium members attended a workshop which addressed the difficult task of planning post-2030. The wide range of variables that could significantly impact the success of mass retrofit, meant scenario planning would help to better assess the range of possibilities and consider the way in which to address the scope of outcomes that might impact a successful programme.

Key findings

The major dependency for the success of a mass retrofit programme is customer acceptance. Regardless of the preparatory work to 2020, the success of any retrofit scheme will depend on customer awareness, understanding and most importantly, trust. All the activities outlined in Section 3 must work towards ensuring these conditions are met, as there is little use in developing solutions, implementing policy and training poly-competent teams if customers do not believe the retrofit process to be a worthwhile investment. Consumer engagement, in terms of mass marketing, service offerings and retrofit open days will be essential to guarantee the work in the other three work areas will have use in 2020 and beyond.

The timeline to 2020 is obviously very front heavy, making it exceptionally ambitious and complex, with each work stream needing to make significant headway before 2015. In fact, it is necessary that the majority of preparatory work should take place in the next two years in order to be ready for 2020. Strong coordination between the work streams will be necessary since a number of the activities work in conjunction with, or are dependent on, one another.

While planning post-2030 remains difficult because of a number of future uncertainties, we have identified the key variables that will likely have the greatest impact on retrofit as including customer acceptance, supply chain development, fuel mix and climate change. These are most likely to have a significant role in changing the pressures on consumers to retrofit their homes, on the supply chain to take-up the franchise business model and the individual house packages as designed in WP3.4b.

4 Key Findings and Recommendations

4.1 Synthesis of Key Learnings across Deliverables and Work Packages

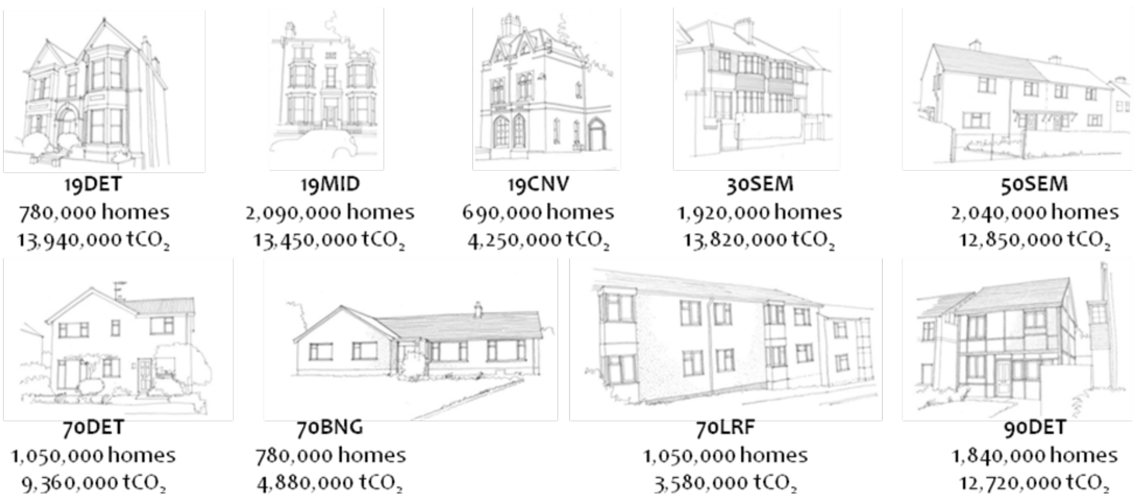
Aesthetics

External wall insulation is a key thermal element for both Retrofix and Retroplus packages, and as such the effect of a mass rollout on neighbourhood streetscapes will need to be considered. The following measures can be explored as part of the product optimisation and improvement of External wall insulation:

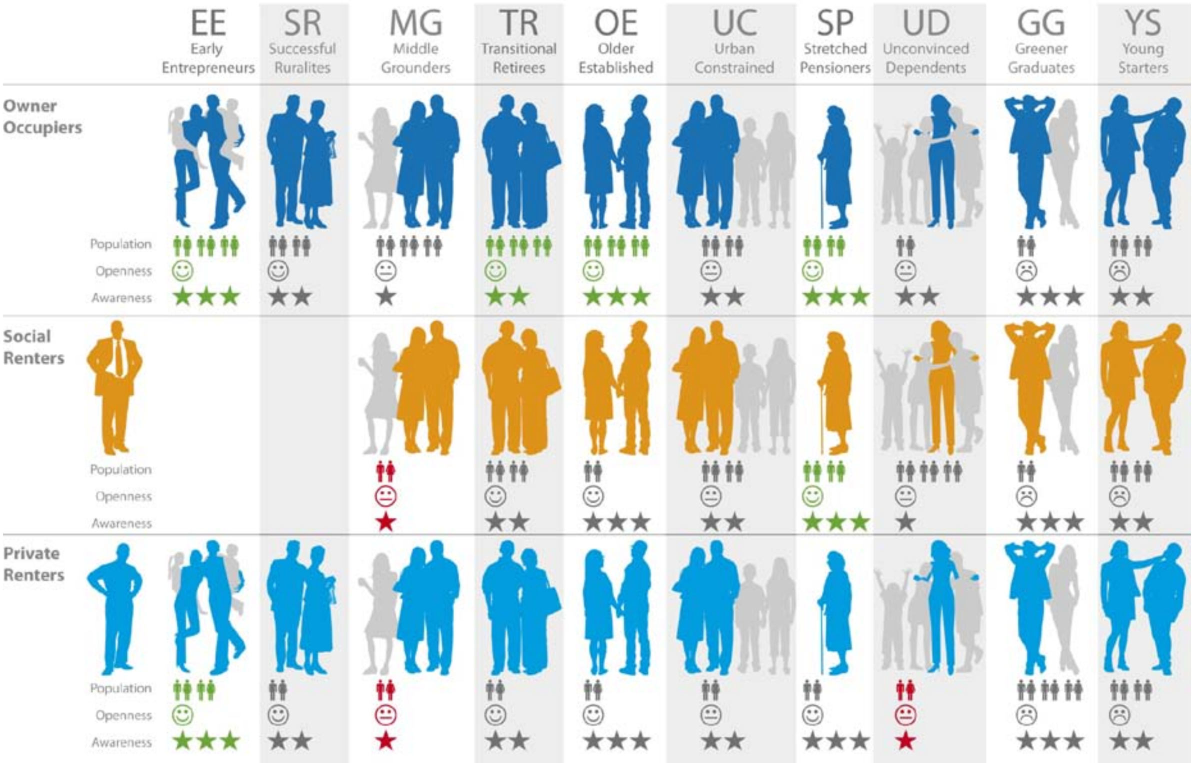
- integrated insulation and wall finish product that can be manufactured off-site
- varieties of wall finishes and colours to avoid monotony on a street
- the use of rapid prototyping to re-create external decorative features rapidly and cheaply
- development of design guidelines for each local area that presents a pattern book or palette of finishes, linked to a local supply chain that can provide packages that are suited to the architectural language of the area.

House Types

The most likely house types to target for mass retrofit should be based not only on their frequency of occurrence but also their impact on overall carbon emissions. These include the following:



In terms of customer types, segments should be considered according to the size of the population, their openness to retrofit, and their awareness of environmental issues. The following table shows that the most likely primary target markets for retrofit would be within the Early Entrepreneurs, Transitional Retirees and Older Established Segments. Stretched Pensioners are open to retrofit but may be limited by their ability to fund the retrofit.



Whole House Solutions

The whole house packages that emerged as a result of this project comprise solutions that scored highly across these categories - solutions that made sense from a design and construction point of view, affordable, and were relatively easy to bring to market and upscale into mass-market implementation. Solutions that were also cost-effective in terms of cost per kWh of energy saved were also included, but were considered in terms of how potential improvements could be applied to both product and supply chain in order to improve scalability and deployment.

"Do it once and do it properly" was the key to the generation of these whole house packages. Incremental piecemeal improvements do yield thermal efficiency improvements, but the installation of these improvements as a whole system would yield benefits in terms of cost effectiveness (avoidance of cost duplication), enhanced performance (better thermal detailing at junctions), risk mitigation (minimise damage/decreased performance of previously installed measures), waste minimisation and disruption.

We all know that the solution to our problems would be a super-thin high-performance insulating film that can be applied in seconds with no visible change to the properties being retrofitted.

However, this product does not exist and realistically if we are to design a programme for mass retrofit that will be deployed successfully by 2050, we need to look at the here and now, analysing currently available materials and taking them through a cycle of continuous optimisation and improvement. Most of the solutions that we would need for mass-scale whole house retrofit currently exist in some shape or form - the key is to work on making them better, high performing, and assembling them as an integrated systems solution that ensures that each component performs as it should instead of the piecemeal approach to retrofit that is employed today.

