Programme Area: Buildings

Project: Building Supply Chain for Mass Refurbishment of Houses

Title: Vital refurbishment report

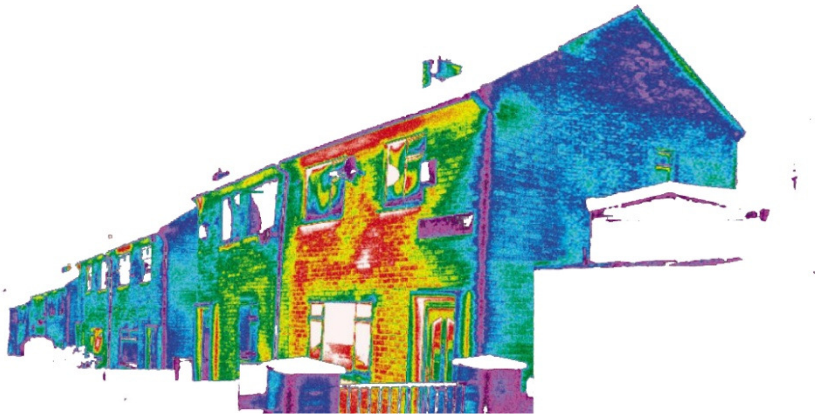
Abstract:

Please note this report was produced in 2011/2012 and its contents may be out of date. This deliverable is number 4a of 7 in Work Package 3. It builds on prior work in deliverables 3.3a (Technical Solutions Matrix) and 3.3b (Whole House Solutions) and critically assesses the challenges and opportunities associated with implementing these solutions across England, Scotland, Wales and Northern Ireland. This assessment takes into account the differences in housing stock and the differing constraints applicable in each country. The goal of the deliverable is to analyse the success of the solutions proposed and identify any gaps which need to be addressed when developing the single dwelling implementation plan, deliverable 3.4b.

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

Virtual Refurbishment Report 3.4a

Revision 1b

Submitted by PRP on behalf of the
ENERGY ZONE CONSORTIUM

8 December 2011

Optimising Thermal Efficiency of Existing Housing

Virtual Refurbishment Report 3.4a

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

1. Contents

2. Executive Summary

The Virtual Refurbishment Report (WP3.4a) 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 is to *analyse the success of the solutions and identify any gaps which need to be addressed when formulating the single dwelling implementation plan*. More detailed aims of the report include:

i. To cover a sufficient range of house types to gain a good picture of the issues involved with implementing a mass retrofit programme
ii. To take the whole house solutions in WP3.3 and examine them with regards to buildability, cost, carbon effectiveness and customer acceptance
iii. To test out whole house solutions proposals on the most frequently occurring house types across the UK, focusing on the variations in construction and housing typology in England, Scotland, Northern Ireland and Wales

In order to cover the wide range of house types across the UK, three predominant house types from each country were considered. In order to test the solutions, we came up with simplified packages to test against these house types for each country. The previous work undertaken on work package 3.3b (Whole House Solutions) features four housing types commonly found in England - the three bed semi, the mid-rise block of flats, the tower block, and the mid-terrace hard to treat property, in which most issues concerning retrofit solutions in England have already been covered. These have been used as a starting point for comparison with the three other countries.

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.

The TE model developed for the ETI was used in conjunction with these chosen house types and the energy efficiency measures outlined in WP3.3. Measures were grouped into work packages A, B and C, according to the level of associated disruption, which can be implemented both within isolation and in conjunction with each other. These outputs have provided a strong idea of the associated costs, fuel and energy savings and reductions in CO_2 emissions. The diversity of construction typologies has resulted in different combinations of work packages in order to achieve the optimum balance of cost and CO_2 reductions.

3. Introduction

Following the work completed in Technical Solutions Matrix (WP 3.3a) and Whole House Solutions (WP 3.3b) reports, the next step was to test the applicability of the proposed technical solutions on the most prevalent house types across the UK. Given the complex nature of energy efficiency installations, cost, energy use, CO_2 reductions and measure effectiveness had to be taken into consideration.

In order to achieve the creation and dissemination of a UK wide retrofit programme, the wide range of potential energy efficiency measures had to be consolidated into 'packages' A, B and C which would achieve maximum cost-effectiveness (more information regarding these packages is provided under Methodology). These three packages reflect the installations and building works that, we predict, would have the biggest impact on improving energy efficiency in UK homes. Despite the wide range of architectural and construction typologies across the four countries, there are basic works that are largely applicable to the majority of UK homes: wall and loft insulation; replacement windows, doors and heating systems, and ground floor insulation combined with mechanical ventilation heat recovery systems and other air tightness measures.

This report aims to explain the differences and unique constraints of each country in order to identify the obstacles likely to be encountered when rolling out a mass retrofit scheme. This background information was then applied to the ETI TE model to identify the costs, energy savings and CO_2 reductions associated with the proposed three installation packages.

4. Methodology

To answer the questions set out for this work package, we used a combination of desktop research, looking at previous documentation on the building fabric and characterisation of the UK's housing stock as well as the stock segmentation results from WP2 as provided by our consortium partners at the BRE. From this we were able to derive a list of the most frequent and most carbon-emitting house types in the UK's housing stock, segmented across the four countries. We coupled this desktop research with case study visits to Scotland, Northern Ireland and Wales in order to understand which details were similar or very different to English construction and housing typology, as well as investigate the wider issues that could potentially affect a future program for mass retrofit.

For the detailed case study visits, we used the pro-forma on the following pages to ensure that we covered as many of the issues that we needed for this stage of the work. This was developed in conjunction with Wates, who provided its own checklists which have been used on actual construction projects, combined with PRP's list of survey items that need to be looked at pre design work.

Finally, we used the ETI TE model in order to test initial whole house packages across a selection of house types in the four countries, to find out how fuel savings, CO_2 emissions and energy consumption vary depending on the house type and location. After the baseline setting for each housing type was established, Package C (wall and loft insulation parameters) was first applied to the model. Following this application, Package B (replacement of windows, doors and heating system) was analysed in the model in conjunction with Package C. Lastly, Package A (ground floor insulation and MVHR, plus airtightness measures) was applied along with both B and C.

Scope and Limitations

Due to programming constraints, the Virtual Refurbishment exercise as a whole was completed over six months, with the first part being carried out mainly in WP3. This first half of WP3 focused on further refining the solutions proposed in the Whole House Solutions report by validating it against real-world examples in the three countries of Scotland, Northern Ireland and Wales. The second half of the exercise began in October 2011 and will continue to the end of December 2011, which involves taking the learnings from this deliverable and presenting it to residents to gauge their reactions.

Where access was granted we were able to visit and survey representative house types externally as well as internally but due to time constraints and the specific access capabilities of our contacts and respondents we were unable to inspect every house type in this study internally.

House Types

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, it's 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. Overall, the aim of the modeling is to establish the cost effectiveness of each package and to identify any potential gaps and obstacles in the retrofit process. The three packages are set out from C to A as Package C is considered the more basic set of measures, while B and A include more installations and improvements.

The three packages are as follows:

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

Package C is based on our hypothesis that wall insulation is currently a measure if we are to achieve the UK's carbon emission reduction targets, and loft insulation is already widely accepted as a thermal measure, where it is accepted by the public and the supply chain is reasonably well established for this measure due to previous incentivisation programmes.

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

Package B has been put together based on public acceptance and straightforwardness of installation. Window and door replacements, while not cost-effective in terms of payback, have a visible appeal to householders, who believe them to be effective in terms of achieving comfort and thermal efficiency. Upgraded heating systems (for costing purposes this consists of an A-rated boiler but could also very well be heat pumps etc.) are included because they are logical next step after the installation of major insulation measures, such as wall insulation. Installing a new heating system after insulation means that they will be optimally sized to take the level of fabric efficiency into consideration.

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

Package A was originally intended to be ground floor insulation plus airtightness and MVHR but unfortunately the model in its current state cannot model the effect and cost of MVHR, so the modeling results only reflect ground floor insulation effects. These issues have been addressed with our project partners and there are plans to model MVHR in the next work package.

Ground floor insulation is the most disruptive measure at the moment, and can be challenging to install in terms of solid floors, which is why it currently isn't considered as a primary measure.

The following tables is an example of the modeling results. Each table shows the results of the calculation as well as a commentary on the ideal sequence for interventions. Figures for energy consumption per square metre and $kgCO_2$ per square metre are colour-coded across the charts so that they can be compared across house types.

House Type	Country	**NI**						
	Year of Construction	1965-1980						
	Type	Detached house						
	Floor Area (gross, m^2)	134	134	134	134	134	134	134
Package	**Package**	**0**	**C**	**B**	A	**C**	**B**	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	19,868	17,075	14,152	12,101	16,901	13,882	11,674
Energy Benchmark	$kWh/m^2/year$	148	127	106		126	104	
Carbon Emissions	Total CO_2 Emissions	12654	7854	6476	5616	7796	6396	5389
	$kgCO_2$ saved		4,800	6,178	7,038	4,858	6,258	7,265
Carbon Benchmark	$kgCO_2/m^2/year$		58.6	48.3		58.2	47.7	
Costs	Construction Cost		£32,092.39	£41,720.23	£48,402.38	£22,310.30	£31,938.14	£38,620.29
	Total Fuel Cost (£/year)	£2,332.00	£1,510.00	£1,275.00	£1,128.00	£1,500.00	£1,261.00	£1,089.00
	Fuel Savings (£/year)		£822.00	£1,057.00	£1,204.00	£832.00	£1,071.00	£1,243.00
	Cost per $kgCO_2$ saved (£)		£6.69	£6.75	£6.88	£4.59	£5.10	£5.32
Effectiveness	Incremental Cost		£32,092.39	£9,627.83	£6,682.15	£22,310.30	£9,627.83	£6,682.15
	Incremental $kgCO_2$ saved		4,800	1,378	860	4,858	1,400	1,007
	Incremental Cost per $kgCO_2$		£6.69	£6.99		£4.59	£6.88	

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104

		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

Irish 1965-1980 detached house - *insulated cavity wall, 100mm loft insulation, double glazing, solid floor, owner occupied*

The C-B option is the best route for these houses, although there isn't very much difference on a cost-per-carbon-savings basis for the IWI option. The baseline CO_2 emissions of a home in Northern Ireland is a lot lower than that of a similar house in other regions and the $kWh/m^2/year$ figure after package B closely approaches the target value of 100 $kWh/m^2/year$. The housing stock in general is relatively new and therefore comparatively more thermally efficient. Solid floors will make the implementation of A difficult.

ETI OTEoEH WP3: Virtual Refurbishment Exercise

REGION		House type	
DATE		Age of property	
CITY		No. of storeys	
ADDRESS		Tenure type	
		No. of occupants/ bedrooms	
CONTACT		Occupancy pattern	
IPHONE CAPTURE	☐ Exterior Shot ☐ GPS Screenshot	EXTERIOR PHOTOS	☐ Streetscape/neighbourhood ☐ Exterior facade ☐ Grounds @ external walls ☐ Grounds – landscape, trees ☐ Door and Window openings ☐ Eaves ☐ Bay windows and balconies ☐ Dormers and rooflights ☐ Service penetrations ☐ Meter boxes ☐ Roof finish ☐ Chimneys and flues ☐ Wall finishes ☐ Party wall @ roof ☐ Passageways ☐ Conservatories/Extensions

EXTERNAL WALLS

Material?
Condition of render, if present?
Structural soundness?
Party wall? Y/N Cavity or Solid?
Presence of:

Overhead telephone cables		External water taps	
Satellite dishes/TV aerials		External stairs/handrails	
Rainwater goods		Gas pipes	
Water meter		Flues and stack penetrations	
Gas meter		Bay windows	
Electricity meter		Balconies	
Switches/wiring		Attached gates or fences	
CCTV/Alarm system		Extension	
External lighting		Conservatory	
Signage		Porch	
Airbricks		Covered walkways	

DOORS

How many external doors?
Material?
Condition?
Presence of:

Draughtsealing		Recessed doorway	
Door glazing		Draught lobby	

WINDOWS

How many?
Material?
Condition of windows?
Condition of reveals and cills?
Glazing type?
Architectural features?
Presence of:

Cracks around openings		Shading device/shutters	
Failure of structural elements		Trickle vents	

ROOF

Material?
Roof type?
Condition of roof finish?
Condition of eaves and soffits?
Eaves depth estimate?
Overshadowed/underneath a tree?
Presence of:

Dormer windows		Chimney	
Roof lights		Flues	
Roof-mounted renewables		Gable end	
Party wall extends above roof		Dropped eaves condition	

INTERIOR PHOTOS

- ☐ Living Room
- ☐ Kitchen
- ☐ Bathroom
- ☐ Loft space
- ☐ Heating system – boiler & HW storage
- ☐ Heating system – distribution
- ☐ Interior decoration
- ☐ Defects

MEASUREMENTS

Temperature

Room	Ambient	Surface Temp
Living		
Kitchen		
Bathroom		
Bedroom		

Moisture

Room	Humidity	Moisture
Living		
Kitchen		
Bathroom		
Bedroom		

Dimensions

Room	Length	Width
Living		
Kitchen		
Bathroom		
Bedroom		
Ceiling Height		

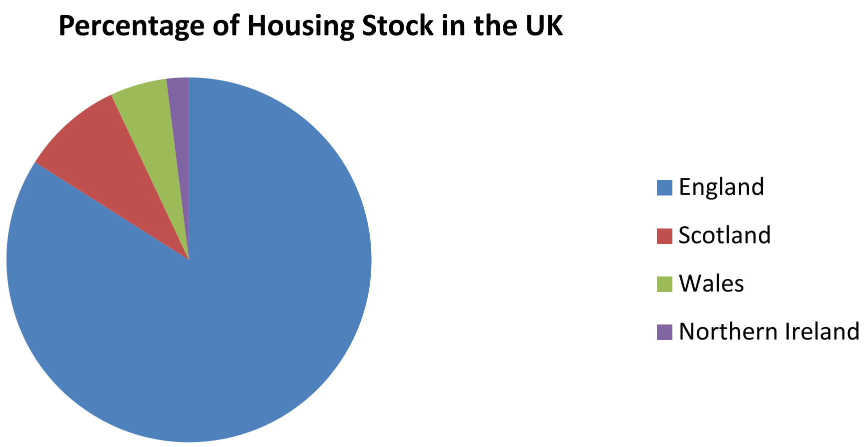
INTERNAL

General comments – features, possessions

5. UK Overview

Housing Stock Comparisons

Across the four countries in the UK, the largest percentage of homes are concentrated in England with 84%, followed by Scotland with 9%, Wales with 5% and Northern Ireland with 2%.



Tenure

There are a number of housing similarities between the four countries. The majority of the homes in the housing stock are owner occupied. This number is highest in Wales, with 66% owner-occupancy, while Scotland has the lowest percentage of owner-occupied dwellings at 59%. The number of owner-occupied dwellings has been increasing since the 1970's across the UK, though this trend may shift in the coming years given the current economic climate. The number of properties owned by registered social landlords is low across the UK, with the highest percentage found in Scotland and Wales, at 13% and 14% respectively, and the lowest in Northern Ireland with 3%.

Dwelling Age

There is a wide variation in dwelling age across the four countries. The newest stock is in Northern Ireland, with 61% of homes built since 1959. The oldest is in Wales, having 61% of the stock built before 1960.

Unfit and non-decent Dwellings

A dwelling is considered to unfit or non-decent due to the following factors: lack of modern amenities, failure to meet minimum statutory requirements, poor state of repair, and lack of a reasonable degree of thermal comfort. These tend to be part of the private rented sector across the UK, while dwellings in the public sector are least likely to be unfit. Dwellings in rural areas also tend to be more likely to be unfit than those in urban locations.

Insulation and double glazing

There are a high percentage of properties with existing loft insulation and double glazing across the housing stock. Progressive improvements in insulation levels have reduced the amount of heat loss in our existing stock considerably; however, we believe the level of improvement can be pushed further. What this does mean however, is that when modeling thermal improvements, that the base case can no longer be assumed to be the fabric of the original construction - this approach would be misleading and would over-emphasise the potential benefits of loft insulation and window replacement.

The increase in the amount of double glazing coincides with the increase of draught-proofed homes across the UK. The percentage of lofts with more than 100mm of insulation varies, ranging from 73.6% of lofts in Northern Ireland to 38.3% in Wales as of 2004 (as of 2004, England and Scotland were at 57.1% and 47.1% respectively). The existence of cavity wall insulation is far more common than solid wall insulation, whether external or internal.

Heating system and fuel types

A high majority of the stock across the UK has central heating systems. While these systems tend to use more energy by heating the whole house instead of a few rooms, they also tend to be more efficient than original heating systems they replace. The dominant fuel in central heating systems is gas in England, Scotland and Wales. However, oil remains the preferred fuel for domestic heating in Northern Ireland due to the fact that most of the country remains off-gas, although recent developments point toward an increase in the coverage of the gas grid. More than two-thirds of all dwellings had oil central heating systems in 2009, although the use of gas grew to 15% in 2009. This unique situation in Northern Ireland begs the question - is the rollout of gas still a goal worth striving for or is this actually an opportunity to skip that phase completely and immediately move to more sustainable community heating solutions or renewable energy powered heating systems?

Housing types

Traditionally, there is a common view that the most representative house type in the UK is a three-bed semi-detached house, and while this is true for England, this is not necessarily true for the other UK countries. In Scotland, there is a higher number of flats, while in Wales there is a higher percentage of terraced houses. In Northern Ireland there is a higher number of bungalows than in any of the other countries.

Domestic architectural styles also vary greatly across the UK, largely influenced by local materials and the dissemination of contemporary styles popular in England.

6. English Housing Stock

ARCHETYPES OVERVIEW

Pre-1919 Properties

A number of popular pre-1919 styles remain, each with distinctive features. Georgian properties, built between 1720 and 1840, tend to be simple 1-3 storey box styles with a fanlight above the front door, rectangular windows and chimneys on both sides of the home, with large box sash windows on the ground floor, and smaller sash or dormer windows on the upper floors. Brick was used extensively, ranging in colour including red, tan or white.

Pre-1919 mid terrace (Georgian)

Victorian terraces, built between 1837 and 1901, are notably different from Georgian which was a result of the increase in decoration on the exterior of the homes. Terraces had tiled roofs and large windows, including deep bay windows. Fancy tiling and terracotta detailing were used extensively, and many homes have a central triangular pediment set against a hipped roof with dormers.

