SECOND EDITION



RESIDENTIAL retro fit

24 case studies

MARION BAELI

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24 case studies

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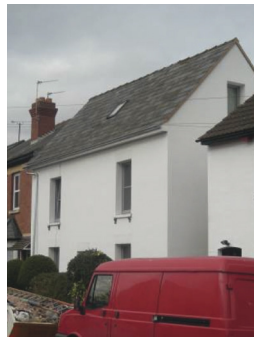

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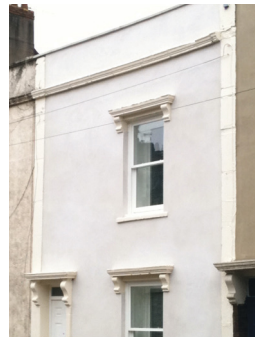

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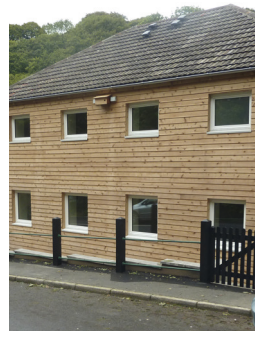

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Definitions

1. UNITS

Unit used	What does it mean?
kWh/m² per year also: kWh/(m²/yr) kWh/(m²a)	Kilowatt-hour per square metre of floor area per year. This is used to express energy intensity of a building, particularly for space heat demand, but can also be used for electricity and hot water. Also used for the production of solar power per square metre of solar panel.
kgCO_2/m²/yr also: kgCO_2/a or kgCO_2/(m²a)	Kilograms of CO_2 (and equivalent gases) per square metre of floor area per year. This is the 'carbon footprint', or CO_2 pollution of the associated energy use of a building or associated CO_2 emissions from the fabrication of building materials. Can also be tons CO_2 per year (1 ton is 1000kg) and for the whole building can be expressed as kgCO_2/a or kilograms of CO_2 per year.
CO_2e	This is the greenhouse potential of emissions, considered as if they were all CO_2. CO_2e can be used to measure the global heating potential of gases other than CO_2, a mixture of CO_2 and other gases and even pure CO_2 because one unit of pure CO_2 = 1 unit of CO_2e.
kgCO_2/kWh	Kilogram of CO_2 emissions per kilowatt hour. Used for fuel CO_2 conversion. SAP 2009 fuel conversion factors have been used throughout the book.
W/m²	To express solar radiation. 1 kWh/m² per year = 8.76 W/m².
W/mK **(k-value)**	Thermal conductivity: The lower the value, the better the material's ability to insulate. Watts per metre per degree temperature difference in Kelvin or Celsius.
W/m²K **(U-value)**	Is the thermal transmittance coefficient and is the rate of heat transfer through 1 m² element with a 1°C/K temperature difference. (Watts per square metre of surface per degree temperature difference across it.) The lower the U-value, the better insulating it is.
m³/(m²h)	Cubic metres (volume) of air exchange per square metre of floor area per hour, resulting from a 50 Pa pressurisation test. Used instead of ach-1 (air changes per hour). This means a volume of 1 m³ of air per hour is exchanged through 1 m² of building element.
pence/kWh	Cost per kWh or £/kWh. In the book, 3.7 pence per kWh of gas and 11 pence per kWh electricity have been used. Future projections can be obtained from: http://www.decc.gov.uk/en/content/cms/statistics/projections/projections.aspx – Guide F.

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), p32.

2. ENERGY SUPPLY AND DEMAND

- **Primary energy demand (kWh/m²/yr) or (total energy demand)**
  Includes energy consumption for: Space heating, hot water, lighting, fans, pumps, cooling, cooking, appliances, etc.
- **Primary energy demand is divided into two categories**
  - **Regulated:** Is the 'regulated' (Building Regulations) use of energy in a building. It comprises of space heating, hot water, ventilation, cooling and fixed lighting.
  - **Unregulated:** This includes energy for cooking, all 'plug' in devices and appliances such as TVs and computers.

  Unregulated energy use is difficult to estimate as it depends on individual user behaviour. Generally around 75% of all electricity use in a dwelling is for unregulated energy use.

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), p277.

3. PRIMARY ENERGY AND ENERGY USE INTENSITY

Primary energy and energy use intensity (EUI) are both metrics used to assess the energy performance of buildings, but they focus on different aspects of energy consumption and have distinct implications.

PassivHaus 'primary energy'

- Focus: Primary energy in the PassivHaus standard measures the total amount of energy required to supply the building with its necessary energy needs. This includes not only the energy consumed directly in the building (heating, cooling and electricity) but also the energy used in the generation, transmission and distribution of that energy to the building.
- Scope: It takes into account the entire energy supply chain – from the extraction of raw energy sources to the final delivery of energy to the building.
- Implications: This metric emphasises the efficiency of the entire energy system and the importance of reducing the overall demand for energy from non-renewable sources. It reflects the energy's environmental impact, including the source of the energy (renewable versus non-renewable).

