Technology Strategy Board
Driving Innovation

Retrofit for the Future

Project final report

Cover note

This report was prepared by the collaborative project team for this Retrofit for the Future project, to provide fuller context on their experiences and the particulars of their retrofit's specification, construction and occupation.

The authors were encouraged to include honest, transparent and constructive comment, garnered from multiple perspectives across their team. All views are taken to be an accurate account from the time.

There may have been further modifications to the property after this report was produced. It is therefore possible that a small minority of statements will no longer be valid.

Although minor modifications have been made to this report by the Technology Strategy Board, these were only to ensure the privacy of individuals, including the residents, and compliance with the Data Protection Act.

This report may contain links to other websites, such as for project partners or the retrofit project. The Technology Strategy Board is not responsible for the content of those websites.

This report has already proven to be a valuable source of information for the technical and cost analysis reports published by the Technology Strategy Board which are available at: www.retrofitanalysis.org

Retrofit for the Future Project Final Report

Project number: ZA202H
Property number: TSB001

Author: Eco-Energy (NI) Ltd

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Driving Innovation

SBRI Government challenges. Ideas from business. Innovative solutions.

Final Report

Project information

- **ZA reference number:** ZA202H
- **Location of property:** Belfast. BT15
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- **Date report issued:** 09. 10. 12

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1. Project details and directory

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Role	Contact	Organisation	Contact details
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Design Team			
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Joiner/Designer		Eco-Energy (NI) Ltd	
Contractor			
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Sub-contractor - electric		Connect Electrical Services	Address: 56 Farmlodge Park, Greenisland, BT38 8YB Tel: 02890 859 100 Email: connectelectricalservices@yahoo.co.uk
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2. Introduction

The focus of Eco-Energy (NI) Ltd had evolved from being PV installers to researching retrofitting existing dwellings. We attended the Retrofit for the Future Belfast workshop and afterwards approached housing associations for a suitable solid wall house we could use to carry out a PHPP assessment to see if an 80% CO_2 reduction was feasible. Grove HA advised they had a house which we used in the initial entry prior to being awarded the feasibility funding. This is the house we retrofitted.

Our aim was to create an exemplar retrofitted solid wall house without altering the facade and show that an 80% CO_2 reduction in a hard to treat property was technically feasible. The design would increase levels of thermal comfort and indoor air quality and introduce natural light and views of the sky for the health and wellbeing of the occupants.

We also wanted to investigate from an embodied energy perspective if retrofitting rather than demolition was a preferred option. This we achieved by systematic deconstruction of the house to enable all material removed to be measured to conduct a life cycle assessment. Sima Pro LCA software was used to evaluate the embodied energy of the retrofit house vs. an equivalent new build.

3. Occupants

The occupants of the pre retrofit house (one adult and two children) were given the option of returning to the house post retrofit or moving to a new build. They chose the new build option; however this delayed the start of the retrofit work on site until the new builds had been finished.

A newsletter was sent around to all existing Grove HA tenants and potential tenants on their waiting list. The newsletter explained the project, however out of around 300 people, not one was interested.

After the retrofit, new tenants moved into the property (two adults, one child).

4. Dates

Event	Date
Project start date (when was the first proposal discussed or agreed)	22.05.09
Planning application submitted (if appropriate)	N/A
Planning permission granted (if appropriate)	N/A
Building Regulations application submitted (if appropriate)	14.09.10
Building Regulations approval granted (if appropriate)	10.11.10
Contract for work let / signed	N/A
Occupants moved out (state if they remained or property was empty)	Aug-Sept 2010
Start on site	01.09.10
Completion of retrofit	27.07.12
Occupants moved in	20.08.12
Monitoring system commissioned and operating properly	10.09.12
Building defects corrected (No defects)	N/A
Building services and controls operating correctly	27.07.12
Official opening	30.07.12
Super Home open day	29.09.12

5. Pre-retrofit property

The mid-terrace house built in 1896 has been owned by Grove Housing Association in North Belfast since 1983. Originally built with 2 bedrooms on the first floor and a third bedroom in the attic, the house was extended in 1986 to include a ground floor kitchen and first floor bathroom resulting in a floor area of 85m² and an internal volume of 212.5m³. Major rehabilitation work was carried out in 2001 which included fitting double glazed uPVC windows, partial drylining, the installation of a gas supply to the property and fitting a non-condensing gas boiler. One of a terrace of mixed social and private dwellings, the rear of the house faces south and shares a common rear alleyway with houses in the adjoining street.