Pre-1919 mid terrace (Victorian)

Following the extensive use of decorative detail during the Victorian period, Edwardian dwellings built between 1901 and 1919 were noticeably less decorative The new housing was modeled more on traditional country building, using local materials and skills, and simple designs. Externally, even in modest homes, the influence of the Arts and Crafts movement is often noticeable, with some terraces faced with a more ‘cottagey’ red brick, and roofs tiled with the more rustic clay plain tiles. Plain sash windows were sometimes relegated to back windows, and casement windows, or rural-style multi-paned sashes, were introduced at the front.

Pre-1919 mid terrace (Edwardian)

1919-1945

There was a housing boom during the 1920's and 1930's, and as the suburbs expanded, the traditional choice had evolved from the earlier Arts & Crafts era of romance and decoration. Mock Tudor Houses and Cottage Style homes were the most common to appear in suburban developments. Houses were a mix of red brick, pebbledash and half timbering with red clay tile roofs and tile hung walls. Other features included leaded glass in iron casement windows set in wood, heavy oak doors with iron nails and fittings, reminiscent of Jacobean and Tudor times.

During the latter part of this period, a modern approach emerged, which was to reject all decoration and to go for a clean cut simple design. The Bauhaus style from Europe was influencing a house style that was plain and stream-lined. Roofs were flat and walls were painted concrete, windows were large and plain.

1930's semi-detached

1945-1964

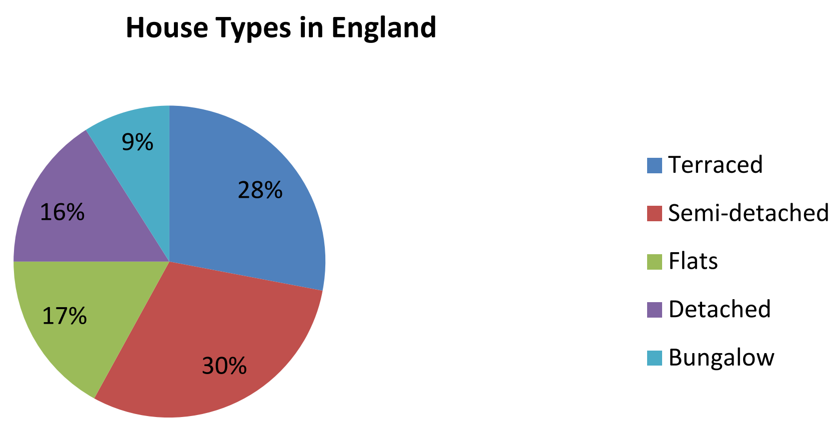
Following WWII, the need for new housing continued, stimulated by the many homes destroyed during the war and the growing population following the 'baby boom' of 1946. Mass housing programs based on a utilitarian standard were rolled out by local authorities, and semi-detached cavity wall dwellings now became the second most common dwelling type in the UK. Given the shortage of money necessary to meet demand, these homes tended to be built cheaply and quickly.

1950's semi-detached

Housing Types

Overall, housing in England accounts for 84% of the housing in the UK with 22.3 million dwellings. Of these, 1 million were vacant as of 2009.

The most common types of dwellings were terraced houses, at 28% (an increase from 14% in 1987), followed by semi-detached houses at 30%. 17% of the housing stock is made up of flats, most of which are purpose built low rise flats. While detached homes and bungalows account for 16% and 9% of the overall housing stock respectively, less than 1% of dwellings in the social sector were detached houses.

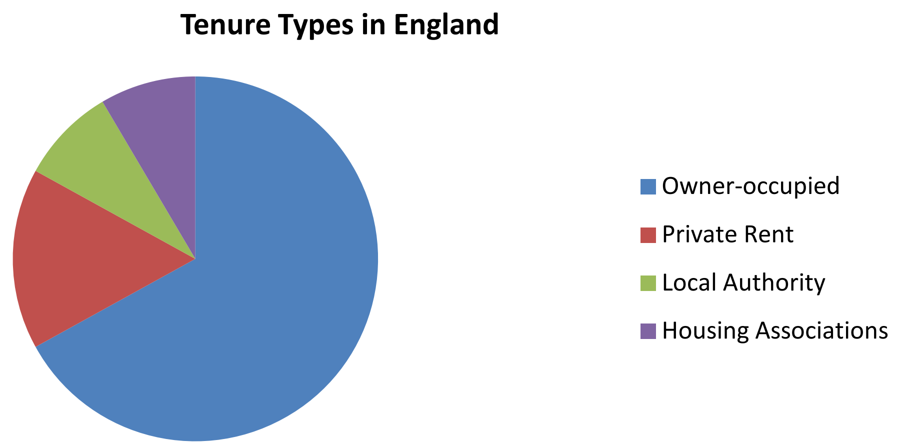


Dwelling Age and Tenure

While some older buildings have been demolished, there has been little decrease in the number of older dwellings. Of the dwellings in England, 38% (8.8 million) were built before 1945, with 4.8 million built before 1919.

The majority of dwellings built before 1945 are part of the private rented stock, at 53%, while 39% are owner occupied, 19% are owned by the local authority and 18% are part of the housing association stock.

The majority of dwellings in England are owner occupied at 67% of the total stock, while 16% is within the privately rented sector and 17% is split evenly between local authority ownership and housing associations.



Construction typologies

Significant improvements in insulation have taken place in English dwellings since the 1970's. In terms of loft insulation, 92.6% of homes with lofts now have some loft insulation. This has risen from 52.2% in 1976. The same level was achieved in 1999, illustrating that the market for lofts that have no insulation has virtually saturated.

However, as building regulations require more insulation, the depths of loft insulation for new homes are increasing, with the installation of 6 inches or more of insulation growing from 14.8% to 20.4% between 1994 and 2005.

Cavity wall insulation has also increased, from 3.8% of cavity wall dwellings in 1976 to 37.9% in 2005. Double glazing ownership has risen from 10.2% of potential installation in 1976 to 84.1% in 2005 (this percentage refers to any house with any number of double glazed windows). This has also led to an increase in draught proofing, with 87.4% of dwellings being draught proofed compared with 84.1% which were double glazed. In 1987, the figures were 65.8% draught proofed compared with 40.8% double glazed.

Heat loss from average dwellings has been steadily reducing as insulation levels improve, falling from 257.8 W/°C per dwelling in 2005 compared to 351 W/°C in 1976.

The proportion of households with no insulation (no loft insulation, no cavity wall insulation where a cavity wall is present, and no double glazed windows) has decreased from 17.6% in 1987 to 6.9% in 2005.

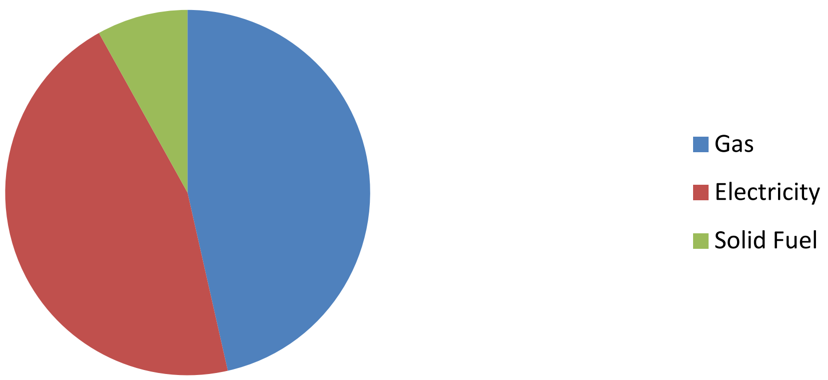
Heating systems

Central heating ownership has been increasing, with 91.5% of English homes having central heating in 2005, compared with 66.5% in 1983 and 88.9% in 2000. The main central heating fuel is gas, with 86.1% of centrally heated homes using gas, compared with 73.4% in 1983.

In 2005, only 8.5% of homes used a non-central heating system. For those without central heating, 46% used gas and 45% used electricity. Solid fuels were used by only 8% of these households.

The older housing stock is typically less energy efficient, with homes built after 1990 having the highest SAP rating (65), and those built before 1919 having the lowest (39). Flats typically have a SAP rating 12 points higher than houses, with low-rise purpose built flats in particular having an average SAP rating of 61. Mid-terraced homes tend to have the highest average SAP rating of all housing types.

Fuels used for Central Heating in England



PREDOMINANT TYPES (FREQUENCY AND CARBON EMISSIONS)

	pre-1919	**1919-1944**	**1945-1964**
	mid-terrace	semi-detached	semi-detached
Current energy consumption (kWh/yr)	29,782	28,055	20,591
Current CO_2 emissions ($kgCO_2$/yr)	7,108	6,779	5,277
Stock Frequency	1,860,000	1,740,000	1,740,000
% of total UK stock	8.5%	8.0%	8.0%
Stock CO_2 emissions (tCO_2/yr)	11,810,000	12,490,000	10,830,000
% total UK CO_2 emissions	8.5%	9.0%	7.8%

CASE STUDIES

As a result of the extensive experience of retrofitting homes in England, both Wates and PRP stand in a strong position to effectively analyse the applicability and suitability of the measures proposed in the ETI TE model. Projects include PRP's Retrofit for the Future projects, Rampton Drift Demonstrator Project in South Cambs, and community retrofit projects. Wates' experience includes mass-scale social housing retrofits with framework schemes in Birmingham, Coventry and Redbridge among others.

We have used this experience as a base for this section of the report, as well as the previous work undertaken on work package 3.3b which features four housing types commonly found in England - the three bed semi, the mid-rise block of flats, the tower block, and the mid-terrace hard to treat property. The following sections for Scotland, Wales and Northern Ireland include more detailed photos and case study examples as a result of recent trips around the UK to learn more about housing types outside of England.

7. Scottish Housing Stock

Archetypes overview

The appearance of Scottish dwellings are distinctly different from the other countries as a result of the extensive use of sandstone and granite in pre-1919 buildings. The large number of tenements built during this time are still in use, their defining features being their thick exposed stone walls. However, the stone was sometimes kept to the front façade, with brick used on the back and sides. Dwellings from this time had slated roofs with half-inch sarking board. Stone continued to be used after this period, but cavity walls with brick and external render grew in popularity after WWII.

Pre-1919 detached

Pre-1919 purpose built low rise

As the use of brick continued, cavity walls were also gaining in popularity, either in layers of brick/cavity/brick or brick/cavity/block. External was sometimes used, and a small number of metal-framed homes were built. After 1945, stone was seldom used, while cavity walls continued their dominance. Ceilings were constructed of plasterboard and sarking board was used in roofs.

1950's purpose built low rise

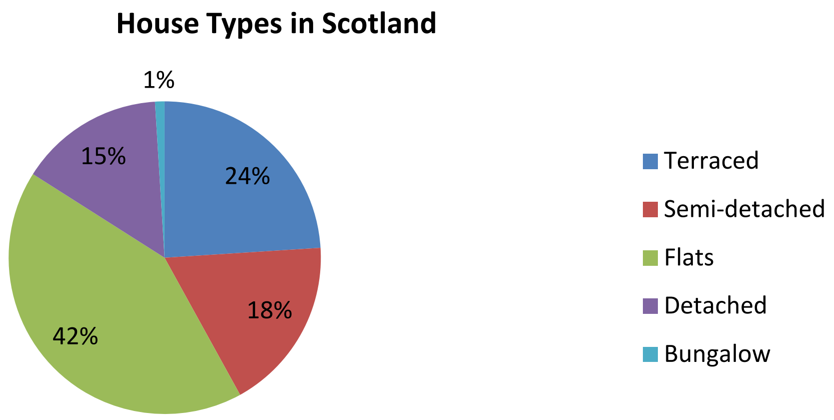
In homes built in 1980, homes were built with a timber frame and brick façade. The use of render over brick has grown in popularity in recent years.

Post-1980 detached

Most common house types

A third of the overall housing stock in Scotland is pre-1945. While pre-1919 dwellings tend to be tenements, new builds post-1982 tend to be detached houses. Scotland has the highest number of flats compared to other countries, accounting for 41% of the stock. It also has the highest percentage of properties owned by social landlords, at 13%, and the lowest percentage of owner-occupied properties, at 59%

The number of dwellings is increasing but the proportions of each house type are changing very little. There is a slight increase in flats and detached houses, and a corresponding drop in the proportion of semi-detached and terraced dwellings. Flats are the most dominant house type.



Construction typologies

Since 1976, the number of homes with loft insulation has risen from 33.1% to 92.1% in 2005. As the market for loft insulation installation in uninsulated lofts has saturated, there has been as increase from 2.2% to 47.2% of those with 4 inches or more of loft insulation between 1976 and 2005.

Cavity wall insulation has increased from 5.7% in 1976 and 46.5% in 2005. Between 1984 and 2005, the percentage with 80% or more of rooms with double glazing has risen from 10.1% to 44.2%. Draught proofing has been increasing, largely due to the rise of double glazing. In 2005, 90.6% of dwellings were draught proofed.

Heat loss of the average dwelling has been steadily been reducing as insulation levels improve. In 2005, it was 238.1 W/°C per dwelling compared with 345.7 W/°C in 1976.

Heating systems

Only about 2% of the housing stock has no central heating. Urban dwellings are also about twelve times less likely to be rated 'poor' than those in rural areas under the NHER rating scheme.

Gas is the main central heating fuel, with 73.3% of centrally heating homes using gas in 2005. Of those homes without central heating, 80% used electricity, 8% used gas and solid fuel was used by 6%.

Households living in older dwellings are more likely to experience fuel poverty with over a third of households (171,000) living in dwellings built before 1919 being fuel poor compared to around a fifth (104,000) of those living in dwellings built before 1982. This is partly related to the fact that houses built after 1982 tend to be more energy efficient.

PREDOMINANT TYPES (FREQUENCY AND CARBON EMISSIONS)

	pre-1919			1919-1964			pre-1919	1980+
	flats - ground	flats - mid	flats - top	flats - ground	flats - mid	flats - top	detached	detached
Current energy consumption* (kWh/yr)	32,233	22,503	30,952	26,235	17,395	24,965	57,814	44,616
Current CO_2 emissions* ($kgCO_2/yr$)	7,371	5,444	7,117	6,049	4,299	5,798	13,069	10,300
Stock Frequency	190,000			150,000			70,000	130,000
% of total UK stock	0.8%			0.6%			0.3%	0.5%
Stock CO_2 emissions (tCO_2/yr)	1,076,000			690,000			1,350,000	1,050,000
% total UK CO_2 emissions	0.6%			0.4%			0.8%	0.6%

*calculated using ETI TE single dwelling model

CASE STUDY VISIT

For the Scottish case study visit, we visited Edinburgh and Glasgow to look at common house types as identified in the table above. We had two regional experts to help us - Stuart Carr, an Associate Director at PRP with over 25 years of experience of housing in Scotland and Nigel Coxon, Operations Manager for Wates, who has extensive experience of retrofitting high-rise tower blocks in Glasgow.

HOUSE TYPES ENCOUNTERED

Pre-war solid stone detached house. Note use of roof ventilators and room-in-roof. Ground floor level air bricks indicate presence of suspended floor.

1950s low-rise block of flats. Could not see any evidence of roof ventilation features, could be an indication that no roof insulation has been installed (ventilators are a requirement when roof insulation is undertaken). Prime candidate for EWI installation.

Semi-detached flats using reconstituted stone ('Forticrete'). post-1980.

Pre-1919 terraced properties of solid stone construction near Inverleith Gardens. Note rooms-in-roof, dormers and bay windows tend to characterise the architectural style.

Pre-1919 Edinburgh tenement blocks - solid stone construction, full height bay windows. Often have retail on the ground floor. Likely to have highly decorated interiors. Bowhill Terrace.

Postwar four-in-a-block house example, built en-masse to provide affordable housing after the war. Note bay window and lack of eaves depth. Also added complication of four different tenants/owners, two of whom own the first floor and roof and the other two owning the ground floor.

Mansard roof on a row of terraced houses. EWI would only tackle half of the problem in this case…

UNIQUE CONSTRAINTS

Scotland has the most unique set of construction techniques of the four countries - roof ventilation techniques, roof construction, window installation and detailing and generally negative attitudes towards cavity wall installation set it apart from English construction, as well as the colder climate and the increased exposure to the elements. These factors need to be considered when generating whole house solutions.

Roof ventilators were more visibly common in Scotland than the other regions. Windows in Scotland have deeper rebates than in England and are installed from the inside after the walls are complete, as opposed to while the building is being built. In terms of roof construction, the use of sarking is standard in Scotland and less common in England and Wales. However, the widespread nature of these features across Scotland means that a country-specific retrofit programme (which is then divided according to building age) is likely to be easily achievable.

8. Welsh Housing Stock

ARCHETYPES OVERVIEW

Welsh architecture is the result of a social and cultural environment that differs from the rest of Britain. The identifiable Welsh 'style', though heavily influenced by England, is defined by the enduring folk or vernacular building used across the country.

Traditional Welsh cottages built before the 19^{th} century still remain in rural areas, with thatched roof and chimneys and the use of local mud, timber and stone for walls. After the beginning of the 19^{th} century, stone and brick cottages became the popular building type, with uniform slate replacing thatch in the mid-19^{th} Century. Homes near mines and quarries were often built using of the rubble left over from these processes.

Pre-1919 mid terrace

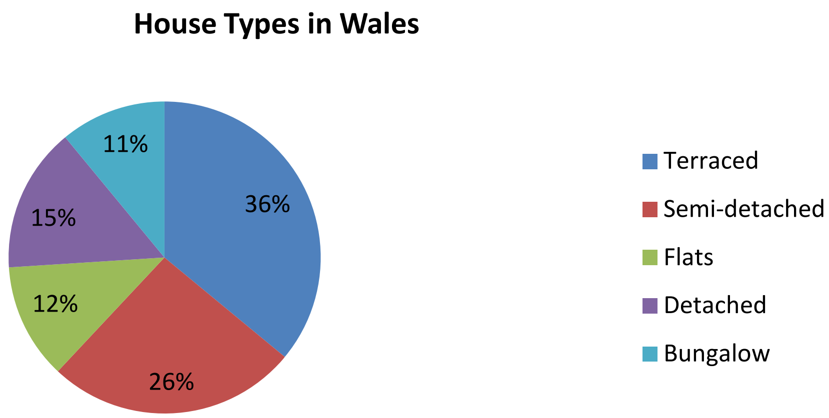
1950's semi detached

Post-1980 detached

Most common house types

Terraced houses are the most common type of dwelling, making up over a third of the stock. These tend to have a higher rate of unfitness than other housing types, though flats (including converted flats, purpose built and flats in commercial buildings) are close behind. Semi-detached and detached houses have the lowest unfitness rates of the Welsh housing stock. Wales has the lowest percentage of Local Authority owned stock across the UK at only 12%, while owner-occupied properties contribute to 66%.