Energy use intensity (EUI)

- Focus: EUI measures the total energy consumed within the building over a year, typically expressed in kWh per square metre of building area (e.g. kWh/m²/yr). It is an indicator of how efficiently the building operates in practice.
- Scope: Unlike primary energy, EUI focuses solely on the energy consumed within the building itself, including all forms of energy use, such as regulated energy (heating, cooling, ventilation) and unregulated energy (appliances, plug loads). It does not account for how the energy was generated or delivered.
- Implications: EUI is a practical, in-use metric that reflects the actual energy consumption of a building. It is useful for comparing the performance of different buildings and is often used in building codes and sustainability standards. EUI is directly tied to the operational efficiency of a building and is a straightforward metric for assessing and improving energy performance.

Key differences

- Primary energy considers the entire energy supply chain, including how energy is produced and delivered, while EUI focuses only on the energy consumed within the building.
- Primary energy is more concerned with the overall environmental impact, including the type of energy used, whereas EUI is more about the building's operational efficiency.
- EUI is easier to measure and monitor during the building's use, making it a more practical metric for day-to-day management and comparison across similar buildings.

4. PROPOSED CARBON EMISSION FACTORS AND PRIMARY ENERGY FACTORS FOR SAP 2012

The definition of primary energy used to calculate the SAP factors can be summarised as follows: primary energy includes all energy found in nature that has not been subject to any conversion or transformation process. It includes the energy contained in raw fuels as well as other forms of energy received as input to the energy supply system. Primary energy covers both renewable and non-renewable energy sources and the definition used here is in accordance with EN 15316-4-5, which states that 'waste heat, surplus heat and regenerative heat sources are included by appropriate primary energy factors'.

Source: Christine Pout *'Proposed Carbon Emission Factors and Primary Energy Factors for SAP 2012' SAP Crown Copyrights (Dec 2011), p14 < http://www.bre.co.uk/filelibrary/SAP/2012/STP11-CO204_emission_factors.pdf>* [accessed 1 May 2025].

5. ENERGY STANDARDS

AECB CarbonLite Retrofit

Criteria	CarbonLite Retrofit
Delivered space heating (kWh/m²/yr)	≤50 kWh/m²/yr (≤100 kWh/m²/yr with certifier approved exemption)
Delivered space cooling (kWh/m²/yr)	≤15 kWh/m²/yr
Either primary energy (PE, varies) or renewable (PER) (kWh/m²/yr)	Report result Report result
Ensure ventilation	Continuous MEV or MVHR must be installed: follow PAS 2035 Annexe C or as required by Part F of the Building Regulations
Airtightness (q50)	≤2.0 m³/m²h
Thermal bridges	Assumed to be less than 0.01 W/mK, else accounted for in PHPP or for retrofits a default heat loss factor may be used.
Surface condensation (fRsi) assessed	fRsi to meet criteria in PHPP, or 0.75 (as Building Regulations/PAS2035), or local standards – whichever is more onerous
Heating system	Existing heating systems may be retained, but a practical plan to allow for future low carbon heating supply must be in place
Thermal comfort	PHPP modelled overheating risk, <10% acceptable (guidance <5% good practice or <3% best practice)

PassivHaus

- Space heat demand: 15 kWh/m²/yr
- Heating load: 10 W/m²
- Pressurisation test result: ‹ 0.6 ACH @ 50 Pa
- Primary energy target for PassivHaus is 120 kWh/m²/yr. Primary energy target for PassivHaus in a UK context is 78 kWh/m²/yr

EnerPHit

- Primary energy: ‹120 kWh/m²/yr + ((space heat demand-15 kWh/m²/yr)*1.2)
- Space heat demand: ‹25 kWh/m²/yr OR meeting criteria for individual components
- Pressurisation test result: ‹1.0 ACH @ 50 Pa

6. RETROFIT FOR THE FUTURE

Energy performance targets for the Retrofit for the Future programme were based on an 80% reduction in CO_2 from an average 1990 baseline for a typical 80 m^2 semi-detached house of 97 kg $CO_2/m^2/yr$

- CO_2 target: 17 kg/m^2/yr (if modelled in SAP) and 20 kg/m^2/yr (if modelled in PHPP*)
- Primary energy target: 115 kWh/m^2/yr
- Space heating: No specific target was set but if the above targets are met, space heating requirements should necessarily be low (i.e. around 40 kWh/m^2/yr)

7. AIRTIGHTNESS

Air leakage, air permeability and air infiltration all express the amount of air exchanged through 1 m^2 of thermal envelope. The terms are synonymous. They are given in m^3/m^2 per hour (@ 50 Pa), which is the standard UK convention of expressing airtightness. The air leakage index excludes the solid ground floor area from the thermal envelope.