The original walls are solid brickwork constructed with imperial sized bricks (9 inches x 2.5 x 4 bricks) creating a wall thickness of 9 inches (230 mm). The rear extension has an outer leaf constructed of brick with a 75 mm cavity and an inner leaf of 100 mm concrete block. The floor slab throughout the house is 60mm of screed and 100 mm of concrete on top of 150 mm consolidated hardcore with no insulation. The pitched roof consisted of fibreous cement slates over non-breathable sarking felt.

The air permeability (Q_{50}) pre-retrofit was measured by BSRIA at 12.43 m³/(h.m²) at 50 Pa, equivalent to an air change rate (N_{50}) of 12.21 ACH. The pre-retrofit house had an EPC of 57 compared to the average in Northern Ireland of 50. Pre-retrofit CO_2 emissions estimated using PHHP was 92.7 kg CO_2 /(m²yr) which is comparable to the TSB derived 1990 CO_2

emissions baseline of 97 kg CO_2 /(m^2yr). This is based on a semi-detached house with an 80m^2 floor area, a similar size to the retrofit house of 85m^2.

We wanted to retrofit a hard to treat house with solid walls as this would hopefully cover many of the eventualities which could be encountered retrofitting other types of housing construction. These Victorian houses built between 1840 and 1919 also represent 17% of the 2004 estimated UK housing stock of 25.5 million. This equates to 4.3 million of the UK's solid wall Victorian built houses with an estimated 2006 figure of 8,000 solid wall houses without any wall insulation in Northern Ireland.

The particular house was selected as it was the only one available within the Grove HA's stock as the occupants were moving to a newly constructed house also owned by Grove HA.

6. Design

The original design submitted to TSB was based around Passivhaus principles and conducting a sensitivity analysis of each proposed retrofit measure using Passivhaus Planning Package (PHPP) software. The Trias Energetica concept was employed to establish a hierarchy of measures. The metrics for each selected measure were entered into PHPP individually and their effect on the dwelling's overall energy balance analysed using the PHPP pre-retrofit base line of 92.7 Kg/(m^2/yr).

After further research into all aspects of low-energy dwellings, the design expanded beyond just using Passivhaus principles. Our retrofit model evolved to include a combination of Passivhaus, Minergie and Active House principles and considered case studies from sources such as the Salford low-energy house. The subsequent design moved away from purely reducing energy at the cost of, for example, introducing daylight and views of the sky into the house for the health benefits of the occupants. We wanted to achieve a comprehensive retrofit to cover issues such as occupant health and well being, day lighting and embodied energy, hence adopting the Active House standard.

Various studies have reported that many low energy houses experience overheating and consequent discomfort for occupants. The retrofit insulation levels were designed to suit summer conditions and took into account the predicted increase in the maximum mean summer temperature expected by 2050.

The Passivhaus recommended ventilation rate of 0.3 - 0.4 ACH was increased to a minimum of 0.5 ACH in line with BRE and supported by studies in Nordic countries as the minimum ventilation rate to remove water vapour from within a dwelling to avoid both damage to the occupants' health and to the health of the building structure. A hybrid system and controls were designed combining active ventilation of an MVHR with passive ventilation via automatically opening roof windows.

The original design included air heating as stipulated by Passivhaus. However, Minergie and Salford low-energy house case studies indicated that any advantages of air heating are outweighed by its disadvantages so a wet system was installed.

The wall insulation strategy developed after research into the impact of internal insulation on the building fabric. To reduce moisture movement from the inside, a high level of airtightness was required to prevent the passage of water vapour and the ventilation rates were designed to reduce the internal vapour pressure. The original design included using aerogel insulation; however, we discovered a number of issues. The price took a sudden increase in 2010 and we then discovered the 2011-2012 production of aerogel was designated for the oil industry with none going to construction. It was also of concern that any retrofit roll-out would be in the hands of one supplier if aerogel was an intrinsic part of the build model. From a practical point, we found it difficult to create a homogeneous insulation layer and difficult to attach aerogel to the wall with any great satisfaction as it winds up the drill bit when drilling holes for fixings. It also sags resulting in voids as evidenced in BRE's Stable Block. The internal insulation changed completely to phenolic bonded to 18mm OSB to create the airtight layer. A siloxane based hydrophobic impregnation was applied to the exterior of the brickwork before the internal insulation was installed.