The percentages of each housing type in 2005 were:



Construction typologies

88.4% of potential lofts now have some loft insulation, which has risen from 48.1% in 1976. Since 1994, those lofts with 3 inches or more of insulation appears to have saturated between 60% and 70%.

Cavity wall insulation ownership has increased from 2.6% of cavity wall dwellings in 1976 to 40.1% in 2005. Double glazing ownership has also risen from 7.1% of potential in 1976 to 84.1% in 2005.

As a result, draught proofing has also increased, with 85.5% of homes being draught proofed compared to 63.3% in 1987.

The proportion of households with no insulation (no loft insulation, no cavity wall insulation where a cavity wall is present, and no double glazed windows) has decreased from 14.7% in 1987 to 9.2% in 2005.

Heating systems
Heat loss of the average dwelling has been steadily been reducing as insulation levels improve. In 2005, it was 267.7 W/°C per dwelling compared with 363.4 W/°C in 1976.

As of 2005, gas was used in 78% of centrally heated homes. This compares with 62.2% using gas in 1983. Solid fuel use has fallen from 23.2% of centrally heated homes in 1983 to 3.1% in 2005.

In 1983, 35% of total homes used some form of non-central heating as their main heating system. In 2005, it has declined to 10.1% of total homes.

In 2005, 44% of those without central heating used gas and 32% used electricity, while solid fuel was only used by 20% of households.

Predominant Types (Frequency and Carbon Emissions)

	pre-1919	1945-1964	1980+
	mid-terrace	semi-detached	detached
Current energy consumption* (kWh/yr)	28,883	19,868	38,499
Current CO_2 emissions* (kgCO_2/yr)	6,930	5,134	9,089
Stock Frequency	170,000	130,000	120,000
% of total UK stock	0.7	0.5	0.5
Stock CO_2 emissions (tCO_2/yr)	1,060,000	800,000	800,000
% total UK CO_2 emissions	0.6	0.4	0.5

Case Study Visit

For the Welsh case study visit, we visited Cardiff and the Valleys to look at common house types as identified in the table above. We had two regional experts to help us - Simon Lannon, principal investigator for the Retrofit 2050 project at the University of Cardiff and Richard Leyshon of Wates Living Space, who has extensive experience in delivering mass-scale refurbishment and retrofit in Wales.

HOUSE TYPES ENCOUNTERED

Circa 1800s stone terraced houses

Abandoned low-rise block of flats - a number of higher density schemes including a few tower blocks were built but they failed to attract a stable base of residents due to the lack of transport and amenity infrastructure. The tower blocks have since been demolished.

Terraced houses on a hill, showing semi-exposed party walls which may prove tricky to externally insulate. This staggered terracing is common in Wales, where the landscape in the valleys tends to be quite hilly and undulating.

Pre-1919 stone terraced housing. The stonework here is very different from stone-built houses in Scotland, as the stone is irregular and usually a by-product of the mining industry.

A newly completed retrofit property - solar panels on the roof are considered as a novelty in Wales. This property has been merged from two adjacent mid-terrace houses. The rightmost window has been converted from a front door into a window.

Storage space for construction materials can be a problem on constrained mid-terrace sites. Here, the small front garden is being used for materials storage.

Stepped terraced housing on a slope is a very common occurrence in the valleys.

Cardiff pre-1919 terraced housing - the recessed doorways are quite a common feature, making heat loss from exposed soffits an issue.

These connected sheds were a common feature for this group of semi-detached properties in Cardiff

UNIQUE CONSTRAINTS

Welsh cavity wall construction is similar in technique to English cavity wall construction which will be helpful in applying similar techniques in both countries and thus improving the efficiency of the process. However, stone terraced properties are quite common, built quickly and on a mass-scale to provide housing for workers in the mining industry. As a consequence they were often built to poor standards, both in terms of building fabric and space provision. This will result in necessarily more extensive work than compared to other house types, both in Wales and across this UK, in order to meet energy efficiency and thermal comfort targets.

Another unique feature for Wales is the undulating nature of the terrain, affecting the morphology of the housing stock in the Valleys. Housing solutions for mass-scale EWI retrofit of these terraces when the facades are not straight and the exposed party walls are all different will be challenging.

9. Northern Irish Housing Stock

ARCHETYPES OVERVIEW

Building styles in Northern Ireland lagged many years behind the metropolitan models they sought to emulate, with local architecture tending to more modest than England and Scotland.

In dwellings built prior to 1919, brick was used extensively in solid wall construction. If the brick and/or work was of poorer quality, it tended to be covered in render. Roofs were usually finished in 'Bangor-blue' slates rather than tiles, and no sarking felt was installed beneath the slate.

Pre-1919 detached

In the 1960's and 1970's, no-fines system-build construction grew in popularity, as well as other non-traditional housing types, including concrete cast in-situ with stone aggregate. They were then rendered externally and lined internally with timber battens and plasterboard.

1970's detached

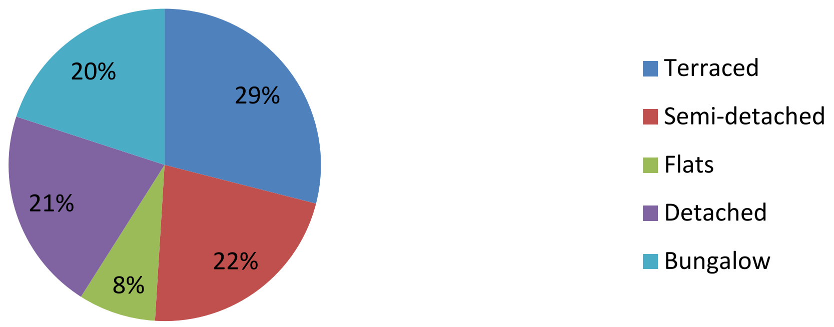
Post-1980 detached

Most common house types

Northern Ireland's total stock is approximately 740, 000 as of 2009, 70% of which is considered to be urban. As of 2009, there has been a decrease in the number of owner-occupied properties, while there has been an increase in private sector rentals of 5%.

68% of the stock in Northern Ireland failed the Decent Homes Standard on thermal comfort in 2009. Unfit buildings tend to be more prevalent in the private sector, and in rural, isolated areas.

House Types in Northern Ireland



Northern Ireland's Housing Stock has grown rapidly between 2006 and 2009, with an annual increase of approximately 12,000 homes. This brings the total stock to 740, 000. 14% of homes were built before 1919, a number which has continued to decrease due to demolition.

Construction typologies

In 2004, 96% of lofts in Northern Ireland had some insulation, which has increased from 41.3% in 1979. In 2009, terrace houses had the lowest rate of full cavity wall insulation (65%) and the highest rate of no wall insulation (21%). However, 67% of occupied dwellings have full cavity wall insulation.

Dwellings in urban areas (65%) had a slightly higher rate of full cavity wall insulation in comparison to dwellings located in rural areas (63%). The highest growth occurred in the Belfast Metropolitan Area from 52% in 2006 to 60% in 2009. However, the highest proportion of dwellings with no insulation remains in the Belfast Metropolitan Area at 26% in 2009, and the lowest in small rural settlements at 11%.

Dwellings with full double glazing have also improved, from 68% in 2006 to 77% in 2009.

As insulation levels improve, heat loss from the average dwelling has steadily dropped from 351 W/°C in 1976 to 257.8 W/°C in 2005.

Heating systems

In 2006, 98% of homes in Northern Ireland had central heating. This has increased to 99% in 2009. Over half of those without central heating were vacant in 2009.

Oil remains the preferred fuel for domestic heating in Northern Ireland. More than two-thirds of all dwellings have oil central heating systems in 2009. The use of solid fuel central heating fell dramatically between 2001 and 2006 from 14% in 2001 to 5% in 2006 and finally 4% in 2009. The use of mains gas for central heating has increased to 15% in 2009.

Predominant Types (Frequency and Carbon Emissions)

	1980+	1965-1980+	pre-1919
	semi-detached	detached	detached
Current energy consumption* (kWh/yr)	28,883	19,868	38,499
Current CO_2 emissions* ($kgCO_2$/yr)	6,236	12,654	17,697
Stock Frequency	60,000	140,000	50,000
% of total UK stock	0.2%	0.4%	0.1%
Stock CO_2 emissions (tCO_2/yr)	338,000	1,413,000	818,000
% total UK CO_2 emissions	0.1%	0.5%	0.3%

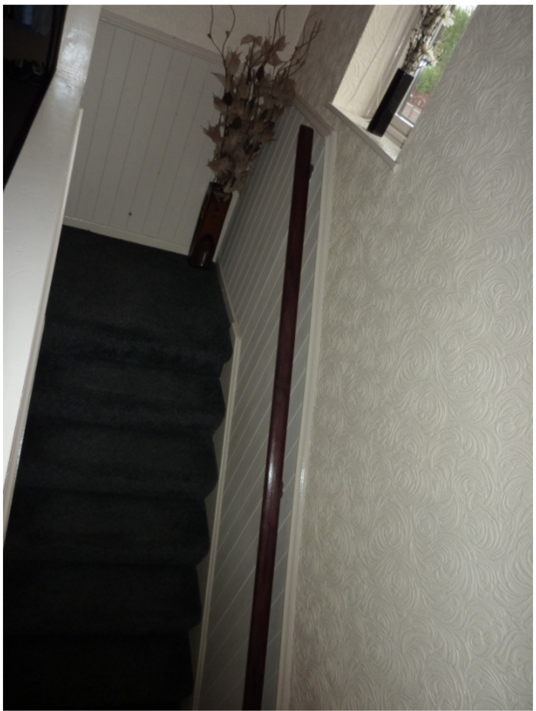
CASE STUDY VISIT

For the Irish case study visit, we visited Belfast (urban) and Ballycastle (predominantly rural) to look at common house types. For Belfast, we interviewed John Gracey (Policy and Standards Manager) and Adrian Blythe (Design and Property Services) from the Northern Ireland Housing Executive and were taken around to see a selection of NIHE stock. In Ballycastle, we went to see Robert Starrs (Senior Housing Officer, NIHE Ballycastle District Office), who showed us a selection of houses from their stock in that area. We also met a local builder to ask him about his perceptions on energy efficiency retrofits.

HOUSE TYPES ENCOUNTERED

High-rise postwar social housing in Belfast.

1950s terraced housing, presumably cavity wall housing with render finish. Potentially ideal for an EWI solution, as the internal spaces may be too small for an IWI installation.



Narrow flight of stairs on an external wall - an IWI constraint

1960s-70s prefabricated flats - would be relatively easy to retrofit due to modular nature of wall panels - can be removed and replaced with similar-sized but insulated panels. These properties often have water ingress issues due to the open balconies. Heat loss thru exposed soffits would be a problem for these as well.

Northern Irish households spend more on average on home improvement than the UK average - £647 annually versus £521 for the UK. This is an example of a redecorated unit in the prefabricated block of flats shown above.

Northern Ireland has the highest occurrence of bungalows - this is a terraced bungalow, which are often allocated to older tenants.

Draught lobbies are a very common feature in terraced housing. The outer door is usually non-thermal, with the inner door being the main, draughtproofed door. The outer doors are often left open in the summer and mid-season to signal a welcome to friends to come in for tea. These properties have insufficient eaves depth to install EWI without an eaves extender.

Enroute to Ballycastle - typical rural bungalow property

Oil storage unit

Typical Ballycastle mid-terrace property, cavity walled construction

Biomass CHP unit being trialled by NIHE on one of the (as yet) unoccupied properties

UNIQUE CONSTRAINTS

Perhaps the most unique constraint in Northern Ireland is the fuel source for heating. While they are currently rolling out mains gas in Belfast, most rural areas continue to use oil or solid fuel as their predominant fuel. There seems to be an interesting opportunity here- while the current trajectory is for the rollout of mains gas, our advancement beyond mains gas in many parts of Europe and the UK may make it possible to skip this step altogether and proceed towards community heating or even microgeneration systems similar to the biomass CHP units that they are testing out in Ballycastle.

The frequency of draught lobbies with non-thermal outer doors also demands a thermal solution that could make a significant difference to both thermal efficiency as well as comfort. As it seems part of the lifestyle to leave the outer door open, it would be worth looking into the heat loss caused by the exposed soffit and wall in the recessed doorway.

The political climate in heavily populated areas like Belfast also pose unique constraints in terms of security and equality which are worth considering in terms of policy, regulation and whole house solution offerings.

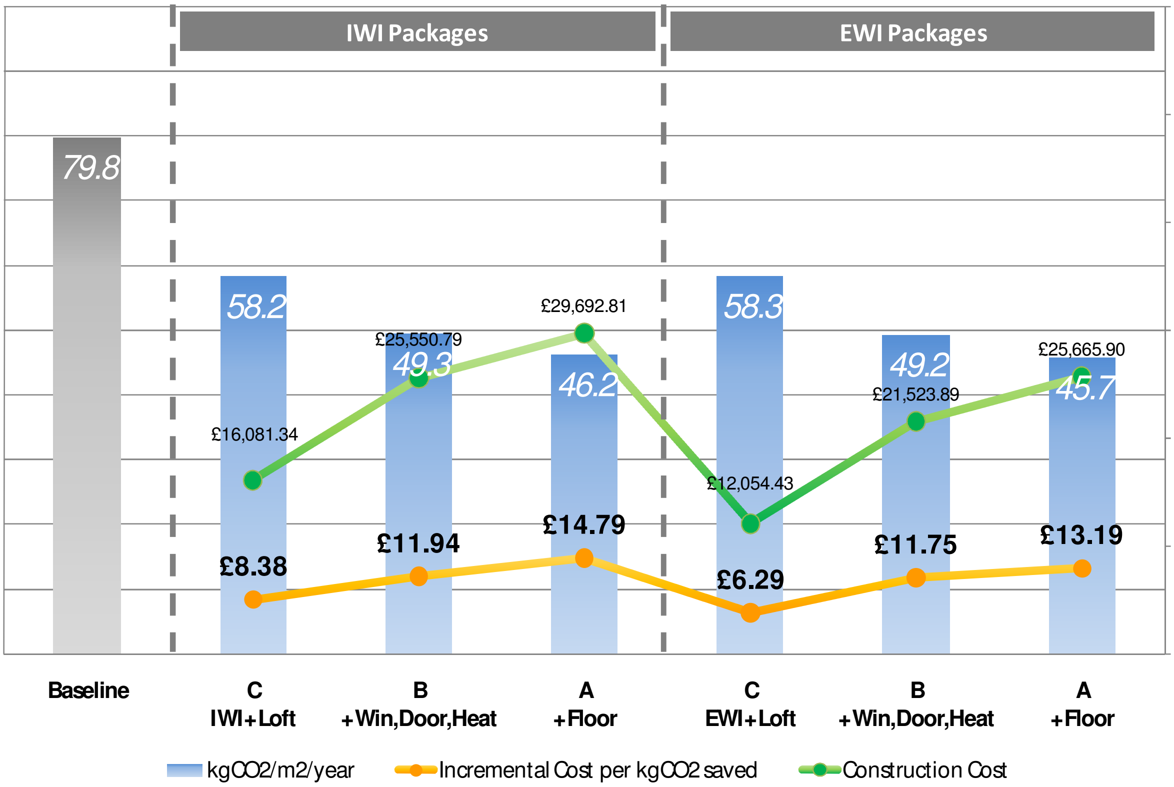
10. Findings

The detailed tables for each of the different housing types have been included in Appendix A of the report. Below we have detailed the findings of the model outputs and have suggested the most cost effective sequence of measures for each housing type:

1. *E19M English pre-1919 mid-terrace house*

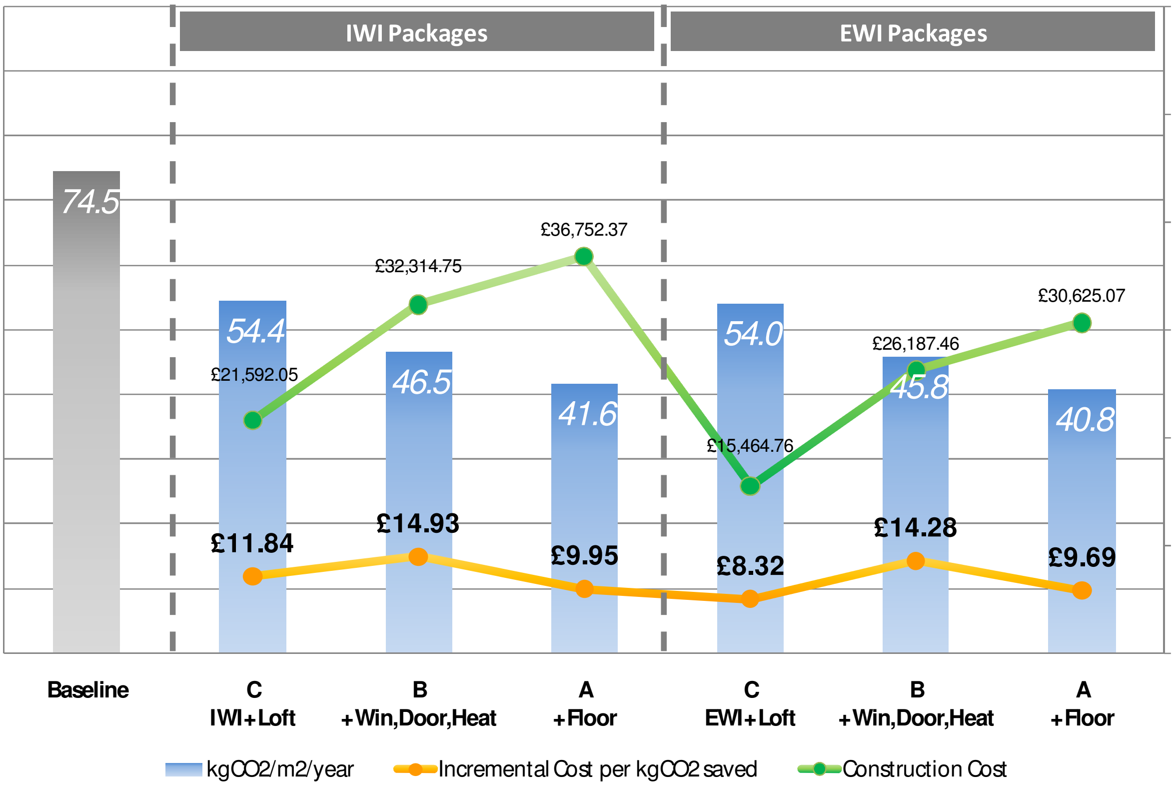
EWI will probably not be acceptable due to heritage, conservation, aesthetic issues in houses of this age. The solution will most likely be a combination of measures based on the IWI packages, although EWI may still be an option if modifications to the external appearance of the property are not a barrier.