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), p210.

8. U-VALUES

Thermally insulating materials do not readily allow heat to pass through them. They reduce space heat demand by delaying the transfer of heat from warm to cold spaces. This reduces the operational energy and carbon footprint of the building. All materials have the capacity to delay heat transfer to some extent; the UK Building Regulations identify good thermal insulators as having a low k-value. 'Super insulated' buildings are defined by the intelligent use of materials, design, and construction detailing that contributes to significantly reduced heat losses from the building fabric

- k-value or l-value (W/mK) is the thermal conductivity, which gives the rate at which heat is conducted through materials. The lower the figure, the better the insulation.
- The R-value (m^2/WK) is the thermal resistance of a material/construction layer and is simply the thickness of a material divided by its k-value. The greater the R, the better its thermal resistance.

$$R = \frac{\text{Thickness (m)}}{\text{k-value (W/mK)}}$$

- U-value (W/m^2K) is the thermal transmittance coefficient and is the rate of heat transfer through 1m^2 of an element with a 1˚C temperature difference. The smaller the U-value, the better the element is at resisting this heat transfer. U-values are calculated as follows:

$$\text{U-value} = \frac{1}{\text{sum of R-values}}$$

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), pp203-4.

9. THERMAL BRIDGING

An area weighted U-value takes into consideration the combination or layering of materials used to create a build-up. It should include adjustments for thermal bridges.

Thermal bridges are areas with reduced insulation or locally higher U-values. They allow significant heat losses and potential for local surface condensation and mould growth. It is estimated that up to 25% of internal heat can be lost through thermal bridges.[1] In a typical house, the heat lost can be as much as 15 kWh/m^2/yr, while on a PassivHaus this is reduced to around 1-5 kWh/m^2/yr.[2]

There are different types of thermal bridges:

- Repeating thermal bridges tend to be evenly distributed in the thermal envelope, e.g. steel cavity wall ties; mortar in insulated blockwork, studs and additional structural timber components in panel constructions.
- Non-repeating thermal bridges or linear thermal bridges are intermittent and usually occur around openings and where materials with different k-values make up the thermal envelope, e.g. around windows and other openings but also cantilevered balconies.

Geometrical thermal bridges result from the shape of the thermal envelope. They can be two-or three-dimensional, depending how many planes intersect, e.g. wall/roof and wall/floor junctions. Corners are particularly sensitive as they have a greater external surface area exposed than internal surface area.

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), p208.

10. RENEWABLES

VHR and MVHR

- Ventilation with heat recovery (VHR) can remove contaminants, smells and CO_2 while providing oxygen and a base heat, simply by extracting stale air and using it to pre-heat fresh air supply with a top-up heating source.
- MVHR is a form of air-to-air heat-pump that uses hot internal air as its source to heat fresh colder air. It can provide all the ventilation and space heating demands of a well-insulated dwelling such as PassivHaus.
- It is always recommended in buildings with airtightness ≤3 m^3/m^2h.[3] If airtightness standards are less than 1 m^3/m^2h, such as in the PassivHaus standard, ventilation with heat recovery negates the need for traditional heating systems. Generally the required 'top-up' heating is provided via air-to-air heating or much smaller localised radiators/heaters.

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), pp 158,159,208, 368.

Heat pump

A heat pump does not create energy. It extracts heat from one location (the 'source'), upgrades the heat and then moves it to another location (the 'sink'). The source of heat can be the ground, water or air.

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), p362.

Air source heat pump

Heat from the air even when outside temperatures are low. They are less efficient than ground source heat pumps since the external air is cooler than the ground. The air source pump is least efficient in winter, which is exactly when space heat demand peaks. Its efficiency also drops when used for hot water provision.

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), p366.

Ground source heat pump

Throughout the year, soil temperatures 10 m deep are fairly stable at 10–14°C. This 'base heat' or 'coolth' can be harvested by a GSHP. Pipework is inserted into the soil horizontally, vertically or with 'slinky coils'.

Labyrinths

Labyrinths or 'earth tubes' involve supplying fresh ventilation air to the building via heavy earthenware pipes buried underground or via elaborate underground (basement) structures built from materials of high thermal capacity.

In summer the underground temperature is lower than the air temperature, so the incoming air is cooled as it passes through the earth pipes or labyrinth. Some fan-power is required to move the air through the pipe or labyrinth, but essentially the cooling is 'free'.

In winter the underground temperature is higher than the air temperature, meaning that the ventilation air is slightly pre-warmed and requires less heating before it is supplied to the occupied spaces.