During deconstruction, we found extensive structural decay, the cause of which we narrowed down to poorly installed insulation. Some walls had been partially dry lined in 2001 using the dot and dab method resulting in a lack of airtightness between the insulation and the internal face of the brickwork. This had allowed warm moisture-laden air to condense on the cold brickwork and plaster behind the dry lining, causing decay in structural timbers and creating areas of toxic mould growth. We found that wooden joists positioned below the dry lining were suffering from wet rot. However, in the attic where dry lining hadn't been installed, the joists were found to be in good condition. The eventual solution was to cut the wooden joists short and slot the ends into a steel universal beam supported on Foam Glas pads positioned within the thermal envelope. This eliminated the thermal bridge between the joist ends and walls, allowing a homogeneous insulation layer and airtight layer to be fitted from floor to eaves.

The intention was to thermally upgrade the existing roof. However, during deconstruction we discovered that mineral wool insulation which had been installed for around twenty five years had been pushed tight up against the sarking felt. The lack of an air gap had caused the original timbers to decay and a new roof was required. Two new roof options were considered: a traditional roof built on site or a roof built off site. We worked with Kingspan Century to design and manufacture a prefabricated roof with a high level of insulation. The roof was delivered to site with apertures for Velux roof windows and both breathable and airtight membranes in place. The old roof was removed and the new roof lifted on and made weather tight within a twenty-four hour period.

We did not use heat pumps or micro CHP on the grounds that the aim was to reduce the space heating load and primary energy consumption. Biomass was not used because of lack of heat load, high NOx emissions and high maintenance. Both solar thermal and PVs were considered for the south facing rear roof. Analysis indicated that the potential CO_2 emission savings by covering the roof with a 2.45 kWp PV array was around five times greater than a solar thermal system suitably sized for the number of occupants.

7. Construction

Eco-Energy (NI) Ltd was the RftF lead company and designed the retrofit. After winning the funding, we endeavoured to employ a contractor to take on the whole retrofit build. All contractors were reluctant to guarantee the skills and diligence of the workforce with regard to providing the airtightness required and insulation layers with no gaps. None would accept a retention in the contract should the required airtightness level not be reached or gaps in the insulation be exposed via thermal imaging. Realising that the only solution was to install the insulation and airtightness measures ourselves, we then sub-contracted other work to a company who subsequently went bankrupt two months into the build which delayed work substantially. We consequently became a management contractor with some trades sub-contracted.

Four main trades were sub-contracted: plasterers, electricians, plumbers and painters. Eco-Energy installed the MVHR system, controls and PVs as originally planned and took on the installation of the insulation, airtightness measures and installing the windows and doors.

Eco-Energy was permanently on site working on the retrofit and supervising sub-contractors. The architect liaised with building control throughout the build and was on site for various inspections.

We attempted to reduce transport embodied energy and buy locally within the island of Ireland. The insulation and windows were manufactured in Ireland with the ventilation ducting manufactured in Belfast. The main piece of equipment sourced from outside the UK was the German Maico MVHR. Thermally broken fixings to attach the internal insulation to the walls took two months to be delivered to site from their manufacturer in Poland. The Luminar translucent aerogel to improve the thermal efficiency of the Velux light tunnel was sourced in Belgium. The rest of the retrofit equipment and products including the PVs and clothes drying cabinet were sourced from within the UK.

The original house build was of reasonable quality. However, the quality of any subsequent work, including the building of the extension in 1986, was extremely poor. These defects were only exposed once some internal rendering and parts of the floors and ceilings had been removed. For example, two internal walls had no foundations even though the architect’s refurbishment drawing from 1985 showed the installation of foundations. One wall had to be demolished and the other underpinned with a foundation. During past refurbishment work, essential load bearing lintels had either not been installed or badly installed requiring extensive remedial work.

As mentioned previously, some walls had been partially dry lined in 2001 using the dot and dab method resulting in a lack of airtightness between the insulation and the internal face of the brickwork. This had allowed warm moisture laden air to condense on the cold brickwork and plaster behind the dry lining, causing damage to structural timbers and creating areas of toxic mould growth. It is evident that drawing or a non intrusive survey cannot be relied upon to reveal the short cuts and sub-standard refurbishment work carried out previously or hidden structural decay. It is estimated that the decay in the building structure caused by poorly installed insulation had caused around £25-30k of damage to the property once the

replacement roof is taken into account. If the house had been left as originally built in 1896 without any of the subsequent refurbishment work carried out, it would have been a far less labour intensive and a more cost effective exercise. The possibilities of decay induced by previous refurbishment work and the cost of remedial work needs to be factored into the future retrofitting of such houses.