The graph below shows that the most cost-effective measure in this case would be EWI+Loft insulation where possible, followed by door, window and heating efficiency upgrades, with the least cost-efficient measure being the installation of floor insulation.



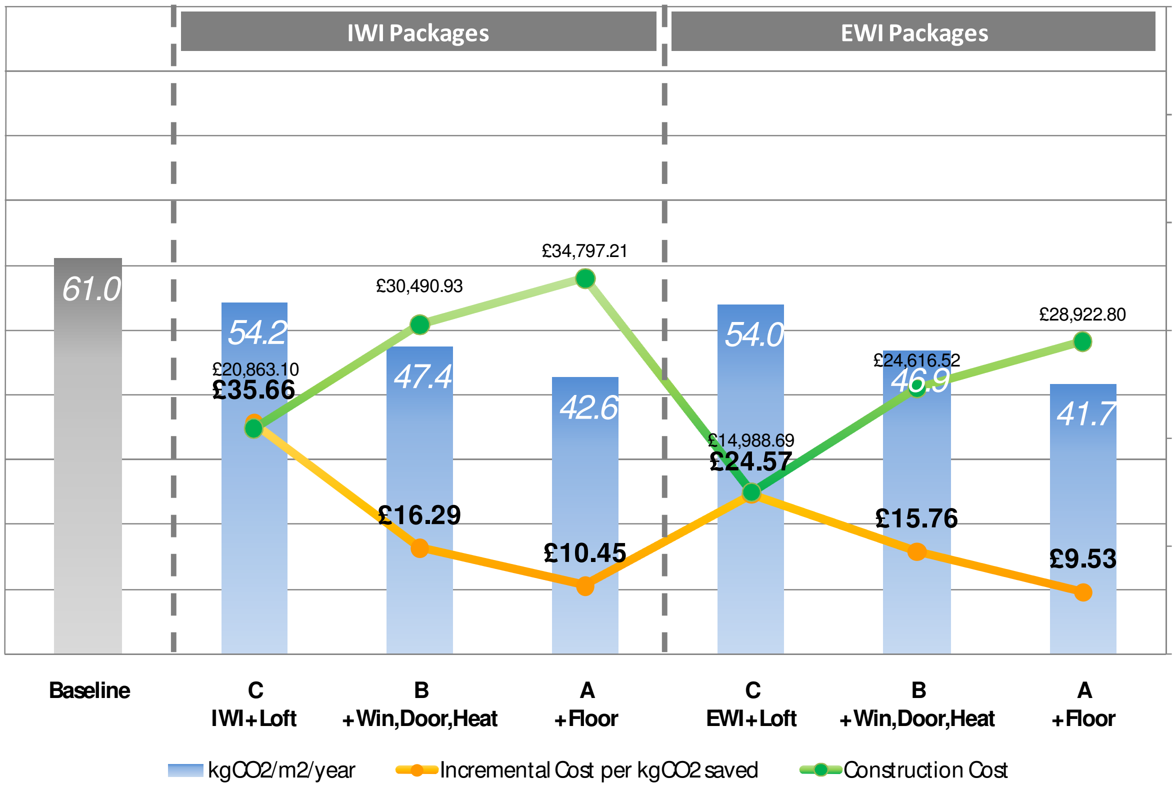
2. E44S English 1919-1944 semi-detached house

There is flexibility with this range of houses, and both EWI and IWI remain viable options, depending on aesthetic appearance of property although EWI is preferable if external appearance is degraded to begin with. An A-C-B sequence seems to work better in terms of cost effectiveness for the IWI approach, while the C-A-B sequence works better when doing EWI. Solid walls have been assumed for the base case.



3. E64S English 1945-1964 semi-detached house

Starting out with C is the most cost inefficient way forward for these properties, as they already have insulated cavities which provide thermal performance. A-B-C for both EWI and IWI options seems to be the most sensible way to proceed. Since these are post-war properties (that tend to be poorly constructed and not extremely architecturally valuable), EWI is probably the preferred option both in terms of cost effectiveness and ease of mass retrofit.



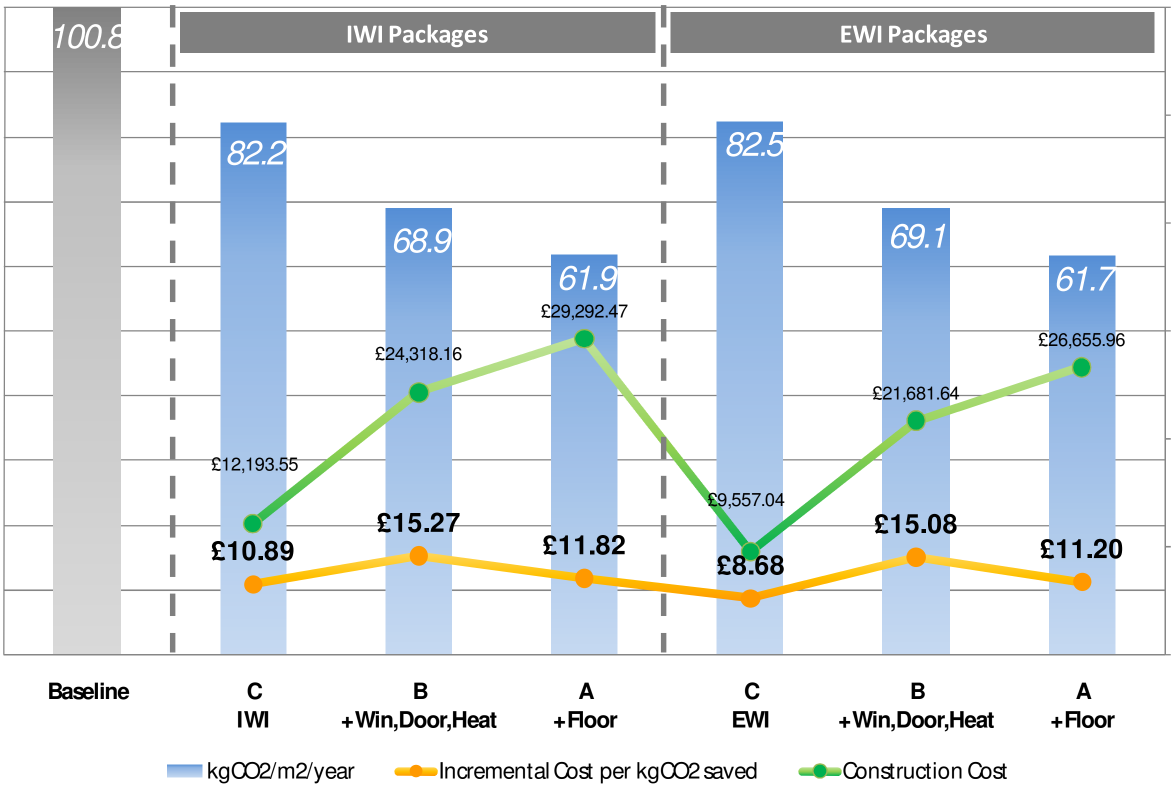
4. S44F Scottish 1919-1944 low-rise flats (ground, mid and top floors)

Ground- The C-B option is the most cost-effective way of retrofitting these flats.

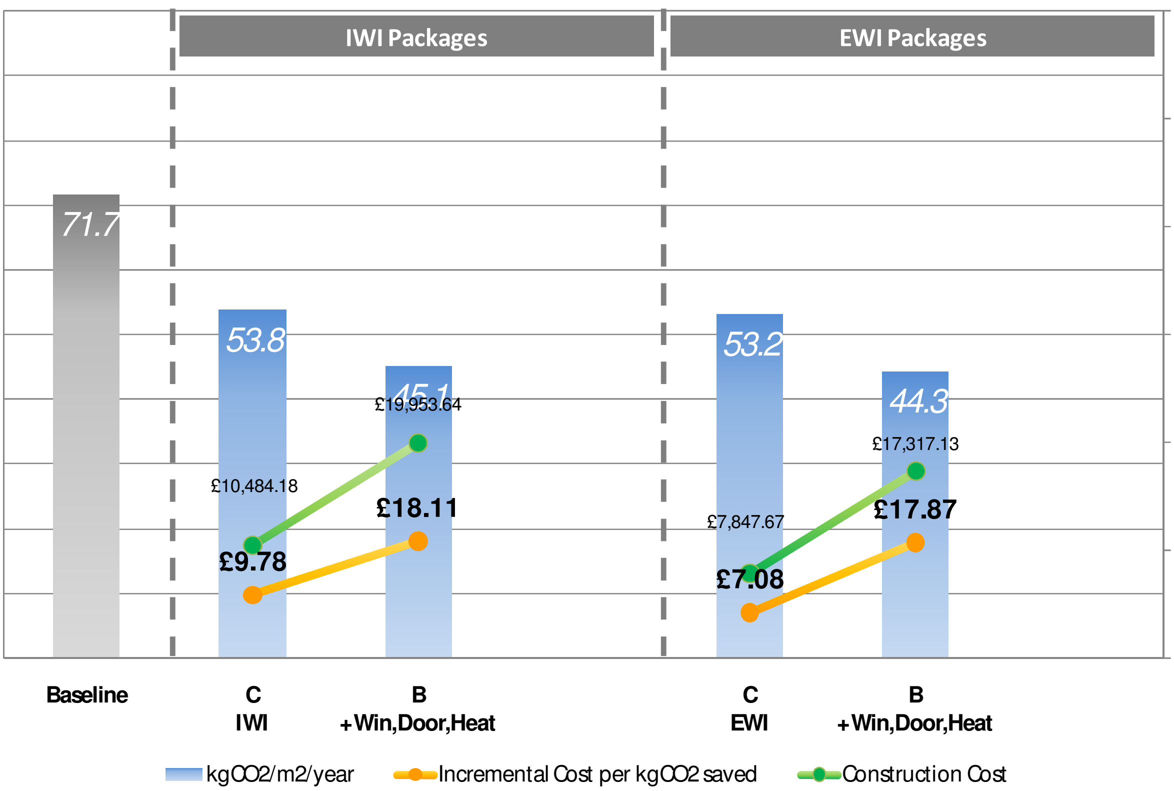
Scottish attitudes towards cavity wall insulation are lukewarm at best - interviews with local experts have suggested that CWI is generally considered to be a bad idea due to problems with condensation. So in Scotland, if a cavity wall is uninsulated it is best to leave it uninsulated and go ahead with EWI, which is the more cost-effective and less disruptive option compared to IWI. Properties have been assumed to have a solid floor which means that A will be difficult, but this needs to be clarified. If the floors are suspended then A will also be possible. The modeled costs are based on the presence of a suspended floor.

Mid and Top Floor- The C-B option is the most cost-effective way of retrofitting these flats, leaning towards EWI wherever possible as it is the more cost-effective option compared to IWI. The A option will not be available due to the absence of an external floor.

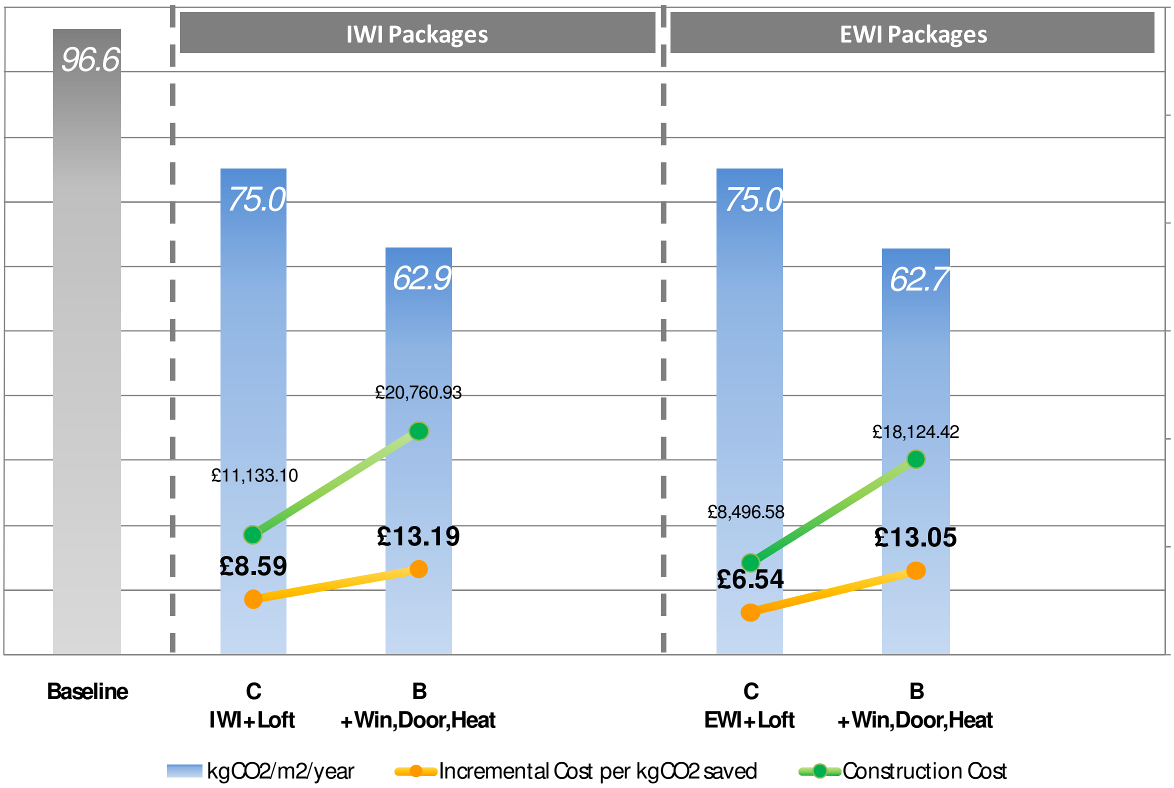
Ground Floor Flat



Mid Floor Flat



Top Floor Flat

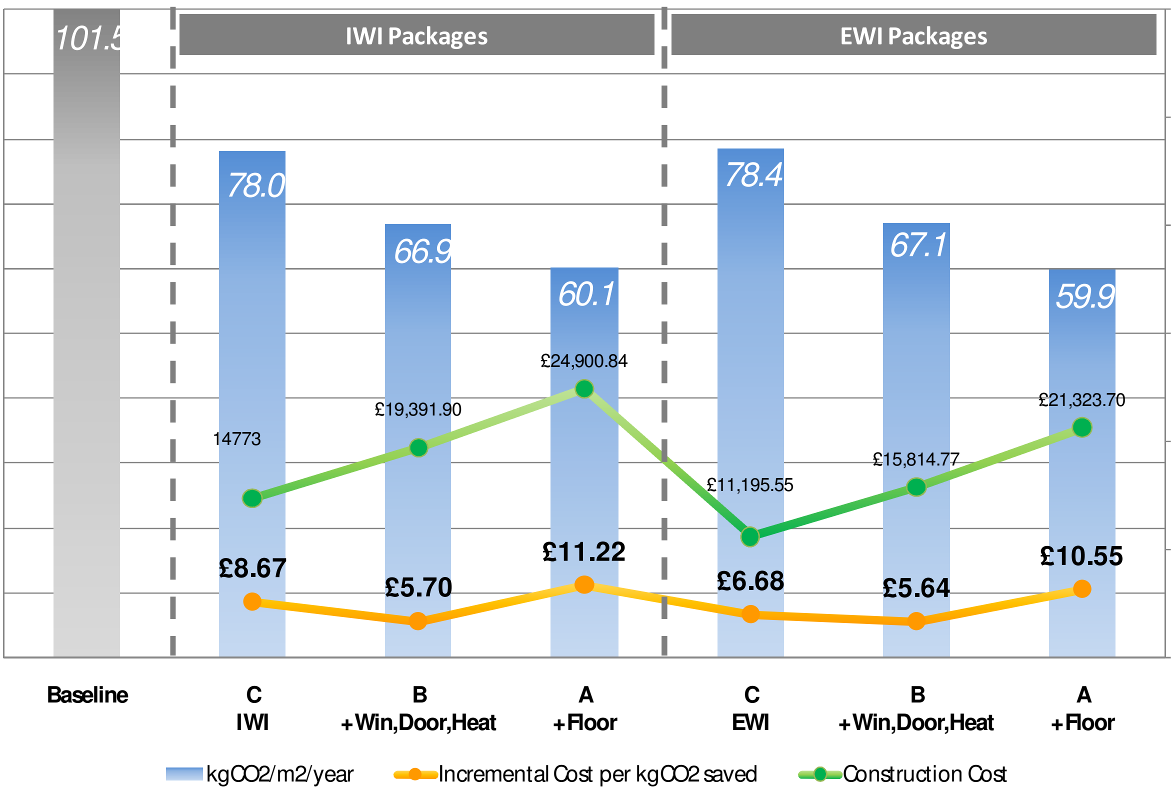


5. S19F Scottish pre-1919 low-rise flats (ground, mid and top floors)

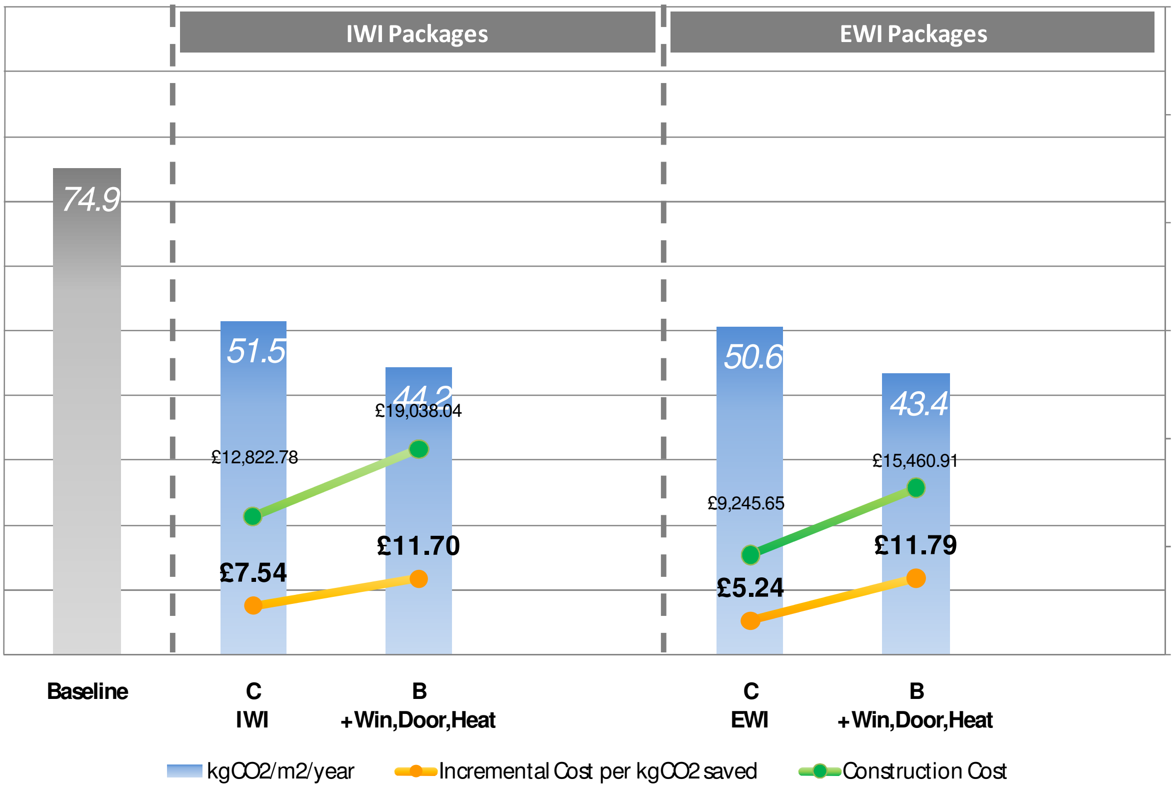
Ground Floor- The B-C-A option is the most cost-effective way of retrofitting these flats. The age of these properties means that EWI is probably not an acceptable solution due to the effect on the streetscape and the aesthetics of these classic tenement buildings. In terms of IWI, one consideration would be the degree of internal decoration that tends to be present inside these properties. There should be further investigation into the possibility of using laser scanning + rapid prototyping to deliver replacement mouldings/features quickly after installing IWI. Properties have been assumed to have a solid floor which means that package A will be difficult.