Source: 'RIBA, Climate change toolkit-03 Principles of Low Carbon Design and Refurbishment' *http://www.architecture.com/Files/RIBAHoldings/PolicyAndInternationalRelations/Policy/Environment/2Principles_LC_De sign_Refurb.pdf*

Photovoltaic

Photovoltaic (PV) cells convert the sun's energy directly into electricity which, when converted from DC to AC, can be used to help meet a building's electrical power demands.

There are different types of PVs:

- Monocrystalline (1 kW peak ≈ 7.5 m^2)
- Polycrystalline (1 kW peak ≈ 10 m^2)
- Amorphous PV (1 kW peak ≈ 20 m^2)

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), p334.

Solar thermal

Solar hot water or solar thermal panels convert energy from the sun into hot water. They can provide heat for space heating and hot water.

There are two types of solar collectors – flat plate and evacuated tube.

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), p339.

11. KEY RECOMMENDATIONS FOR THERMAL COMFORT:

- Ideal relative humidity (RH) is 40–65%. Over 70% can lead to mould growth, which aggravates asthma and allergies. Reducing RH to below 50% reduces dust mites.
- Warm feet can be achieved with well-insulated floors or by underfloor heating; occupants experience discomfort if the temperature of floor level is below 19°C, or is 3°C lower than the temperature at head level when seated.
- Ideal internal temperatures are 18–21°C in winter and 22–27°C in summer.
- Ensure adequate ventilation to keep internal CO_2 concentrations below 1,000–12,000 ppm; with windows closed, levels are usually below 800 ppm. Levels above this may make a room feel stuffy, and could indicate concentration of other pollutants; this might impact concentration and respiration.
- To retain winter internal air quality, use mechanical extract ventilation (MEV) or whole-house ventilation with heat recovery (MVHR), especially if airtightness ≤3–5 m3/(m2h).
- Internal air movement to be ≤0.1–0.3 m/s otherwise occupants experience discomfort near cooling/air outlets; specify a minimum warm air supply temperature of 16.5°C to maintain comfort, as the PassivHaus standard.
- 'Adaptive comfort': user control allows each person to achieve thermal comfort by adapting the internal environment, for example, the opening/closing of windows/blinds and adjusting heating/cooling, which should be easy to understand, operate and maintain.

Source: Sofie Pelsmakers, *The Environmental Design Pocketbook* (RIBA Publishing, 2012), p136.

Foreword

At the heart of sustainability for buildings is their capacity to adapt over time to meet the evolving needs of their occupants. The UK's vast housing stock has grown and transformed over generations, shaping the distinctive character of our neighbourhoods, towns and cities. Yet, when a building can no longer serve our changing lifestyles it is often abandoned or demolished – because only active use gives a building value, and only value attracts the investment needed for renewal.

Given today's housing shortages, energy inefficiencies and finite resources, we must approach the reinvention of existing buildings stock with creativity, expertise and a holistic mindset. Sharing real-world experience is key to finding solutions – and that's what this book sets out to do.

Retrofit, renovation, refurbishment, restoration and repair are all means of extending a building's useful life. In the context of this book, the term **'retrofit' is used specifically to refer to the upgrading of a building to enable it to respond to the imperative of climate change.** The book shows what others have done to achieve this, and seeks to share the knowledge that has been gained as a result.

Since the first edition of this book was published over 12 years ago, the strategy for reducing greenhouse gas emissions from the UK's housing stock has evolved significantly. This shift has been driven by both technological advancements and the growing urgency to address climate change and reduce reliance on fossil fuels.

In the early stages, efforts focused largely on improving fabric efficiency – enhancing insulation, airtightness and overall energy performance. This 'fabric first' approach aimed to reduce energy demand, particularly for space heating, which was primarily provided by gas boilers. By improving the building envelope, emissions from natural gas combustion could be significantly lowered. Government-backed programmes, such as the research and development project Retrofit for the Future (2009), and the incentives the Green Deal and the Energy Company Obligation (ECO), supported these improvements, encouraging measures like high-performance insulation and double glazing.

However, as the UK electricity grid has become cleaner – thanks to the rise of renewable energy sources like wind and solar power – the emphasis has shifted from simply reducing energy use to changing the source of energy itself. Even the most efficient homes will still produce emissions if powered by fossil fuels. This has led to an increased adoption of electric systems, particularly air source heat pumps, which use electricity to deliver both heating and hot water efficiently.

With the continued decarbonisation of the grid, electric heating has become not only more practical, but also more sustainable. The reduced carbon intensity of electricity means that efficient technologies, like heat pumps, now play a central role in aligning the housing sector with the UK's commitment to net zero carbon emissions by 2050 in combination with a fabric improvement approach.