There are a number of factors that influence the success of a particular measure or solution - it is not simply about cost or performance. Supply chain maturity, consumer acceptance and the robustness of national and local policies all play a crucial role. These include the following:

Design and Construction	Supply Chain	Customer Acceptance	Policy	Cost
• Visual impact on the streetscape • Range of aesthetic choices • Ease of installation • Waste generation • Ease of installation	• Potential for offsite manufacture or automation • Availability of materials/Lead time • Availability of skilled installers • Robust installation methods/processes • Scalability	• Disruption potential • Ease of use • Awareness • Lifestyle impact • Desirability/Visual impact on the householder	• Carbon reduction effectiveness • Potential for provision of funding mechanisms • Quality assurance of installation and products • Health and Safety • Minimal planning or regulatory constraints	• Capital Cost • Cost of ancillary works • Cost escalation risk • Maintenance costs • Availability of funding

Retrofix packages were designed to improve the thermal efficiency to a level which would make a significant step towards the 2050 Climate Change commitments (20-50% savings) without excessive cost. These packages typically include external wall insulation, loft insulation, floor edge insulation, draught proofing, single room heat recovery, a boiler upgrade, how water tank and distribution system insulation, improved controls and airtightness. The potential for CO2 savings is typically between 20-55% for a Retrofix whole house package, with the pre-1919 detached property (with Successful Ruralite occupants) demonstrating a considerably higher percentage of improvement than the rest of the house types modelled due to an inefficient base position in terms of carbon emissions. In contrast, the post-1980 detached property (with Elderly Established occupants) demonstrated the least benefit from the Retrofix refurbishment solution, due to its newer and therefore relatively energy-efficient fabric.

Retroplus packages include all of the solutions in the Retrofix packages plus floor insulation, replacement doors and windows, better standards of airtightness and more innovative heating systems. These packages would are less cost effective on a cost per kg of CO2 saved (new doors and windows are not cost-effective on this basis, however they do yield psychological and visible benefits that are part of the overall value proposition for the consumer), and are likely to involve a greater level of disruption than the Retrofix packages. Retroplus packages offer up to 18% more savings in CO_2 emissions compared to the retrofit option, potentially saving between 30-65%.

Again, for Retroplus the highest percentage of improvement is demonstrated by the pre-1919 detached property (with Successful Ruralite occupants) and the lowest percentage improvement is demonstrated by the 1965-1980 low rise flat (with Young Starter occupants).

The majority of dwelling/household combinations generally showed increased savings ranging from 1% to 7% for Retrofix and 5% to 12% for Retroplus using projected carbon factors and weather data for 2030.

Innovation

One element which has not been included as a significant barrier, but which can contribute to the overall success of the programme is product innovation. The essential products necessary for retrofit are already available, although some will need to become more widely available and with reduced costs. Roll-out is not therefore wholly dependent on radical product innovation, although thinner insulation, easy to install materials and specialist products will be useful for hard to treat homes or dwellings with non-standard features.

While product innovation is not essential, the supply chain will require a significant step-change and a complete re-designing of supply from an end to end perspective. Key changes include reducing waste through collaboration, optimised site delivery, simplified accreditation for materials and systems, effective training for industry and transparent funding mechanisms and incentives. Without these innovations, retrofit is likely to remain costly and slow, and therefore largely unattractive to the wider UK public.

Cost

Current costs of retrofit are high due to the piecemeal, silo-based method that the construction industry uses for costing and for delivering the work. It is apparent that there is a lot of potential for optimising the process (of the costing itself as well as the retrofit activity) in order to bring down the costs. The costing exercises show that the low-carbon options costs over twice as much as doing a 'quick and easy' - basic thermal improvements with minimal disruption. And incentives such as a room in roof or a new kitchen and bathroom (depending on the standard of course) could cause a quadrupling of the cost. So while saying that we could offer retrofit with a free kitchen and bathroom sound like quite a romantic and inspiring notion, the reality is that it would probably be the other way around - we could target customers who are already eyeing a new kitchen/bathroom package or a loft conversion, and offer them a value proposition for a thermal upgrade at the same time.

Going for the Quick and Easy scenario is the cheapest approach but it is unlikely to achieve our carbon reduction targets. Going for Q&E means ensuring that the home is not performing badly, but for the house to reach "low carbon" or "zero carbon" it will be necessary to implement more thermal efficiency measures. The challenge is to assess how these costs can be reduced, perhaps through offsite manufacture and new technologies, or supply chain optimisation.

4.2 RECOMMENDATIONS FOR ROLL-OUT

The major dependency for the success of a mass retrofit programme is customer acceptance. Regardless of the preparatory work to 2020, the success of any retrofit scheme will depend on customer awareness, understanding and most importantly, trust. All the activities outlined in the work package 3.7 for the four workstreams - technical solutions, supply chain, customer acceptance and policy - must work towards ensuring these conditions are met, but there is little use in developing solutions, implementing policy and training poly-competent teams if customers do not believe the retrofit process to be a worthwhile investment. Consumer engagement, in terms of mass marketing, service offerings and retrofit open days will be essential to guarantee the work in the other three work areas will have use in 2020 and beyond. Effective marketing and consumer engagement activity is therefore vital from 2012 and onwards. This will include tangible evidence of successes achieved with demonstrator projects and early adopter case studies. It will be important to engage with consumers using a range of media, targeted to specific customer types throughout the period to 2020 and beyond. The major obstacles beyond customer demand are likely to include:

- Available funding and cost
- Heritage and aesthetic concerns
- Improved trust in the building industry
- Appropriate upskilling

The timeline to 2020 is obviously very front heavy, making it exceptionally ambitious and complex, with each work stream needing to make significant headway before 2015. In fact, it is necessary that the majority of preparatory work should take place in the next two years in order to be ready for 2020. Strong coordination between the work streams will be necessary since a number of the activities work in conjunction with, or are dependent on, one another. If each of the tasks outlined for the four workstreams are achieved by 2020, a mass retrofit programme is likely to have a successful and efficient roll-out. The initiatives are aimed to create the conditions in 2020 that support both customer interest acceptance and supply chain development. The key factors that will have to be in place at the beginning of the decade are:

- Stable and supportive national and local policy
- A trustworthy and efficient supply chain
- Cost effective materials and products
- Effective and robust standard whole house packages
- Attractive marketing and value propositions

While planning post-2030 remains difficult because of a number of future uncertainties, we have identified the key variables that will likely have the greatest impact on retrofit as including customer acceptance, supply chain development, fuel mix and climate change. These are most likely to have a significant role in changing the pressures on consumers to retrofit their homes, on the supply chain to take-up the franchise business model and the individual house packages as designed in our whole house solutions work package.

5 Knowledge Gaps and Further Work

The issue of rolling out whole house retrofit is of course a complex and multidisciplinary one - and requires the coordination of several disciplines from materials innovation R&D, architecture, construction, consumer engagement, government, process manufacture, supply chain trades and could benefit from the input of disciplines as far as chemistry, physics, nanotechnology and robotics in order to solidify the nebulous vision of a streamlined and ultra-efficient retrofit delivery industry that not only has all the dream materials possible at its disposal; has construction workers who are 100% highly skilled at doing everything, always come prepared, never make mistakes and never spend hours on their tea breaks; government policy that is dependable, robust and risk free; a logistical infrastructure where everything gets delivered instantaneously and on-demand; a robotic retrofit machine that laser-scan surveys, 3D-prints replacement parts and installs everything perfectly within a day; but also consumers that are absolutely begging for retrofit and want undertake retrofit much, much more than they would want a pair of athletics tickets for the London 2012 Olympics.

Unfortunately, things are not as easy as that and there is still a lot of work to be done. Our work to date has shown us is that the issues are quite complex and here are just a few things to take forward that could help increase the chances of our success:

Scenario Planning - Work package 3.5, our Mass Scale Implementation Plan report, not only outlines a set of multidisciplinary tasks to 2020 that should help pave the way for the success of the mass retrofit programme but also sets out a "Plan B" (also a Plan C and D) for when things don't go as planned due to the uncertainly of fuel sources and climate change. A further more detailed scenario planning exercise would help to identify risks so that we can plan ahead for how they can be mitigated, or identify the sensitivity to specific events that are crucial to the success or failure of a mass retrofit programme.

Consumer Focus - Marketing to consumers was never a focus of this project, but we did get a peek into the different consumer segments which further strengthens the case for the need to understand what motivates people, how we can encourage uptake, and how people really use energy so that we can make any energy modelling more robust and realistic - carbon emissions and energy consumption is extremely sensitive to changes in occupancy, usage behaviour and temperature settings and there is little statistical evidence that conclusively links these factors to defined consumer segments. Further research into this area is needed in order to understand the market and how it will evolve by the time we roll-out a programme of mass retrofit.

Survey tools - The need for a robust and efficient survey methodology and possibly innovative tools is crucial if the supply chain is to get off to a good start. Good survey data means designers can design quicker and more accurately and that the works has a whole can finish more efficiently and predictably. An iterative pilot field demonstration of the survey process and the data outputs would help to establish the process flow for the survey would help to test survey designs and develop one that becomes that standard for retrofit providers - with a standard it can be certified and trusted, avoiding repetition of efforts and making it useful to the entire supply chain, not just the designers or the contractors.

Choices, choices - Our virtual refurbishment exercise only served to make us realise that no matter how hard you work to create a sensible set of housing typologies, the fact remains that every house is different - even if they were geometrically the same, we can always guarantee that their occupants would have tried their best to make them different from each other. Therefore it is not enough to have standard whole house packages, even if they are based on house type. A bespoking tool will need to be developed to take these standard packages further so that more of the guesswork is taken out and the design customisation time is minimised. This tool needs to consider any unique features that may exist, risks and constraints to the retrofit, and wide range of solutions available in order to narrow down the choices to the ones that are the most logical, safe, and appropriate to the property being retrofitted. As part of our work on work package 3.5, we developed a series of decision trees by technical solution that assesses the branching scenarios one might encounter when faced with a real property. The tool at the moment is unwieldy but it would certainly be possible to convert it into a portable electronic format that would form the basis of a surveying or preliminary design tool.