Mid and Top Floor- The C-B option is the most cost-effective way of retrofitting these flats. The A option will not be available due to the absence of an external floor. The age of these properties means that EWI is probably not an acceptable solution due to the effect on the streetscape and the aesthetics of these classic tenement buildings.

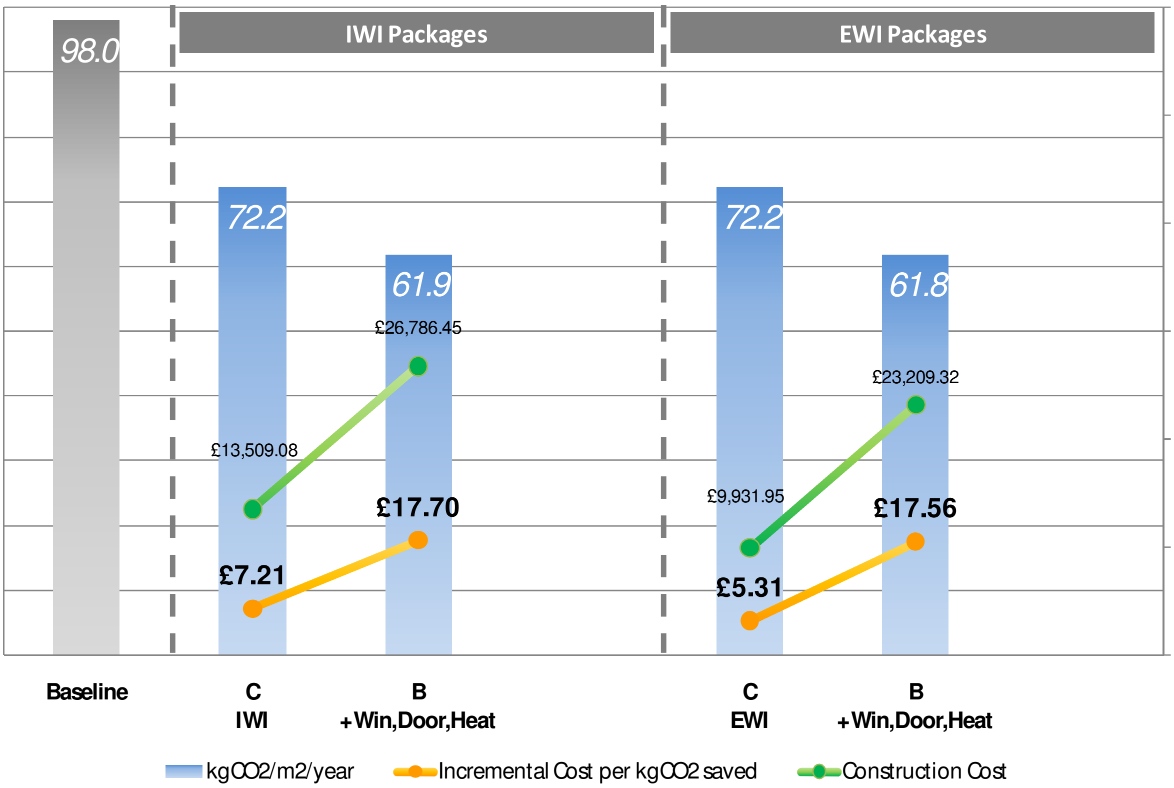
Ground Floor Flat



Mid-floor Flat

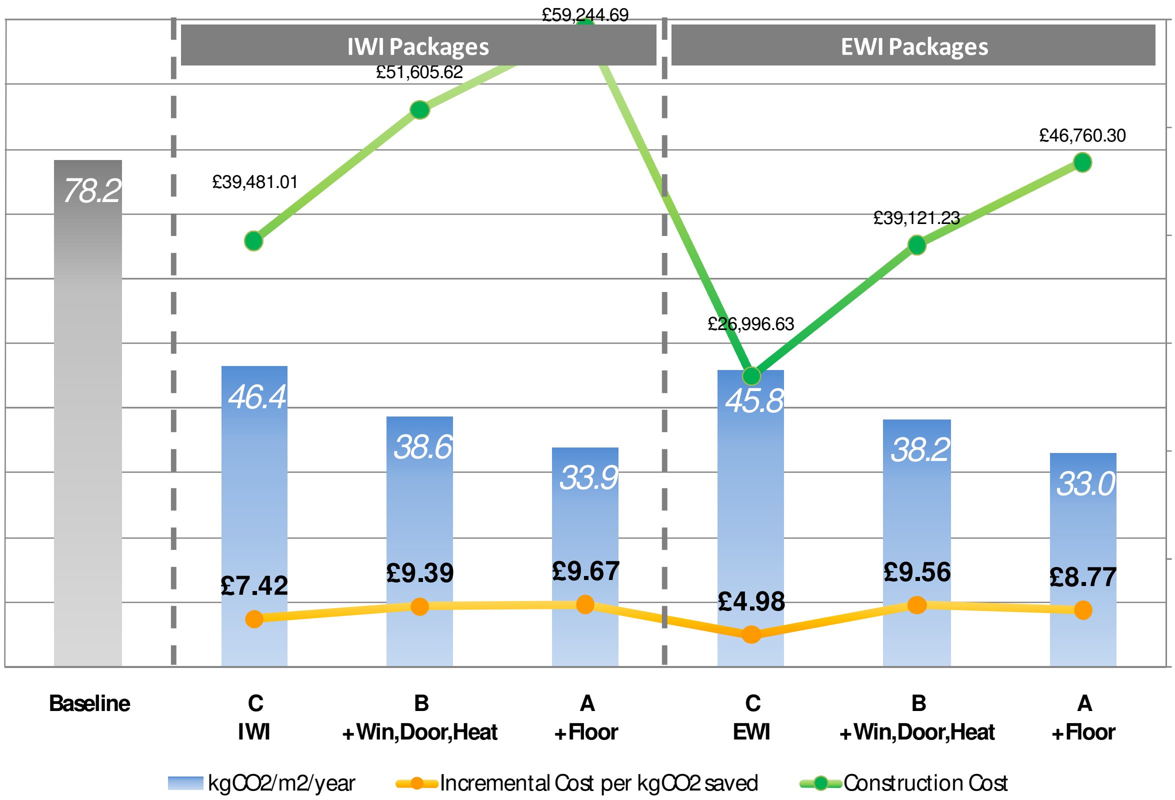


Top Floor Flat



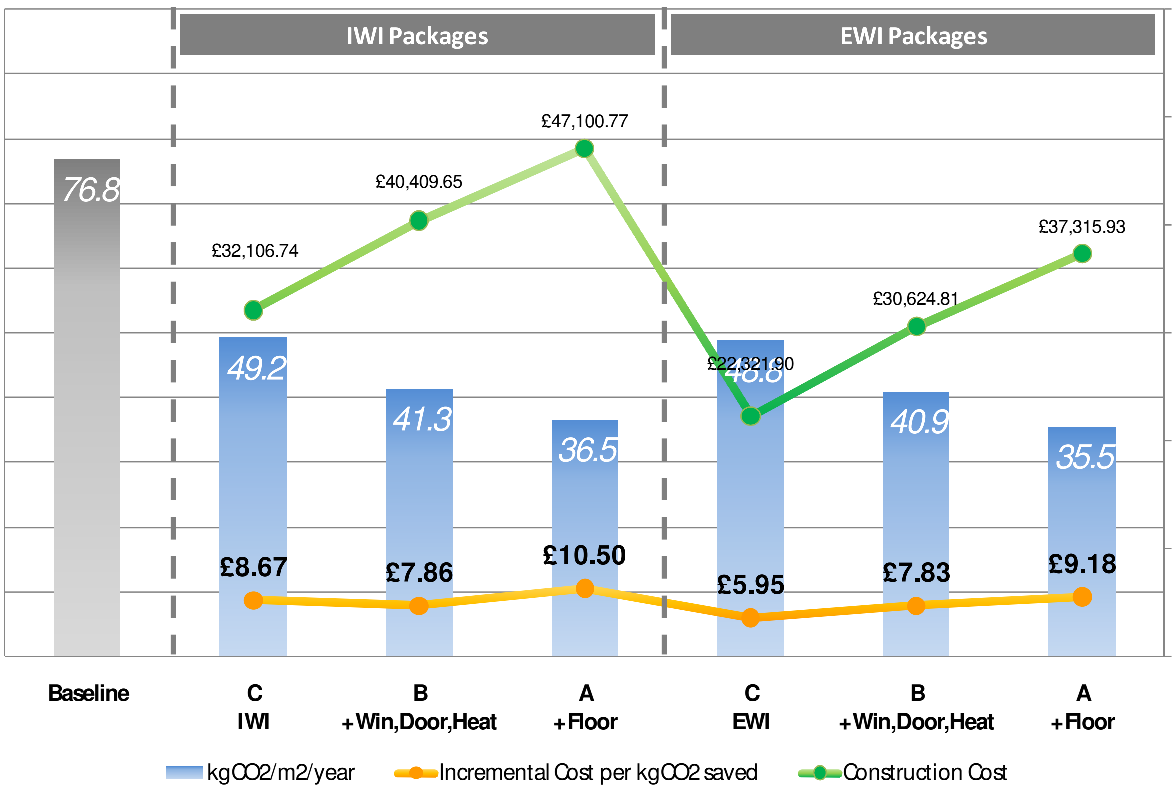
6. S19D Scottish pre-1919 detached house

The C-B-A route works better for IWI installations, while the C-A-B route works better for EWI installations in terms of cost. The issue with IWI is that these houses have thick stone walls that already have high thermal mass and as a result, the addition of IWI to the interiors may reduce space standards substantially. For both IWI and EWI there may be issues to do with loss of daylight due to thicker walls. As such, the use of thinner insulation or a special attention to daylight design detailing to the window reveals should be considered.



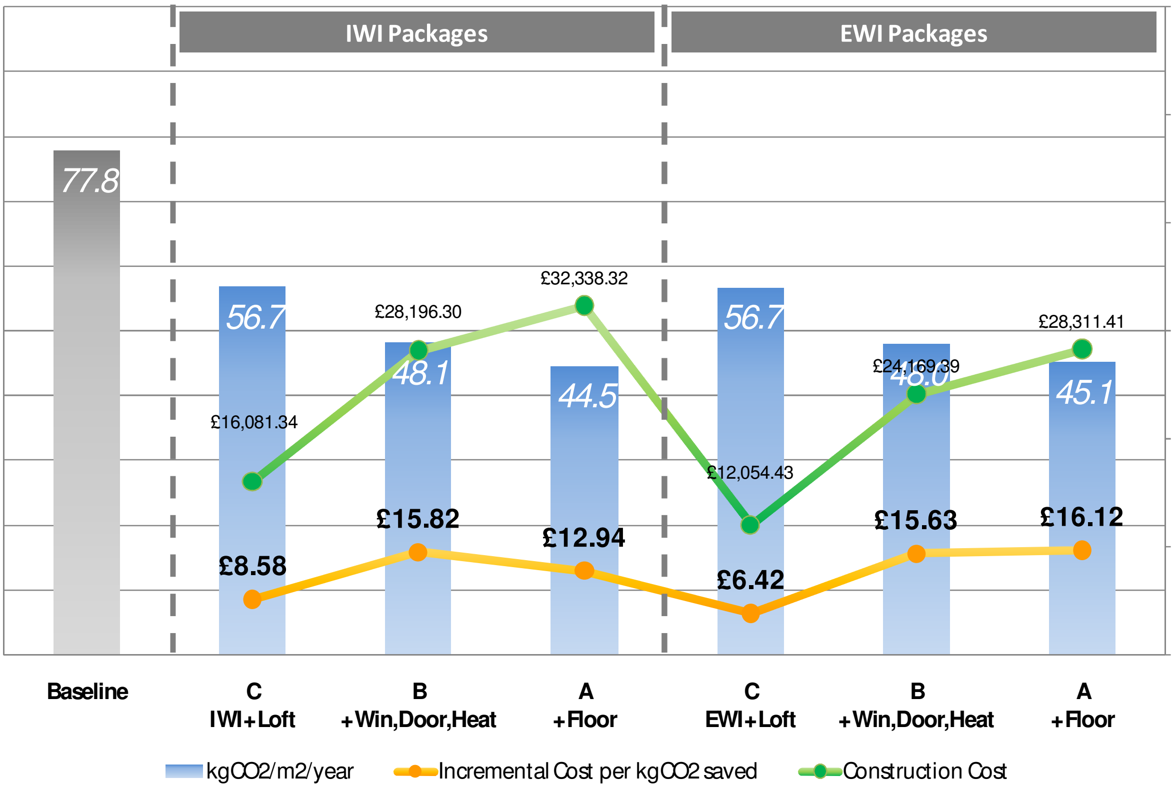
7. S80D Scottish post-1980 detached house

The B-C option is the best route for these houses. Modern construction often means better fabric thermal performance and the most cost-effective first step in this case seems to be upgrading the windows, doors and heating systems, and then improving the walls and roof. Solid floors will make the implementation of A difficult. The costs in the chart below are based on the existence of a suspended floor.



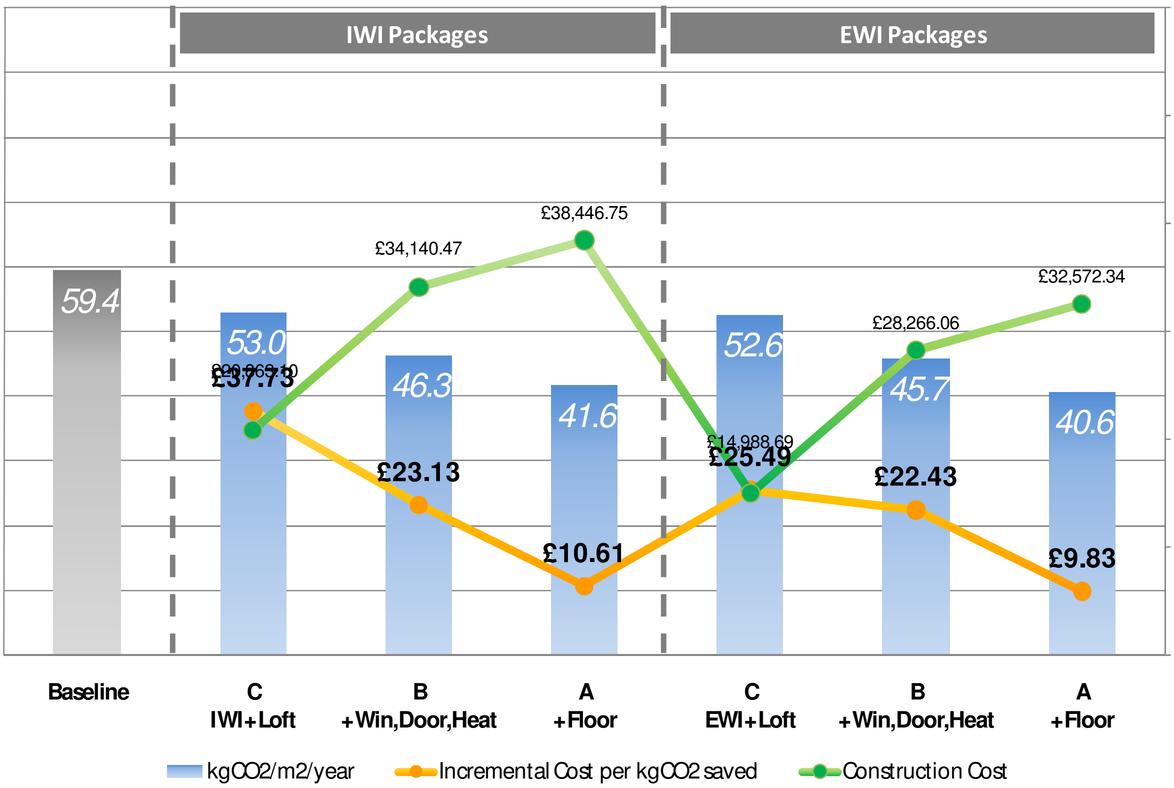
8. W19M Welsh pre-1919 mid-terrace house

Welsh stone walls and Scottish stone walls are not the same type of stone - Welsh stone walls were a by-product of the mining industry and as such are more like rubble as opposed to regularly cut pieces. For this type the C-A-B approach seems the most cost efficient, provided the floors are suspended and the A option is actually cost effective to do. EWI is the more cost-effective solution compared to IWI (as well as a more preferable solution in terms of preserving space standards). However, there may be issues due to the fact that most of Welsh mid-terrace housing sits in a very hilly landscape, where rooflines have not been sloped to match the street. Consequently, houses will be stepped, leaving little bits of end wall that may or may not need to be insulated depending on the presence of a warm roof.