StudioPDP

PRACTICE PROFILE

Studio PDP is a design-led, multidisciplinary practice, offering architecture, urban and interior design and associated services. Their work is unique, sustainable and people-orientated. As well as designing new buildings and environments, they are adept at improving and adapting existing buildings; retrofitting or reinventing for new use, or returning spaces to their original purpose.

While working at Studio PDP, as an architect from 2004 and then as a partner from 2015 to 2023, Marion Baeli was instrumental in researching and integrating retrofit and sustainable architecture knowledge in the practice. Her pioneering work in this field led to several innovative projects, including 100 Princedale Road, the first Victorian residential retrofit in the UK to attain certified PassivHaus standards, as well as further projects designed to achieve net zero.

The practice designs with sustainability in mind from the outset by using a fabric first approach, minimising operational energy demand, responsibly sourcing materials and by applying sound environmental principles. A low-carbon design agenda means the environmental impact of the design and construction of a project is thought through very carefully. The practice continuously strives to reduce carbon emissions through research, learning and training.

Key retrofit projects include Eighty Strand, the iconic former Shell Mex House, which was transformed into a workplace of tomorrow; the former House of Fraser department store on Oxford Street, which now has a new lease of life; and the practice studio at 5–6 Eccleston Yards, now a BCO Award Winning workspace.

Established in 1994 by Paul Davis, the practice rebranded as PDP London in 2015, and, in 2023, as Studio PDP.

This publication is an important extension to the original book with expert research and lessons learned to encourage the retrofitting of the nation's homes. It is a study that the practice is proud to have supported.



PRACTICE PROFILE

10 Design, a member of 10N – a collective created by Egis – is a global architecture and masterplanning practice. Headquartered in London, a dynamic team of 400 architects and designers is located across nine studios in London, Hong Kong, San Francisco, Dubai, Edinburgh, Miami, Dallas, Shenzhen and Singapore.

10 Design brings together international reach with local nuance, designing and delivering projects at all scales and complexities. Placing priority on environmental, economic, and social responsibility, the practice's varied portfolio covers a broad range of sectors – mixed-use, hospitality and wellness, retail, civic and cultural, commercial, education and sciences, residential, masterplanning and urban design – and increasingly combines uses, drawing from a bank of expertise. Renowned for its innovative and multidisciplinary approach, 10 Design has earned over 340 international awards, and is recognised as one of the top 50 most significant architectural practices in the world on the WA100 list.

While the practice has built a strong global reputation through ambitious new-build projects, it also acknowledges the urgent need to address the climate crisis and the challenges of the existing built environment. In response, 10 Design's London studio has a dedicated team, led by Marion Baeli, focusing on adaptive reuse and sustainable transformation of existing buildings, reaffirming its commitment to a more resilient, low-carbon future.

For more information, visit 10design.co



CHAPTER 1

Introduction

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The UK's housing stock has a strong identity and cultural significance. Rows of Victorian terraces with coloured front doors are often seen as a quintessential part of the British aesthetic. It is a recognisable housing stock, and one of the oldest in Europe, with over half of its dwellings still dating from before 1960.

As these houses were constructed during a time when the use of fossil fuels and the emission of greenhouse gases were not widely recognised concerns, and long before the advent of modern central heating systems, their building fabric was not designed with efficient heat retention in mind. Historically, indoor comfort was achieved through different means; before the widespread adoption of central heating, residents primarily relied on open fires or individual room heaters, along with heavy clothing and bedding, to cope with the cold. Consequently, occupants of these homes adapted to the variability of UK winter temperatures, and an average indoor temperature of around 12°C, by adjusting their attire and using localised sources of heat rather than expecting uniform warmth throughout the house.

Since then, standards of comfort and our outlook on activities surrounding our energy use, particularly in the built environment, have changed vastly. Rising levels of greenhouse gases, mainly CO_2, have become a serious concern for most of the world's governments over the past few decades. The UK government recognised the urgency of addressing greenhouse gas emissions and, in 2008, introduced the Climate Change Act, a legally binding commitment to reduce greenhouse gas emissions. Originally, the Act set a target of reducing emissions by at least 80% by 2050 compared to 1990 levels, with an interim target of a 34% reduction by 2020. However, in light of the Paris Agreement and updated scientific evidence, the Act was amended in 2019 to set a more ambitious target of achieving net zero emissions by 2050. In 2024, the UK government reaffirmed its commitment to this target, alongside stricter carbon budgets and a greater focus on sustainable solutions.

As of 2025, the UK is progressing towards the next set of carbon budgets, with targets to reduce emissions by 68% by 2030, and by 78% by 2035 relative to 1990 levels. The latest assessment by the Committee on Climate Change (2025) indicates that while some progress has been made, the UK is still facing significant challenges in achieving its 2050 target, particularly with regard to residential energy efficiency and the pace of retrofitting programmes. The transition towards low-carbon homes is seen as a crucial part of the solution, yet there are persistent concerns over the affordability and accessibility of green technologies for homeowners and tenants.