The WHO Guidelines for Indoor Air Quality (2009) warn that the risk of adverse effects to occupant's health by increased exposure to dampness and mould is being created by energy conservation measures that are not properly carried out. To this we would add that the risk of severe adverse effects extends to the structure of the building.

The reduced volume in the attic third bedroom meant that a disproportionate amount of labour, materials and design were spent shoe-horning in the M&E and keeping it as a bedroom. Closing the attic off and dedicating it to M&E would have reduced the house from three to two bedrooms which goes against the ethos of optimising a building's foot print. Adding a prefabricated unit to the rear of the house may potentially be a better option for these 2½ storey houses.

8. Commissioning and occupancy

No problems were encountered during the commissioning process.

All services were commissioned, run and then tuned prior to occupants moving in. Employees of Eco-Energy took turns in living in the retrofit house to check the services and eliminate any snags. Living in the house enabled, for example, the thermostatic hot water controls for the bath, shower and sinks to be set at their optimum temperature and flows to be set.

The space heating was adjusted using the boiler controls which monitor the space heating return temperature to ensure the heat load of the boiler system is in condensing mode whenever operating. The boiler system consists of a system boiler and flue gas heat exchanger. The boiler is interlocked with the ventilation system so it can only provide space heating when the MVHR is operating and the Velux roof windows are closed.

The ventilation system was balanced by adjusting the supply air valves and extract dampers to provide a minimum of 0.5 ach equating to 120m^3/hour of supply air. The hygrostat in the bathroom was adjusted to turn the MVHR onto boost at 55% RH. The CO_2 sensor turns the MVHR onto boost at 800ppm. The air extract volume flow to the clothes drying cabinet which is connected to the ventilation system was adjusted to enable wet towels to dry overnight.

The PVs were commissioned in accordance with the MCS requirements.

Operating the retrofit house is uncomplicated and possibly easier than a normal house as there are fewer controls so occupants do not need to be trained to live in the house. The controls consist of a simple on and off switch which activates all services, plus two room analogue thermostats.

The occupants were given guided tours and instructions before taking over the property and all aspects of the house explained. The occupants were visited twice in the first month after moving in to gauge how the house was working and commented that they like the simplicity of the controls and that the house takes care of itself.

9. Costs

Item Stage>	Design stage		Post-construction		Comments
	Materials	Labour	Material	Labour	
Management and administration					
Design	0	4700	0	13000	Includes: Architect. Energy specialist. Project management.
Construction overall	58700	63450	59150	60000	
- Prelims					
- Fabric/airtight measures	21150	10000	17000	22650	Time consuming, many corners, nothing plumb or square. Homogeneous layer essential, no voids. 1.6 km of airtightness tape used.
- Building services (conventional)	5875	4000	5000	3600	
- Low /zero carbon technologies	9400	2500	5000	2500	Price per kWp reduced dramatically.
- Consequential costs	2000	2000	3500	4000	These costs only cover consequential work as a result of the energy efficiency measures installed.
Occupant temporary housing					
Monitoring equipment	7400	0	6500	1000	Includes BSRIA reporting services. Other monitoring, moisture in walls, heat meters, data will be collected foc.
Monitoring and reporting service					As above

10. Doing it again

The original design included air heating and minimal increased daylighting. We would now only use wet heating systems in a retrofit for numerous reasons. These include the ability to have different temperature zones and not taking away ownership from occupants to adjust the temperature in individual rooms. The increased daylight via roof windows allowed a hybrid ventilation system to be fitted and provide passive purge ventilation, a potential necessity in the future to provide cooling. Cooling via solar shading is provided by Bloc Out blinds which also increase the thermal performance of the windows.

There is nothing we would avoid doing again. If the requirement was for a whole house 80% retrofit pending the monitoring results, we would use the same design. For lower CO_2 reduction retrofits, the design would be based around a hierarchy of non-conflicting retrofit measures.