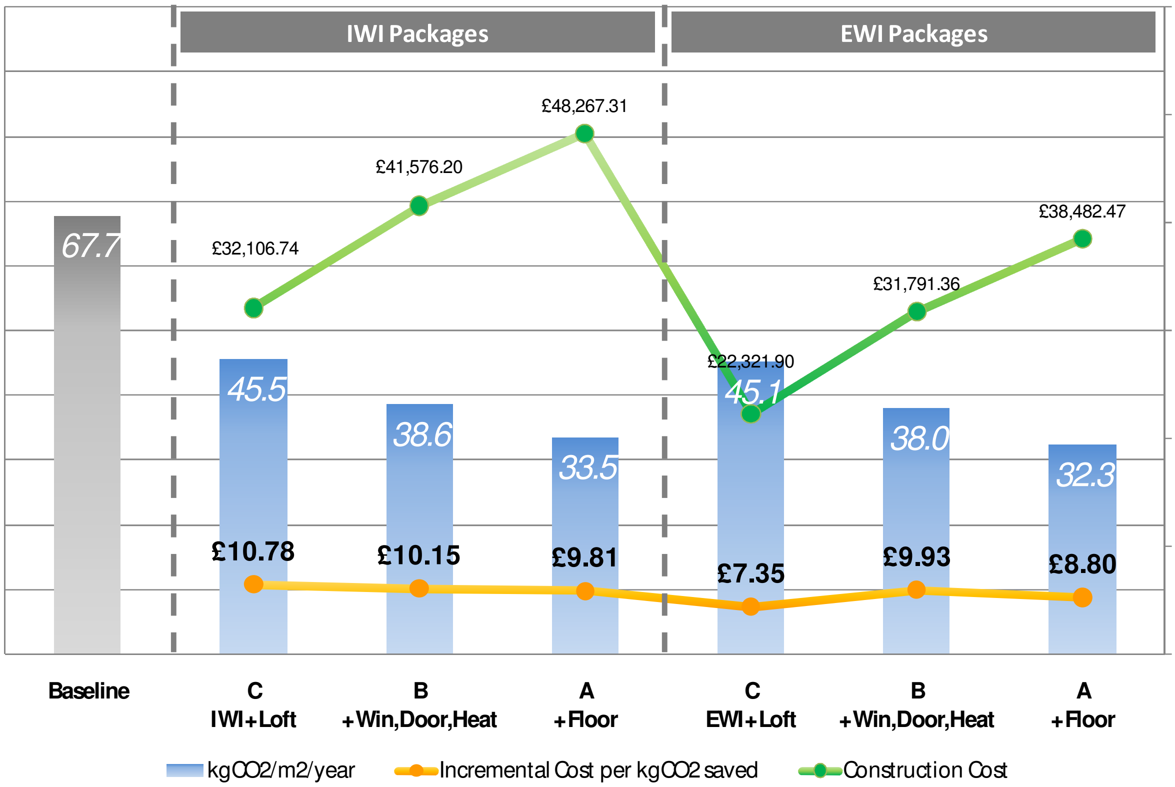
9. W64S Welsh 1945-1964 semi-detached house

Welsh cavity wall construction closely matches that of English construction, so these properties will behave similarly to the English 1945-1964 semi. There is the possibility of installing either EWI/IWI, depending on aesthetic appearance of property. EWI is indeed preferable if the external appearance is of no architectural significance and would actually be improved with EWI. An A-B-C sequence seems to work better in terms of cost effectiveness for the both IWI and EWI options.



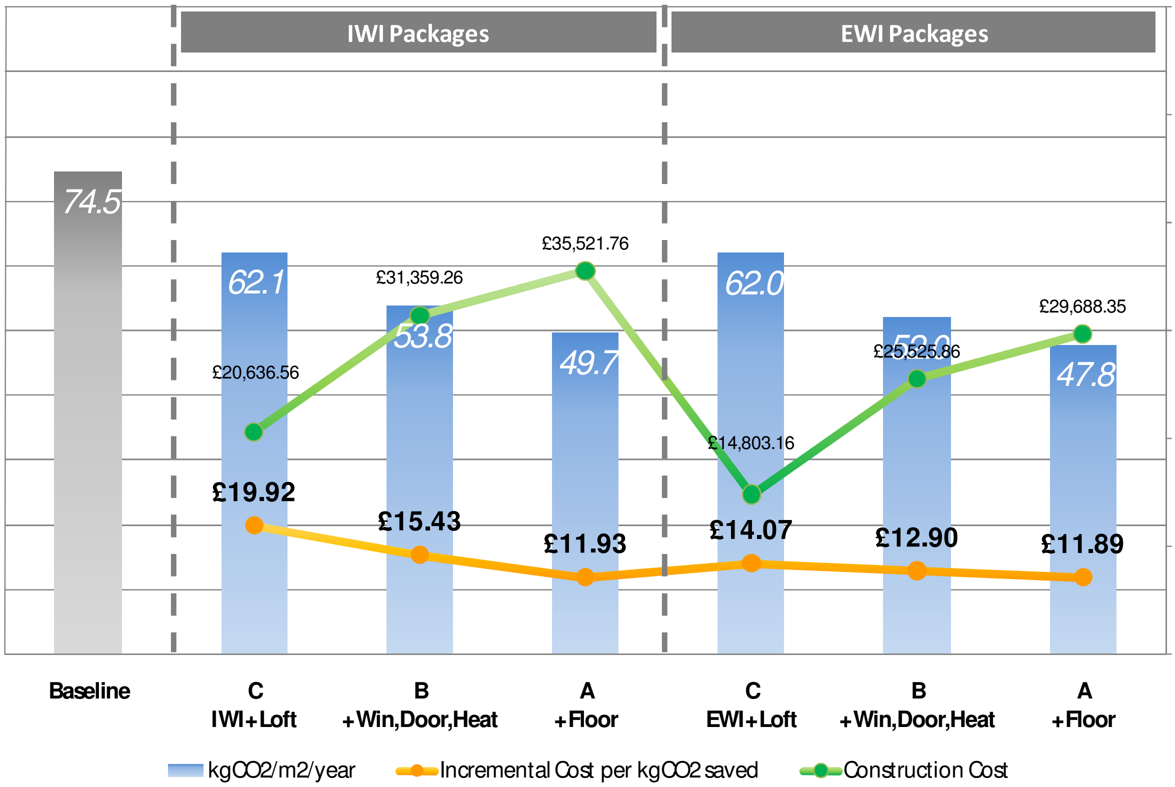
10. W80D Welsh post-1980 detached house

The A-B-C option is the best route for these houses. The more modern construction means better fabric thermal performance and the most cost-effective first step in this case seems to be ground floor insulation (as this would be the part of the house least likely to be insulated in the current state), then upgrading the windows, doors and heating systems, and finally improving the walls and roof.



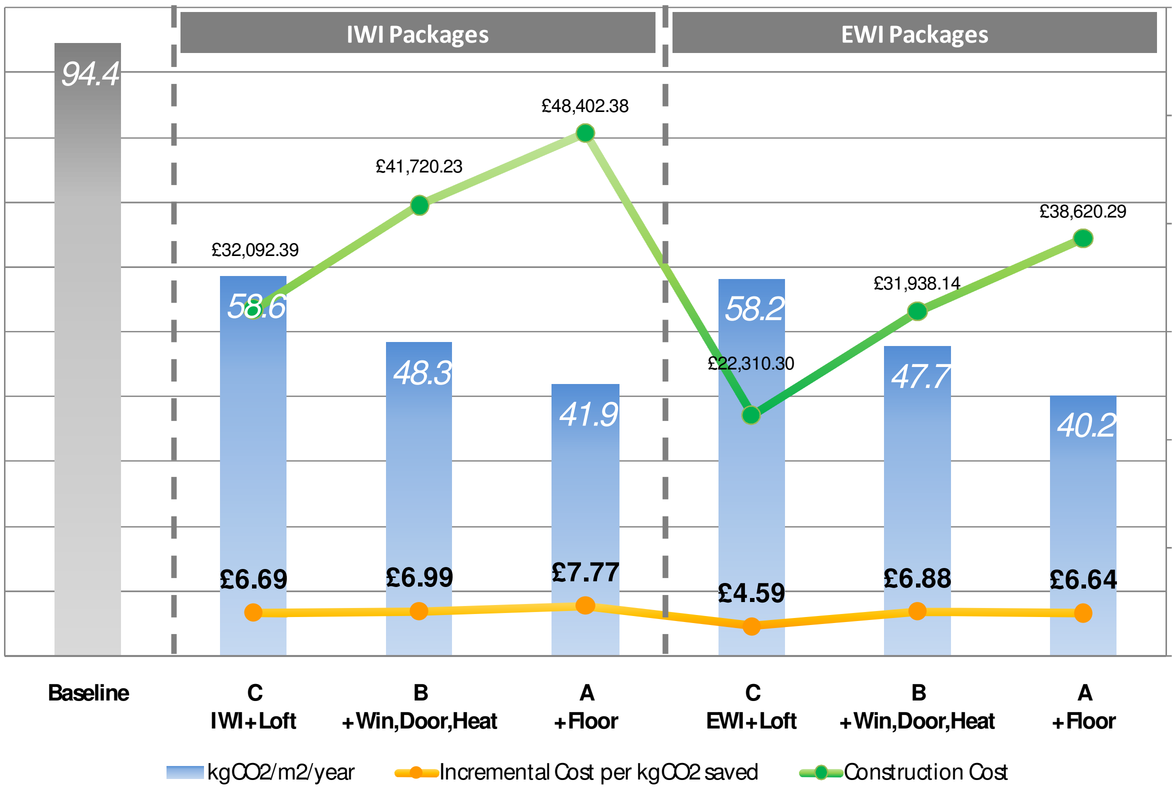
11. NI80S Northern Irish post-1980 semi-detached house

The B-C option is the best approach for these houses. The relatively modern construction means better fabric thermal performance and the most cost-effective first step in this case seems to be upgrading the windows, doors and heating systems, and then improving the walls and roof. Solid floors will make the implementation of A difficult. The costs below have been modeled based on the existence of suspended floors.



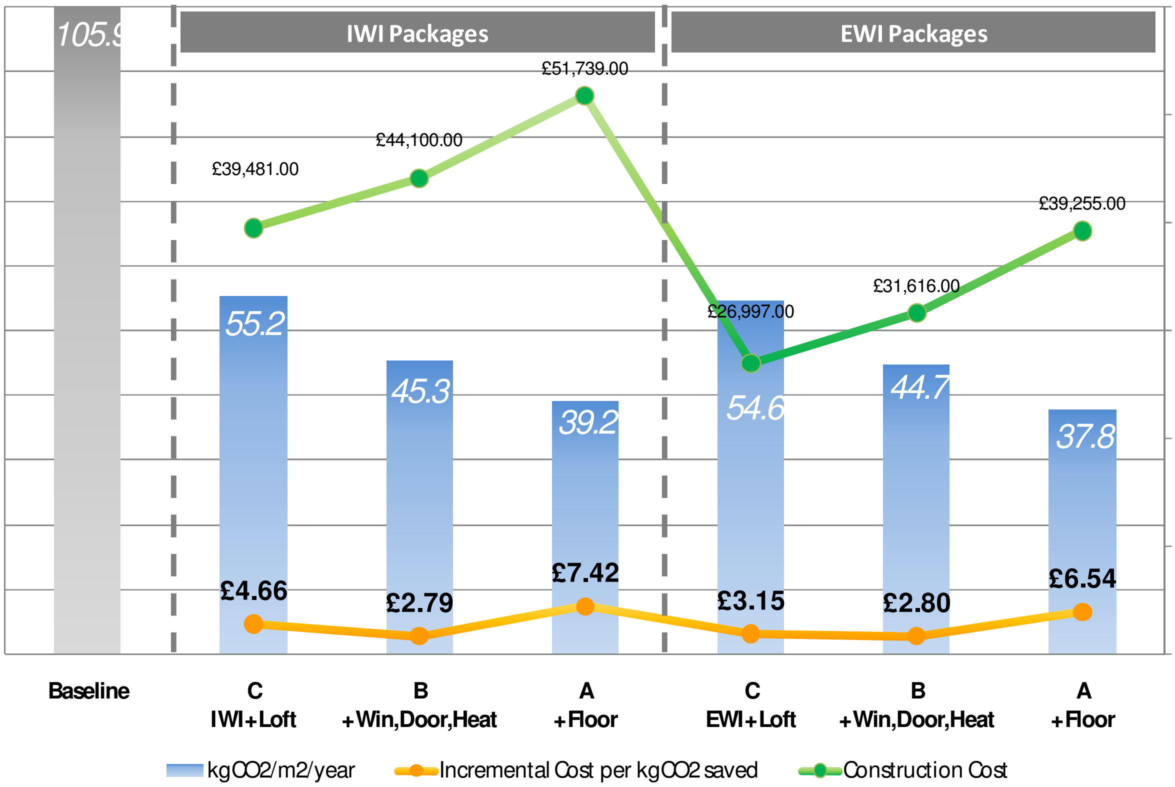
12. NI80D Northern Irish 1965-1980 detached house

The C-B option is the best route for these houses, although there isn't very much difference on a cost-per-carbon-savings basis for the IWI option. The baseline CO_2 emissions of a home in Northern Ireland is a lot lower than that of a similar house in other regions and the kWh/m^2/year figure after package B closely approaches the target value of 100 kWh/m^2/year, a target set by the ETI. The housing stock in general is relatively new and therefore comparatively more thermally efficient. Solid floors will make the implementation of A difficult. The costs in the chart below have been modeled assuming the existence of a suspended floor.



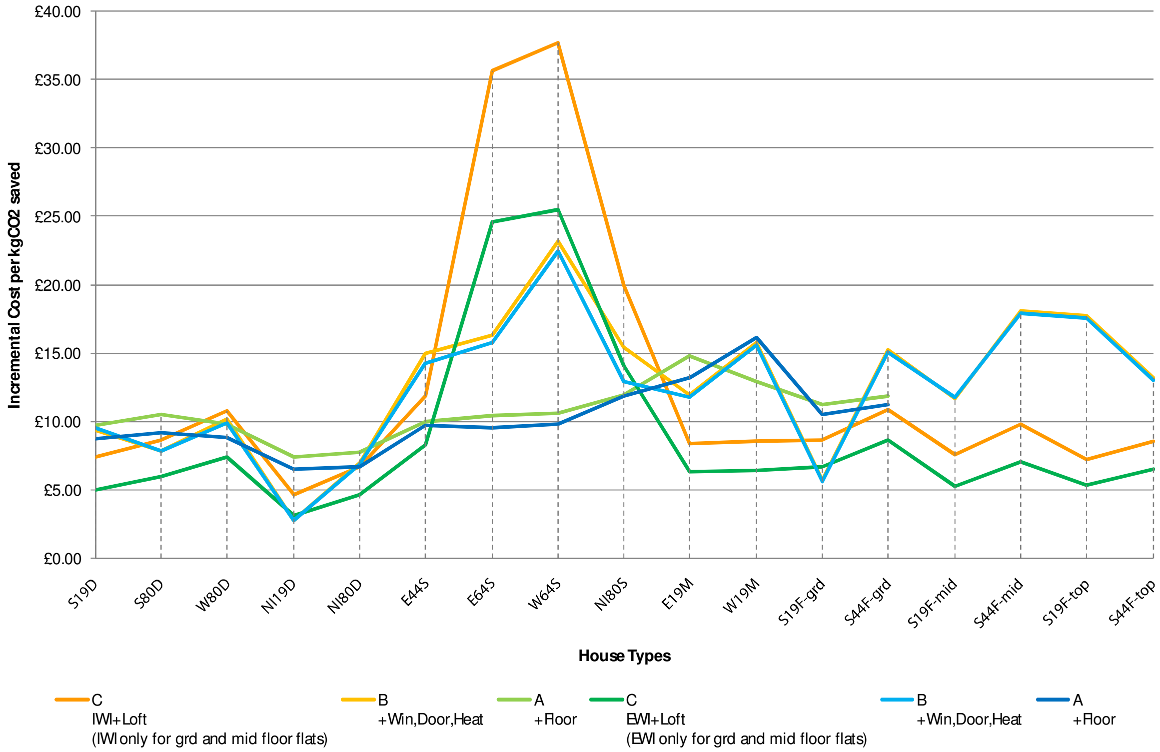
13. NI19D Northern Irish pre-1919 detached house

The B-C option is the best route for these houses in terms of cost-per-carbon savings. 15% of the houses of this type in this age band have had internal wall insulation added, so this could potentially be a way forward. EWI is also a possibility as the majority of these houses will be in rural locations, allowing for space around the house to accommodate EWI. Floors may be solid stone and therefore A will prove to be difficult.



11. Analysis

The following graph shows a summary of the incremental costs per kgCO2 saved across all of the house types:



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 exeption 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 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 and disruptive. Few people are likely to elect to have internal wall insulation measures done, given the scale of disruption and concern over personal belonging, valuables and pets. There is also the associated loss of internal space which is a major concern for many homes. External wall insulation is more apt to be an accepted form of wall insulation, although its application will be limited by homes in Conservation Areas and other historic areas. 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. There are again problems associated with heritage homes or houses in Conservation Areas, as planning policy may require specific doors and windows in order to maintain the architectural integrity of the area. For example, acceptable double glazed sash windows may increase the overall cost considerably.

Convincing the public to undertake package A is likely to be the most difficult measure. The level of disruption is comparable to internal wall insulation with regard to expected mess and the need to move resident belongings. However, under floor 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.

Obstacles

With the modeling and solutions as they stand it is clear that the target of 100kWh/m^2/year (a working target suggested by the ETI) is quite challenging, and only a few of the properties come close to meeting the criteria. Simple payback calculations yield very unconvincing results, as payback times are often in excess of 30 years. In terms of motivating potential homeowners there needs to be a better motivator than just simple payback.