The UK Department for Energy Security and Net Zero (DESNZ), which succeeded the Department of Energy and Climate Change (DECC), is responsible for driving the country's emissions reduction efforts. As of 2023, residential buildings accounted for around 18% of the UK's greenhouse gas emissions, primarily from fuel combustion for heating and electricity use.[4] This highlights the crucial role the housing sector plays in achieving the UK's net zero goals by 2050. While these emissions present a significant challenge, they also represent an opportunity. Retrofitting the UK's housing stock is not just about reducing CO2 emissions; it is also essential in preventing buildings from falling into disrepair, addressing issues of fuel poverty, mould and poor ventilation, and ultimately improving the comfort and quality of life for residents.

In recent years, there has been a growing focus on advancing retrofitting efforts to reduce energy consumption in homes, with government schemes and incentives aiming to support low-income households. The rollout of green technologies, such as heat pumps, solar panels and improved insulation, has gained momentum, but barriers remain, particularly around the upfront cost of installation and the need for skilled labour. Nonetheless, retrofitting is increasingly recognised as an essential element of the UK's strategy for a sustainable future.

SO WHAT ARE THE SOLUTIONS?

With 27 million existing dwellings and only 210,000 new homes built each year (according to 2024 data), if we were to rely solely on new construction we would fall far short of meeting the Climate Change Act targets. Over 80% of the housing stock that will exist in 2050 is already in place, which means the real challenge lies in transforming existing buildings. The question is: how can we ensure that these homes continue to be used, attract the necessary financial investment to avoid deterioration, maintain their cultural significance and, most importantly, reduce energy consumption to address the climate crisis?

Ongoing research must provide solutions for all stakeholders – homeowners, landlords, builders, tenants and housing associations – to help them achieve the required reductions in energy use. Equally important is ensuring a comfortable living environment and a good quality of life for the 16% of households in fuel poverty, most of whom are in the least energy-efficient homes.[5]

So, what options do we have to transform these older houses into spaces that are both comfortable and sustainable? Could demolition and rebuilding be a viable alternative?

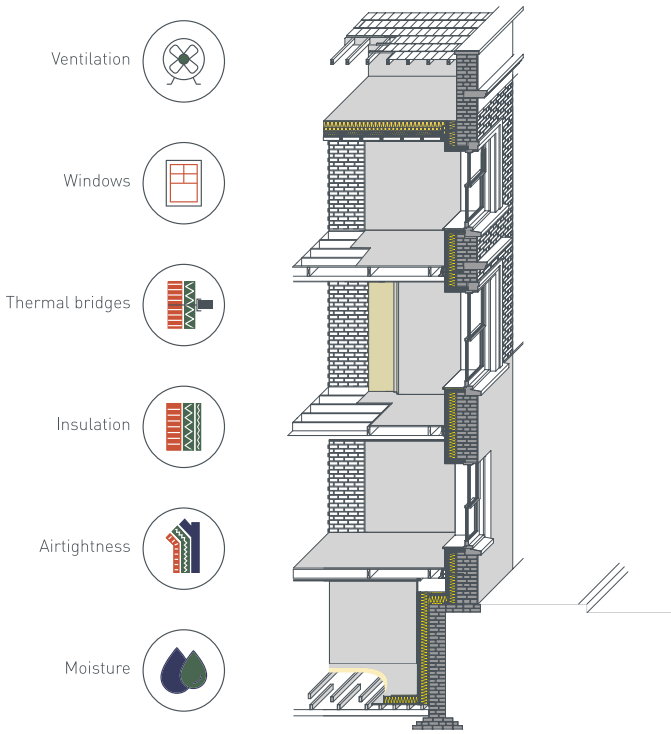
The growing focus on embodied carbon has greatly influenced the retrofit versus rebuild debate, especially as more local authorities embrace a 'retrofit first' approach. Westminster City Council and Glasgow City Region, for example, have introduced policies prioritising retrofitting existing buildings to cut carbon emissions, recognising the significant role embodied carbon plays in overall sustainability.[6] While the decision between retrofitting and rebuilding was once ambiguous, there is now a growing consensus that retrofitting is the more sustainable option. This shift highlights the importance of reducing carbon emissions not only from the operational energy use of buildings, but also from the materials and processes involved in new construction. These policies are part of a broader trend toward sustainable urban development, where preserving existing structures is key to meeting net zero targets.

From a societal perspective, retrofitting also seems more acceptable than rebuilding,[7] particularly when it would require complete relocation, as seen with the Pathfinder programmes.[8] Retrofitting *in situ* could provide much-needed revitalisation for communities, helping households escape fuel poverty by tackling rising energy costs and improving health and living standards. Additionally, retrofitting can create long-term employment opportunities by driving the development of new skills and technologies to carry out these upgrades, benefiting both the economy and the environment.