To reduce the costs by leaving out a piece of equipment or a process on site such as not achieving such a high level of airtightness (0.31 ACH) depends on feedback from the monitoring. Retrofitting a single property does not have the economy of scale to reduce buying costs. The feedback from the monitoring should enable a value engineering process to be conducted and cost versus performance optimised.

The design process included MSc and PhD research which enabled informed design decisions to be made. The design process continued during work on site when better solutions became apparent. A retrofit model involving a hierarchy of non-conflicting retrofit measures for this type of house is now evolving. Input from the monitoring results and other RftF projects will contribute towards future retrofit designs.

To speed up retrofits and reduce timescales, it is nessessary to build up a workforce around experts within the various trades who have the experience of working on airtight low energy retrofits. At the start of this project, we could not locate one company or a single person within Northern Ireland with retrofit experience. We now have around twelve people of various trades who served their retrofit apprenticship on this project who have a good understanding of airtightness and were on site for the numerous blower door tests.

Eco-Energy were on site every day and managed each trade on site throughout the retrofit and stood over any work being carried out to ensure standards were kept high and that airtightness was not compromised. This time-consuming process meant that it was only suitable to have one trade on the site at once. This process would not be so necessary on future retrofits.

For efficiency gains, to optimise productive time spent on site in a larger programme of retrofits roll out and tominimise traffic disruption in narrow terraced streets whilst reducing transport CO_2, retrofit components could be containerised off site. We found some retrofit components delivered to site were not to specification. As a result of this problem, using a just-in-time delivery to site strategy for crucial energy efficiency components which are not in specification can halt all work on site. Containerising well in advance so that just-in-time

distribution to site can be carried out would allow components to be inspected to ensure that only components within specification arrive on site.

The success of retrofit replication on a scale of 50 houses would initially depend upon raising finance and arrangements for decanting occupants. Both these factors would depend on the level of CO_2 reduction required as this would dictate how intrusive the retrofit work would be and if the house needs to be unoccupied during the retrofit. To ascertain what measures would be installed requires a baseline, a hierarchy of cost effective non-conflicting retrofit measures and the percentage CO_2 reduction established. Our experience on the RftF project suggests that an EPC would only provide a sufficient robust baseline if the assessment was conducted by someone with a sound knowledge of house construction and energy.

To reach the 80% CO_2 emission reduction target requires the supply of good quality products and equipment that are installed correctly and in a competent manner by a skilled and diligent workforce. Reflecting on the poor quality refurbishment work that was uncovered during the de-construction of the project house, ensuring the skills and diligence of the workforce are paramount for any future retrofit roll out.

For 80% CO_2 reduction retrofits, prefabricated units built under a factory QA process would reduce the numbers of skilled work force required on site. For 50 houses, there would an economy of scale for component purchase but it would still be necessary to assemble a skilled diligent work force and manage the work on site to ensure success. The house we retrofitted was one of a row of 20, all which have poorly built rear extensions with little volume and a lack of daylighting. A potential solution could be to demolish these extensions and replace with an industrial prefabricated module containing pre-plumbed and pre-wired M&E services (MVHR, boiler, DHW cylinder, PV inverter) and upgraded kitchen and bathroom. There would be no need to insulate the rear soild wall which would be within the thermal envelope and it would allevaite the problems regarding decay of adjacent building components. Timber frame highly insulated extentions could sit on mini-piles and would not require traditional foundations with their associated cost, embodied energy and weather dependant installation issues.

11. Business benefits

During the course of the retrofit we identified the need for components which are not available. These range from insulated uPVC profiles for window installation to domestic controls for hybrid ventilation and MVHR/boiler interlocks. We have acquired Invest NI Innovation funding for one component and are working with the University of Ulster and a manufacturer on other developments.

We recognise there is a gap in the market regarding applying airtightness measures and MVHR systems, business which we are pursuing. We have now been appointed Maico MVHR agents for Ireland as the direct result of the retrofit.

All participants including the trades and product manufacturers have had enquiries as a direct result of their involvement in the project. Eco-Energy has received seven leads regarding MVHR systems and the plumber has six leads. There have been numerous case studies by manufactures of products used in the build, including ones by Velux, Baxi and Saint Gobain. The project has been covered extensively by magazines within the island of Ireland.

The value of retrofit business we expect as a result of the project over the next five years we estimate will be in excess £250k/year and growing. This must be taken in the context that retrofit is a start up business for Eco-Energy.