12. Next Steps

As we have now completed the modeling of solutions and analysed their applicability across the wide range of UK housing types, the next step is to shift from thermal efficiency to focus on customer understanding and acceptance with WP 3.4b.

Ideally, we would like to now run the model measure by measure, rather than by grouped packages. This will help to provide a more accurate assessment of the cost-effectiveness of each individual measure. Overall, this will be more beneficial since a set package may not be suitable for homes which have already had some work done (i.e. a home may require wall insulation but not loft insulation if it has already been installed). As a result of programming constraints, the model was still being developed at the time of this report and packages of measures were developed for ease of analysis. With the TE model now completed, we will be able to consider each measure individually for our next work package.

Appendix B- Data Tables

The following tables show the results of inputting the three packages into the ETI TE model. Each table shows the results of the calculation as well as a commentary on the ideal sequence for interventions. Figures for energy consumption per square metre and $kgCO_2$ per square metre are colour-coded across the charts so that they can be compared across house types.

E19M English pre-1919 mid-terrace house

House Type	Country	England						
	Year of Construction	Pre-1919						
	Type	Mid-terrace house						
	Floor Area (gross, m^2)	89	89	89	89	89	89	89
Package	Package		C	B	A	C	B	A
	Insulation type		IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	29,782	20,094	16,061	14,645	20,112	16,014	14,430
Energy Benchmark	$kWh/m^2/year$	334	225	180	164			
Carbon Emissions	Total CO_2 Emissions	7108	5189	4396	4116	5193	4387	4073
	$kgCO_2$ saved		1,919	2,712	2,992	1,915	2,721	3,035
Carbon Benchmark	$kgCO_2/m^2/year$		58.2	49.3	46.2			
Costs	Construction Cost		£16,081.34	£25,550.79	£29,692.81	£12,054.43	£21,523.89	£25,665.90
	Total Fuel Cost (£/year)	£1,359.00	£1,029.00	£893.00	£844.00	£1,029.00	£891.00	£837.00
	Fuel Savings (£/year)		£330.00	£466.00	£515.00	£330.00	£468.00	£522.00
	Cost per $kgCO_2$ saved (£)		£8.38	£9.42	£9.92	£6.29	£7.91	£8.46
Effectiveness	Incremental Cost		£16,081.34	£9,469.46	£4,142.02	£12,054.43	£9,469.46	£4,142.02
	Incremental $kgCO_2$ saved		1,919	793	280	1,915	806	314
	Incremental Cost per $kgCO_2$		£8.38	£11.94	£14.79			

PACKAGES		
C	Wall+Loft insulation	
B	Window, door and boiler	
A	Ground floor insulation	
		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104
		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

English pre-1919 Mid-terrace - *solid wall, 50mm loft insulation, double glazing, suspended floor, owner occupied*
EWI will probably not be possible due to heritage/conservation/aesthetic issues so limited to IWI. In terms of IWI the C-B-A package approach works in terms of incremental cost effectiveness.

E44S English 1919-1944 semi-detached house

House Type	Country	England						
	Year of Construction	1919-1944						
	Type	Semi-detached house						
	Floor Area (gross, m^2)	91	91	91	91	91	91	91
Package	Package		C	B	A	C	B	A
	Insulation type		IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	28,055	18,845	15,194	12,942	18,671	14,852	12,538
Energy Benchmark	$kWh/m^2/year$	308	207	167	142	205	163	138
Carbon Emissions	Total CO_2 Emissions	6779	4956	4238	3792	4921	4170	3712
	$kgCO_2$ saved		1,823	2,541	2,987	1,858	2,609	3,067
Carbon Benchmark	$kgCO_2/m^2/year$		54.4	46.5	41.6	54.0	45.8	40.8
Costs	Construction Cost		£21,592.05	£32,314.75	£36,752.37	£15,464.76	£26,187.46	£30,625.07
	Total Fuel Cost (£/year)	£1,304.00	£990.00	£867.00	£790.00	£984.00	£855.00	£776.00
	Fuel Savings (£/year)		£314.00	£437.00	£514.00	£320.00	£449.00	£528.00
	Cost per $kgCO_2$ saved (£)		£11.84	£12.72	£12.30	£8.32	£10.04	£9.99
Effectiveness	Incremental Cost		£21,592.05	£10,722.70	£4,437.61	£15,464.76	£10,722.70	£4,437.61
	Incremental $kgCO_2$ saved		1,823	718	446	1,858	751	458
	Incremental Cost per $kgCO_2$		£11.84	£14.93	£9.95	£8.32	£14.28	£9.69

PACKAGES		
C	Wall+Loft insulation	
B	Window, door and boiler	
A	Ground floor insulation	
		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104
		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

English 1919-1944 Semi-detached - *solid wall, 50mm loft insulation, double glazing, suspended floor, owner occupied*

Can do either EWI/IWI depending on aesthetic appearance of property. EWI if external appearance is degraded to begin with. A-C-B sequence seems to work better in terms of cost effectiveness for the IWI approach, while the C-A-B sequence works better when doing EWI. Solid walls have been assumed for the base case.

E64S English 1945-1964 semi-detached house

House Type	Country	England						
	Year of Construction	1945-1964						
	Type	Semi-detached house						
	Floor Area (gross, m^2)	87	87	87	87	87	87	87
Package	Package	0	C	B	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	20,591	17,638	14,625	12,544	17,513	14,400	12,117
Energy Benchmark	$kWh/m^2/year$	238	204	169	145	202	166	140
Carbon Emissions	Total CO_2 Emissions	5277	4692	4101	3689	4667	4056	3604
	$kgCO_2$ saved		585	1,176	1,588	610	1,221	1,673
Carbon Benchmark	$kgCO_2/m^2/year$		54.2	47.4	42.6	54.0	46.9	41.7
Costs	Construction Cost		£20,863.10	£30,490.93	£34,797.21	£14,988.69	£24,616.52	£28,922.80
	Total Fuel Cost (£/year)	£1,043.00	£942.00	£841.00	£770.00	£938.00	£833.00	£755.00
	Fuel Savings (£/year)		£101.00	£202.00	£273.00	£105.00	£210.00	£288.00
	Cost per $kgCO_2$ saved (£)		£35.66	£25.93	£21.91	£24.57	£20.16	£17.29
Effectiveness	Incremental Cost		£20,863.10	£9,627.83	£4,306.28	£14,988.69	£9,627.83	£4,306.28
	Incremental $kgCO_2$ saved		585	591	412	610	611	452
	Incremental Cost per $kgCO_2$		£35.66	£16.29	£10.45	£24.57	£15.76	£9.53

PACKAGES		
C	Wall+Loft insulation	
B	Window, door and boiler	
A	Ground floor insulation	
		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104
		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

English 1945-1964 Semi-detached - *insulated cavity wall, 50mm loft insulation, double glazing, suspended floor, owner occupied*

Starting out with C is the most cost inefficient way forward for these properties, as they already have insulated cavities which provide thermal performance. A-B-C for both EWI and IWI options seems to be the most sensible way to proceed. Since these are post-war properties (that tend to be poorly constructed and not particularly architecturally interesting), EWI is probably the preferred option both in terms of cost effectiveness and ease of mass retrofit

S19F Scottish pre-1919 low-rise flats (ground, mid and top floors)

House Type	Country	Scotland						
	Year of Construction	Pre-1919						
	Type	Low rise flat ground floor						
	Floor Area (gross, m^2)	73	73	73	73	73	73	73
Package	Package	0	C	B	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	32,233	23,635	19,518	17,036	23,770	19,605	16,972
Energy Benchmark	kWh/m^2/year	444	325	269	235			
Carbon Emissions	Total CO_2 Emissions	7371	5668	4858	4367	5695	4876	4354
	$kgCO_2$ saved		1,703	2,513	3,004	1,676	2,495	3,017
Carbon Benchmark	$kgCO_2/m^2$/year		78.0	66.9	60.1			
Costs	Construction Cost		£14,772.68	£19,391.90	£24,900.84	£11,195.55	£15,814.77	£21,323.70
	Total Fuel Cost (£/year)	£1,380.00	£1,086.00	£947.00	£863.00	£1,091.00	£950.00	£861.00
	Fuel Savings (£/year)		£294.00	£433.00	£517.00	£289.00	£430.00	£519.00
	Cost per $kgCO_2$ saved (£)		£8.67	£7.72	£8.29	£6.68	£6.34	£7.07
Effectiveness	Incremental Cost		£14,772.68	£4,619.22	£5,508.93	£11,195.55	£4,619.22	£5,508.93
	Incremental $kgCO_2$ saved		1,703	810	491	1,676	819	522
	Incremental Cost per $kgCO_2$		£8.67	£5.70	£11.22			

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

		kWh/m^2/year
Energy Benchmark	max	444
	average	210
	min	104

		$kgCO2/m^2$/year
Carbon Benchmark	max	82
	average	51
	min	32

Scottish pre-1919 ground floor flat - *solid stone wall, no external roof, double glazing, solid floor, owner occupied/privately rented*
The B-C-A option is the most cost-effective way of retrofitting these flats. The age of these properties means that EWI is probably not an acceptable solution due to the effect on the streetscape and the aesthetics of these classic tenement buildings. In terms of IWI, one consideration would be the degree of internal decoration that tends to be present inside these properties. Is there scope for using laser scanning + rapid prototyping to deliver replacement mouldings/features quickly after installing IWI? Properties have been assumed to have a solid floor which means that A will be difficult.

House Type	Country	Scotland						
	Year of Construction	Pre-1919						
	Type	Low rise flat mid floor						
	Floor Area (gross, m^2)	73	73	73	73	73	73	73
Package	Package	0	C	B	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	22,503	13,918	11,209	11,153	13,582	10,895	10,835
Energy Benchmark	kWh/m^2/year	310	192	154				
Carbon Emissions	Total CO_2 Emissions	5444	3744	3213	3204	3678	3151	3141
	$kgCO_2$ saved		1,700	2,231	2,240	1,766	2,293	2,303
Carbon Benchmark	$kgCO_2/m^2$/year		51.5	44.2				
Costs	Construction Cost		£12,822.78	£19,038.04	£19,038.04	£9,245.65	£15,460.91	£15,460.91
	Total Fuel Cost (£/year)	£1,048.00	£755.00	£664.00	£663.00	£744.00	£653.00	£652.00
	Fuel Savings (£/year)		£293.00	£384.00	£385.00	£304.00	£395.00	£396.00
	Cost per $kgCO_2$ saved (£)		£7.54	£8.53	£8.50	£5.24	£6.74	£6.71
Effectiveness	Incremental Cost		£12,822.78	£6,215.26	£0.00	£9,245.65	£6,215.26	£0.00
	Incremental $kgCO_2$ saved		1,700	531	9	1,766	527	10
	Incremental Cost per $kgCO_2$		£7.54	£11.70				

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

		kWh/m^2/year
Energy Benchmark	max	444
	average	210
	min	104

		$kgCO2/m^2$/year
Carbon Benchmark	max	82
	average	51
	min	32

Scottish 1919-1944 mid floor flat - *solid stone wall, no external roof, double glazing, no external floor, owner occupied/privately rented*
The C-B option is the most cost-effective way of retrofitting these flats. The A option will not be available due to the absence of an external floor. The age of these properties means that EWI is probably not an acceptable solution due to the effect on the streetscape and the aesthetics of these classic tenement buildings.

House Type	Country	Scotland						
	Year of Construction	Pre-1919						
	Type	Low rise flat top floor						
	Floor Area (gross, m^2)	73	73	73	73	73	73	73
Package	**Package**	**0**	**C**	**B**	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	30,952	21,490	17,676	17,617	21,499	17,656	17,597
Energy Benchmark	$kWh/m^2/year$	426	296	243				
Carbon Emissions	Total CO_2 Emissions	7117	5244	4494	4482	5246	4490	4478
	$kgCO_2$ saved		1,873	2,623	2,635	1,871	2,627	2,639
Carbon Benchmark	$kgCO_2/m^2/year$		72.2	61.9				
Costs	Construction Cost		£13,509.08	£26,786.45	£26,786.45	£9,931.95	£23,209.32	£23,209.32
	Total Fuel Cost (£/year)	£1,336.00	£1,013.00	£885.00	£883.00	£1,014.00	£884.00	£882.00
	Fuel Savings (£/year)		£323.00	£451.00	£453.00	£322.00	£452.00	£454.00
	Cost per $kgCO_2$ saved (£)		£7.21	£10.21	£10.17	£5.31	£8.83	£8.79
Effectiveness	Incremental Cost		£13,509.08	£13,277.37	£0.00	£9,931.95	£13,277.37	£0.00
	Incremental $kgCO_2$ saved		1,873	750	12	1,871	756	12
	Incremental Cost per $kgCO_2$		£7.21	£17.70				

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104
		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

Scottish 1919-1944 top floor flat - *solid stone wall, 50mm loft insulation, double glazing, no external floor, owner occupied/privately rented*

The C-B option is the most cost-effective way of retrofitting these flats. The A option will not be available due to the absence of an external floor. The age of these properties means that EWI is probably not an acceptable solution due to the effect on the streetscape and the aesthetics of these classic tenement buildings.

S44F Scottish 1919-1944 low-rise flats (ground, mid and top floors)

House Type	Country	Scotland						
	Year of Construction	1919-1944						
	Type	Low rise flat ground floor						
	Floor Area (gross, m^2)	60	60	60	60	60	60	60
Package	**Package**	**0**	**C**	**B**	A	**C**	**B**	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	26,235	20,577	16,543	14,414	20,672	16,588	14,345
Energy Benchmark	$kWh/m^2/year$	437	343	276		345	276	
Carbon Emissions	Total CO_2 Emissions	6049	4929	4135	3714	4948	4144	3700
	$kgCO_2$ saved		1,120	1,914	2,335	1,101	1,905	2,349
Carbon Benchmark	$kgCO_2/m^2/year$		82.2	68.9		82.5	69.1	
Costs	Construction Cost		£12,193.55	£24,318.16	£29,292.47	£9,557.04	£21,681.64	£26,655.96
	Total Fuel Cost (£/year)	£1,137.00	£944.00	£808.00	£735.00	£947.00	£810.00	£733.00
	Fuel Savings (£/year)		£193.00	£329.00	£402.00	£190.00	£327.00	£404.00
	Cost per $kgCO_2$ saved (£)		£10.89	£12.71	£12.54	£8.68	£11.38	£11.35
Effectiveness	Incremental Cost		£12,193.55	£12,124.60	£4,974.32	£9,557.04	£12,124.60	£4,974.32
	Incremental $kgCO_2$ saved		1,120	794	421	1,101	804	444
	Incremental Cost per $kgCO_2$		£10.89	£15.27		£8.68	£15.08	

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104
		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

Scottish 1919-1944 ground floor flat - *non-insulated cavity wall, no external roof, double glazing, solid floor, owner occupied/local authority*

The C-B option is the most cost-effective way of retrofitting these flats. Scottish attitudes towards cavity wall insulation are lukewarm at best - interviews with local experts have suggested that CWI is generally considered to be a bad idea due to problems with condensation. So in Scotland, if a cavity wall is uninsulated it is probably best to leave it uninsulated and go straight to EWI, which is the more cost-effective and less disruptive option compared to IWI. Properties have been assumed to have a solid floor which means that A will be difficult, but this needs to be clarified. If the floors are suspended then A will also be implementable.

House Type	Country	Scotland						
	Year of Construction	1919-1944						
	Type	Low rise flat						
		mid floor						
	Floor Area (gross, m^2)	60	60	60	60	60	60	60
Package	**Package**	**0**	**C**	**B**	A	**C**	**B**	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	17,395	11,983	9,315	9,266	11,793	9,092	9,039
Energy Benchmark	$kWh/m^2/year$	290	200	155		197	152	
Carbon Emissions	Total CO_2 Emissions	4299	3227	2704	2695	3190	2660	2650
	$kgCO_2$ saved		1,072	1,595	1,604	1,109	1,639	1,649
Carbon Benchmark	$kgCO_2/m^2/year$		53.8	45.1		53.2	44.3	
Costs	Construction Cost		£10,484.18	£19,953.64	£19,953.64	£7,847.67	£17,317.13	£17,317.13
	Total Fuel Cost (£/year)	£836.00	£651.00	£562.00	£560.00	£645.00	£554.00	£552.00
	Fuel Savings (£/year)		£185.00	£274.00	£276.00	£191.00	£282.00	£284.00
	Cost per $kgCO_2$ saved (£)		£9.78	£12.51	£12.44	£7.08	£10.57	£10.50
Effectiveness	Incremental Cost		£10,484.18	£9,469.46	£0.00	£7,847.67	£9,469.46	£0.00
	Incremental $kgCO_2$ saved		1,072	523	9	1,109	530	10
	Incremental Cost per $kgCO_2$		£9.78	£18.11		£7.08	£17.87	

PACKAGES		
C	Wall+Loft insulation	
B	Window, door and boiler	
A	Ground floor insulation	
		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104
		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

Scottish 1919-1944 mid floor flat - *non-insulated cavity wall, no external roof, double glazing, no external floor, owner occupied/local authority*
The C-B option is the most cost-effective way of retrofitting these flats, leaning towards EWI wherever possible as it is the more cost-effective option compared to IWI. The A option will not be available due to the absence of an external floor.

House Type	Country	Scotland						
	Year of Construction	1919-1944						
	Type	Low rise flat						
		top floor						
	Floor Area (gross, m^2)	60	60	60	60	60	60	60
Package	**Package**	**0**	**C**	**B**	A	**C**	**B**	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	24,965	18,421	14,706	14,659	18,400	14,649	14,601
Energy Benchmark	$kWh/m^2/year$	416	307	245		307	244	
Carbon Emissions	Total CO_2 Emissions	5798	4502	3772	3762	4498	3760	3751
	$kgCO_2$ saved		1,296	2,026	2,036	1,300	2,038	2,047
Carbon Benchmark	$kgCO_2/m^2/year$		75.0	62.9		75.0	62.7	
Costs	Construction Cost		£11,133.10	£20,760.93	£20,760.93	£8,496.58	£18,124.42	£18,124.42
	Total Fuel Cost (£/year)	£1,094.00	£871.00	£745.00	£744.00	£870.00	£743.00	£742.00
	Fuel Savings (£/year)		£223.00	£349.00	£350.00	£224.00	£351.00	£352.00
	Cost per $kgCO_2$ saved (£)		£8.59	£10.25	£10.20	£6.54	£8.89	£8.85
Effectiveness	Incremental Cost		£11,133.10	£9,627.83	£0.00	£8,496.58	£9,627.83	£0.00
	Incremental $kgCO_2$ saved		1,296	730	10	1,300	738	9
	Incremental Cost per $kgCO_2$		£8.59	£13.19		£6.54	£13.05	

PACKAGES		
C	Wall+Loft insulation	
B	Window, door and boiler	
A	Ground floor insulation	
		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104
		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

Scottish 1919-1944 top floor flat - *non-insulated cavity wall, 50mm loft insulation, double glazing, no external floor, owner occupied/local authority*
The C-B option is the most cost-effective way of retrofitting these flats, leaning towards EWI wherever possible as it is the more cost-effective option compared to IWI. The A option will not be available due to the absence of an external floor.