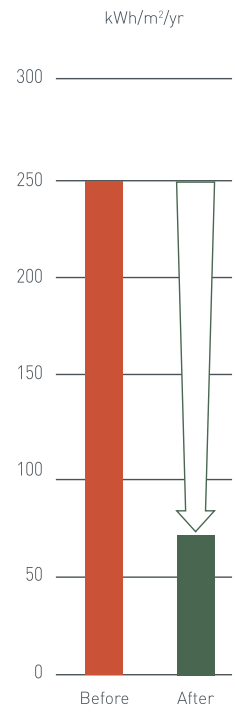
HOW IS RETROFIT DEFINED?

For the purposes of this publication, it is important to clarify the meaning of the term 'retrofit'. Here, it is defined as a construction approach that involves introducing new materials, products and equipment into an existing building to reduce its energy consumption. The term 'retrofit' is used in contrast to 'renovation' or 'refurbishment', which are typically focused on repairs, aesthetic improvements or restoring a building to good condition without necessarily addressing its energy efficiency.

The term 'deep retrofit' is often used to describe retrofit projects that go beyond simple upgrades. A deep retrofit typically involves a comprehensive combination of improvements that significantly reduce a building's CO_2 emissions, usually aiming for an 80% reduction, in line with the goals set out in the Climate Change Act.



Retrofit core principles Fabric improvements



Deep reduction in energy demand

ABOUT THIS BOOK AND THE RETROFIT FOR THE FUTURE PROGRAMME

This publication presents 24 case studies that showcase how UK practitioners have approached the challenge of meeting ambitious carbon reduction targets within the context of existing residential buildings. With the exception of five case studies, all are drawn from the Retrofit for the Future programme (outlined on the following page). These case studies share similar typologies – primarily individual houses, with one flat – along with common characteristics such as tenure (social housing), budgets (including £150,000 funding from TSB) and the target of reducing CO_2 emissions by 80%.

Each Retrofit for the Future project team followed its own procedures for designing retrofit strategies. However, all teams used the same baseline – pre-retrofit conditions – against which the effectiveness of the proposed measures could be assessed. In addition, the same energy prices were used across the projects for consistency.

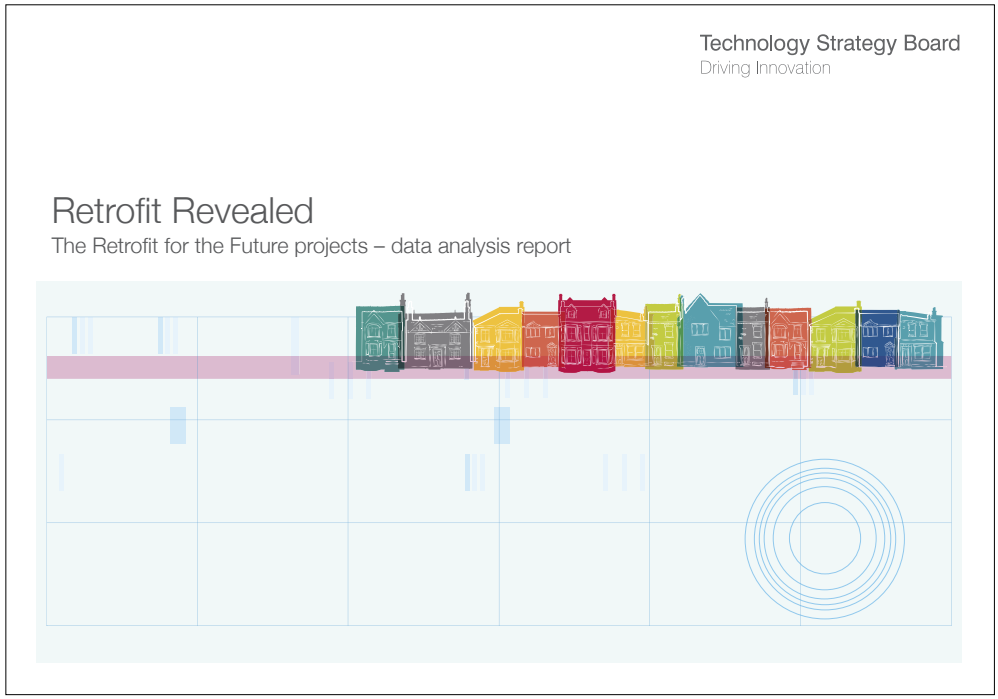
The individual houses featured in these case studies have been selected to represent the diversity of the UK housing stock. They cover a range of construction types, including solid masonry, cavity walls and timber frame. To provide a comprehensive view of what retrofit can involve, the buildings are classified into two categories: pre-1919 and post-1919. This distinction corresponds to the shift in UK construction methods from solid masonry to more efficient cavity-wall construction, providing a broad spectrum of building types for the retrofit process.