S19D Scottish pre-1919 detached house

House Type	Country	Scotland						
	Year of Construction	Pre-1919						
	Type	Detached house						
	Floor Area (gross, m^2)	167	167	167	167	167	167	167
Package	Package	0	C	B	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	57,814	30,945	24,398	20,408	30,456	24,024	19,628
Energy Benchmark	kWh/m^2/year	346	185	146	122	182	144	117
Carbon Emissions	Total CO_2 Emissions	13069	7749	6458	5668	7652	6384	5513
	kgCO_2 saved		5,320	6,611	7,401	5,417	6,685	7,556
Carbon Benchmark	kgCO_2/m^2/year		46.4	38.6	33.9	45.8	38.2	33.0
Costs	Construction Cost		£39,481.01	£51,605.62	£59,244.69	£26,996.63	£39,121.23	£46,760.30
	Total Fuel Cost (£/year)	£2,432.00	£1,515.00	£1,294.00	£1,157.00	£1,499.00	£1,281.00	£1,131.00
	Fuel Savings (£/year)		£917.00	£1,138.00	£1,275.00	£933.00	£1,151.00	£1,301.00
	Cost per kgCO_2 saved (£)		£7.42	£7.81	£8.00	£4.98	£5.85	£6.19
Effectiveness	Incremental Cost		£39,481.01	£12,124.60	£7,639.07	£26,996.63	£12,124.60	£7,639.07
	Incremental kgCO_2 saved		5,320	1,291	790	5,417	1,268	871
	Incremental Cost per kgCO_2		£7.42	£9.39	£9.67	£4.98	£9.56	£8.77

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

Energy Benchmark		kWh/m^2/year
	max	444
	average	210
	min	104

Carbon Benchmark		kgCO2/m^2/year
	max	82
	average	51
	min	32

Scottish pre-1919 detached house - *solid wall, 50mm loft insulation, double glazing, suspended floor, owner occupied*

The C-B-A route works better for IWI installations, while the C-A-B route works better for EWI installations in terms of cost. The issue with IWI is that because these houses are stone wall construction, they are already thermally massive and the walls are very thick, so the addition of IWI to the interiors may reduce space standards substantially. For both IWI and EWI there may be issues to do with loss of daylight due to thicker walls - thinner insulation or special attention to daylight design detailing to the window reveals should be considered.

S80D Scottish post-1980 detached house

House Type	Country	Scotland						
	Year of Construction	1980+						
	Type	Detached house						
	Floor Area (gross, m^2)	134	134	134	134	134	134	134
Package	Package	0	C	B	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	44,616	25,914	20,554	17,340	25,677	20,293	16,609
Energy Benchmark	kWh/m^2/year	333	193	153		191	151	
Carbon Emissions	Total CO_2 Emissions	10300	6597	5541	4904	6550	5489	4760
	kgCO_2 saved		3,703	4,759	5,396	3,750	4,811	5,540
Carbon Benchmark	kgCO_2/m^2/year		49.2	41.3		48.8	40.9	
Costs	Construction Cost		£32,106.74	£40,409.65	£47,100.77	£22,321.90	£30,624.81	£37,315.93
	Total Fuel Cost (£/year)	£1,937.00	£1,300.00	£1,118.00	£1,009.00	£1,291.00	£1,109.00	£984.00
	Fuel Savings (£/year)		£637.00	£819.00	£928.00	£646.00	£828.00	£953.00
	Cost per kgCO_2 saved (£)		£8.67	£8.49	£8.73	£5.95	£6.37	£6.74
Effectiveness	Incremental Cost		£32,106.74	£8,302.91	£6,691.11	£22,321.90	£8,302.91	£6,691.11
	Incremental kgCO_2 saved		3,703	1,056	637	3,750	1,061	729
	Incremental Cost per kgCO_2		£8.67	£7.86		£5.95	£7.83	

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

Energy Benchmark		kWh/m^2/year
	max	444
	average	210
	min	104

Carbon Benchmark		kgCO2/m^2/year
	max	82
	average	51
	min	32

Scottish post-1980 detached house - *non-insulated cavity wall, 100mm loft insulation, double glazing, solid floor, owner occupied*

The B-C option is the best route for these houses. The more modern construction means better fabric thermal performance and the most cost-effective first step in this case seems to be upgrading the windows, doors and heating systems, and then improving the walls and roof. Solid floors will make the implementation of A difficult.

W19M Welsh pre-1919 mid-terrace house

House Type	Country	Wales						
	Year of Construction	Pre-1919						
	Type	Mid-terrace house						
	Floor Area (gross, m^2)	89	89	89	89	89	89	89
Package	Package	0	C	B	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	28,883	19,420	15,523	13,910	19,400	15,458	14,161
Energy Benchmark	$kWh/m^2/year$	324	218	174	156	218	173	159
Carbon Emissions	Total CO_2 Emissions	6930	5056	4290	3970	5052	4277	4020
	$kgCO_2$ saved		1,874	2,640	2,960	1,878	2,653	2,910
Carbon Benchmark	$kgCO_2/m^2/year$		56.7	48.1	44.5	56.7	48.0	45.1
Costs	Construction Cost		£16,081.34	£28,196.30	£32,338.32	£12,054.43	£24,169.39	£28,311.41
	Total Fuel Cost (£/year)	£1,328.00	£1,006.00	£874.00	£819.00	£1,005.00	£872.00	£828.00
	Fuel Savings (£/year)		£322.00	£454.00	£509.00	£323.00	£456.00	£500.00
	Cost per $kgCO_2$ saved (£)		£8.58	£10.68	£10.93	£6.42	£9.11	£9.73
Effectiveness	Incremental Cost		£16,081.34	£12,114.96	£4,142.02	£12,054.43	£12,114.96	£4,142.02
	Incremental $kgCO_2$ saved		1,874	766	320	1,878	775	257
	Incremental Cost per $kgCO_2$		£8.58	£15.82	£12.94	£6.42	£15.63	£16.12

PACKAGES		
C	Wall+Loft insulation	
B	Window, door and boiler	
A	Ground floor insulation	
		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104
		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

Welsh pre-1919 Mid-terrace - *solid stone wall, 50mm loft insulation, double glazing, suspended floor, owner occupied*

Welsh stone walls and Scottish stone walls are not the same type of stone - Welsh stone walls were a by-product of the mining industry and as such are more like rubble as opposed to regularly cut pieces. For this type the C-A-B approach seems the most cost efficient, provided the floors are suspended and the A option is actually cost effective to do. EWI is the more cost-effective solution compared to IWI (as well as a more preferable solution in terms of preserving space standards), however there may be issues due to the fact that most of Welsh mid-terrace housing sits in a very hilly landscape, where rooflines have not been sloped to match the street (which is quite a common occurrence), houses will be stepped, leaving little bits of end wall that may or may not need to be insulated depending on the presence of a warm roof.

W64S Welsh 1945-1964 semi-detached house

House Type	Country	Wales						
	Year of Construction	1945-1964						
	Type	Semi-detached house						
	Floor Area (gross, m^2)	87	87	87	87	87	87	87
Package	Package	0	C	B	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	19,868	17,075	14,152	12,101	16,901	13,882	11,674
Energy Benchmark	$kWh/m^2/year$	230	197	164	140	195	160	135
Carbon Emissions	Total CO_2 Emissions	5134	4581	4007	3601	4546	3954	3516
	$kgCO_2$ saved		553	1,127	1,533	588	1,180	1,618
Carbon Benchmark	$kgCO_2/m^2/year$		53.0	46.3	41.6	52.6	45.7	40.6
Costs	Construction Cost		£20,863.10	£34,140.47	£38,446.75	£14,988.69	£28,266.06	£32,572.34
	Total Fuel Cost (£/year)	£1,018.00	£923.00	£824.00	£754.00	£917.00	£815.00	£740.00
	Fuel Savings (£/year)		£95.00	£194.00	£264.00	£101.00	£203.00	£278.00
	Cost per $kgCO_2$ saved (£)		£37.73	£30.29	£25.08	£25.49	£23.95	£20.13
Effectiveness	Incremental Cost		£20,863.10	£13,277.37	£4,306.28	£14,988.69	£13,277.37	£4,306.28
	Incremental $kgCO_2$ saved		553	574	406	588	592	438
	Incremental Cost per $kgCO_2$		£37.73	£23.13	£10.61	£25.49	£22.43	£9.83

PACKAGES		
C	Wall+Loft insulation	
B	Window, door and boiler	
A	Ground floor insulation	
		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104
		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

Welsh 1945-1964 Semi-detached - *insulated cavity wall, 50mm loft insulation, double glazing, suspended floor, owner occupied*

Welsh cavity wall construction closely matches that of English construction, so these properties will behave similarly to the English 1945-1964 semi. Can do either EWI/IWI depending on aesthetic appearance of property. EWI if external appearance is of no architectural significance and could actually be improved with EWI. A-B-C sequence seems to work better in terms of cost effectiveness for the both IWI and EWI options.

W80D Welsh post-1980 detached house

House Type	Country	**Wales**						
	Year of Construction	1980+						
	Type	Detached house						
	Floor Area (gross, m^2)	134	134	134	134	134	134	134
Package	**Package**	**0**	**C**	**B**	**A**	**C**	**B**	**A**
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	38,499	23,457	18,717	15,275	23,167	18,323	14,486
Energy Benchmark	$kWh/m^2/year$	287	175	139	114	173	137	108
Carbon Emissions	Total CO_2 Emissions	9089	6110	5177	4495	6053	5099	4339
	$kgCO_2$ saved		2,979	3,912	4,594	3,036	3,990	4,750
Carbon Benchmark	$kgCO_2/m^2/year$		45.5	38.6	33.5	45.1	38.0	32.3
Costs	Construction Cost		£32,106.74	£41,576.20	£48,267.31	£22,321.90	£31,791.36	£38,482.47
	Total Fuel Cost (£/year)	£1,729.00	£1,216.00	£1,056.00	£938.00	£1,206.00	£1,042.00	£911.00
	Fuel Savings (£/year)		£513.00	£673.00	£791.00	£523.00	£687.00	£818.00
	Cost per $kgCO_2$ saved (£)		£10.78	£10.63	£10.51	£7.35	£7.97	£8.10
Effectiveness	Incremental Cost		£32,106.74	£9,469.46	£6,691.11	£22,321.90	£9,469.46	£6,691.11
	Incremental $kgCO_2$ saved		2,979	933	682	3,036	954	760
	Incremental Cost per $kgCO_2$		£10.78	£10.15	£9.81	£7.35	£9.93	£8.80

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104

		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

Welsh post-1980 detached house - *insulated cavity wall, 100mm loft insulation, double glazing, suspended floor, owner occupied*

The A-B-C option is the best route for these houses. The more modern construction means better fabric thermal performance and the most cost-effective first step in this case seems to be ground floor insulation (as this would be the part of the house least likely to be insulated in the current state), then upgrading the windows, doors and heating systems, and finally improving the walls and roof.

NI80S Northern Irish post-1980 semi-detached house

House Type	Country	**NI**						
	Year of Construction	1980+						
	Type	Semi-detached house						
	Floor Area (gross, m^2)	84	84	84	84	84	84	84
Package	**Package**	**0**	**C**	**B**	A	**C**	**B**	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	28,883	19,420	15,523	13,910	19,400	15,458	14,161
Energy Benchmark	$kWh/m^2/year$	345	232	186		232	185	
Carbon Emissions	Total CO_2 Emissions	6236	5200	4505	4156	5184	4353	4003
	$kgCO_2$ saved		1,036	1,731	2,080	1,052	1,883	2,233
Carbon Benchmark	$kgCO_2/m^2/year$		62.1	53.8		62.0	52.0	
Costs	Construction Cost		£20,636.56	£31,359.26	£35,521.76	£14,803.16	£25,525.86	£29,688.35
	Total Fuel Cost (£/year)	£1,179.00	£1,002.00	£884.00	£824.00	£999.00	£858.00	£798.00
	Fuel Savings (£/year)		£177.00	£295.00	£355.00	£180.00	£321.00	£381.00
	Cost per $kgCO_2$ saved (£)		£19.92	£18.12	£17.08	£14.07	£13.56	£13.30
Effectiveness	Incremental Cost		£20,636.56	£10,722.70	£4,162.50	£14,803.16	£10,722.70	£4,162.50
	Incremental $kgCO_2$ saved		1,036	695	349	1,052	831	350
	Incremental Cost per $kgCO_2$		£19.92	£15.43		£14.07	£12.90	

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

		$kWh/m^2/year$
Energy Benchmark	max	444
	average	210
	min	104

		$kgCO2/m^2/year$
Carbon Benchmark	max	82
	average	51
	min	32

Irish post-1980 semi-detached house - *insulated cavity wall, 100mm loft insulation, double glazing, solid floor, owner occupied*

The B-C option is the best route for these houses. The relatively modern construction means better fabric thermal performance and the most cost-effective first step in this case seems to be upgrading the windows, doors and heating systems, and then improving the walls and roof. Solid floors will make the implementation of A difficult.

NI80D Northern Irish 1965-1980 detached house

House Type	Country	NI						
	Year of Construction	1965-1980						
	Type	Detached house						
	Floor Area (gross, m²)	134	134	134	134	134	134	134
Package	Package	0	C	B	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	19,868	17,075	14,152	12,101	16,901	13,882	11,674
Energy Benchmark	kWh/m²/year	148	127	106		126	104	
Carbon Emissions	Total CO_2 Emissions	12654	7854	6476	5616	7796	6396	5389
	$kgCO_2$ saved		4,800	6,178	7,038	4,858	6,258	7,265
Carbon Benchmark	$kgCO_2/m^2/year$		58.6	48.3		58.2	47.7	
Costs	Construction Cost		£32,092.39	£41,720.23	£48,402.38	£22,310.30	£31,938.14	£38,620.29
	Total Fuel Cost (£/year)	£2,332.00	£1,510.00	£1,275.00	£1,128.00	£1,500.00	£1,261.00	£1,089.00
	Fuel Savings (£/year)		£822.00	£1,057.00	£1,204.00	£832.00	£1,071.00	£1,243.00
	Cost per $kgCO_2$ saved (£)		£6.69	£6.75	£6.88	£4.59	£5.10	£5.32
Effectiveness	Incremental Cost		£32,092.39	£9,627.83	£6,682.15	£22,310.30	£9,627.83	£6,682.15
	Incremental $kgCO_2$ saved		4,800	1,378	860	4,858	1,400	1,007
	Incremental Cost per $kgCO_2$		£6.69	£6.99		£4.59	£6.88	

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

		kWh/m²/year
Energy Benchmark	max	444
	average	210
	min	104

		kgCO2/m²/year
Carbon Benchmark	max	82
	average	51
	min	32

Irish 1965-1980 detached house - *insulated cavity wall, 100mm loft insulation, double glazing, solid floor, owner occupied*

The C-B option is the best route for these houses, although there isn't very much difference on a cost-per-carbon-savings basis for the IWI option. The baseline CO_2 emissions of a home in Northern Ireland is a lot lower than that of a similar house in other regions and the kWh/m²/year figure after package B closely approaches the target value of 100 kWh/m²/year. The housing stock in general is relatively new and therefore comparatively more thermally efficient. Solid floors will make the implementation of A difficult.

NI19D Northern Irish pre-1919 detached house

House Type	Country	NI						
	Year of Construction	Pre-1919						
	Type	Detached house						
	Floor Area (gross, m²)	167	167	167	167	167	167	167
Package	Package	0	C	B	A	C	B	A
	Insulation type	none	IWI	IWI	IWI	EWI	EWI	EWI
Energy	Total_Energy_Consumption	38,499	23,457	18,717	15,275	23,167	18,323	14,486
Energy Benchmark	kWh/m²/year	230	140	112		139	110	
Carbon Emissions	Total CO_2 Emissions	17697	9231	7576	6547	9130	7478	6310
	$kgCO_2$ saved		8,466	10,121	11,150	8,567	10,219	11,387
Carbon Benchmark	$kgCO_2/m^2/year$		55.2	45.3		54.6	44.7	
Costs	Construction Cost		£39,481.00	£44,100.00	£51,739.00	£26,997.00	£31,616.00	£39,255.00
	Total Fuel Cost (£/year)	£3,213.00	£1,764.00	£1,481.00	£1,305.00	£1,747.00	£1,464.00	£1,264.00
	Fuel Savings (£/year)		£1,449.00	£1,732.00	£1,908.00	£1,466.00	£1,749.00	£1,949.00
	Cost per $kgCO_2$ saved (£)		£4.66	£4.36	£4.64	£3.15	£3.09	£3.45
Effectiveness	Incremental Cost		£39,481.00	£4,619.00	£7,639.00	£26,997.00	£4,619.00	£7,639.00
	Incremental $kgCO_2$ saved		8,466	1,655	1,029	8,567	1,652	1,168
	Incremental Cost per $kgCO_2$		£4.66	£2.79		£3.15	£2.80	

PACKAGES	
C	Wall+Loft insulation
B	Window, door and boiler
A	Ground floor insulation

		kWh/m²/year
Energy Benchmark	max	444
	average	210
	min	104

		kgCO2/m²/year
Carbon Benchmark	max	82
	average	51
	min	32

Irish pre-1919 detached house - *solid wall, 50mm loft insulation, double glazing, solid floor, owner occupied*

The B-C option is the best route for these houses in terms of cost-per-carbon savings. 15% of the houses of this type in this age band have had internal wall insulation added, so this could potentially be a way forward, and EWI is certainly possible as well as most of these houses will be in rural locations - allowing for space around the house to accommodate EWI. Floors may be solid stone and therefore A will prove to be difficult.