These projects are genuinely groundbreaking, marking some of the earliest attempts in the UK to achieve such ambitious levels of energy efficiency. At the same time, they were deliberately designed with scalability in mind. For example, they primarily rely on materials and products that are readily available within the UK, and the majority of the work can be completed using standard skilled labour – making widespread replication both practical and achievable.

The Retrofit for the Future (RftF) programme, initiated by the Technology Strategy Board (now Innovate UK) in 2009, received £17 million in funding through the Small Business Research Initiative (SBRI). The programme's goal was to demonstrate innovative approaches to deep retrofitting the UK's social housing stock.[9] The RftF programme was split into two phases: Phase 1 focused on developing 194 design and feasibility studies, while Phase 2 selected 86 of these studies and provided each with up to £150,000 to implement retrofit proposals across more than 100 properties. Of the 24 projects featured in this publication, 18 are drawn from the RftF programme, showcasing a diverse range of building types, ages, regional locations and technological solutions.

Applicants to the RftF competition were required to adopt a 'whole-house' approach to achieve an 80% reduction in CO_2 emissions. This involved addressing a household's total energy needs and CO_2 impact, and developing a comprehensive package of measures to reduce these. To ensure the projects provided valuable insights for the industry, applicants were also required to include a full set of monitoring equipment, in line with a standard specification. An online database collects energy and environmental performance data from each project, and the analysis of this data will be a key output from the RftF programme.[10]



UK HOUSING STOCK PROFILE – CONDITION

In order to provide some background information for these case studies, it is important to give some basic characteristics of the UK housing stock and reference current government policies that apply to them.

The UK housing stock is one of the oldest in Europe. It includes almost 13 million dwellings built before 1960, including 4.7 million built before 1919, which is the least energy-efficient housing type of all. Many of these Victorian homes have a staggering average mean energy use (heating and lighting) of 480 kWh/m^2/yr, while the more recent post-1990 dwellings' mean energy use is little more than half of this figure at 270 kWh/m^2/yr. This difference is due to a better understanding of building physics through the years, the introduction of cavity wall construction (primarily implemented to prevent the passage of moisture into the interior of the building) and building regulations that are gradually becoming more stringent on the efficiency of building thermal envelopes.

The Victorian housing stock is certainly the most 'energy hungry' of all housing stocks in the UK. However, it is important not to automatically classify it as inherently inefficient.

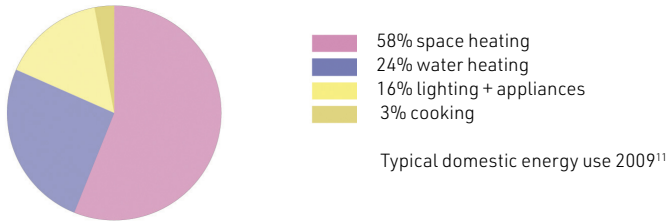
In fact, a Victorian terraced house with a small footprint will have a relatively small heat loss factor (area of heat loss/treated floor area, approximate GIA) in comparison with, for example, a detached bungalow built in the 1960s, which will have a vast heat loss area in comparison to its floor area. The lower the 'form factor', the lower the insulation thickness required to achieve the same total heat loss.

It would also be wrong to consider all Victorian properties as not inherently airtight either. When the internal layer of plaster is continuous and in good condition, it is not uncommon to find Victorian properties achieving an airtightness of five air changes per hour (ACH). With good care and repairs, this existing layer of plaster can be used in retrofits as part of the airtightness strategy.

These two examples – form factor and airtightness – only point out the importance of approaching a retrofit project free of any preconceived ideas of the existing performance of a building and free of ready-made solutions as there is no 'one size fits all' approach in retrofit. Each proposal presented in this publication is unique to the property and the result of a careful assessment by a knowledgeable practitioner.

STRATEGIES FOR RETROFIT

So how can the most energy-hungry dwellings be turned into more efficient homes? In a typical house, the activity that requires the most energy is by far space heating, representing approximately 58% of the total energy use.



Typical domestic energy use 2009[11]

To be most effective, a retrofit strategy needs to focus primarily on reducing the space-heating demand, i.e. enhancing the capacity of the building fabric and services to retain the heat inside the building. This is achieved by the retrofitting of low heat transfer elements (that are capable of stopping the heat from escaping), typically with the installation of a significant layer of insulation on the external walls, ground floors and roofs, and the upgrading of windows and doors combined with particular attention to airtightness to avoid draughts and potential heat loss paths. This approach is commonly called the 'fabric first' approach, which forms the basic principle of all 'deep retrofit' cases that are presented in this publication.

It is fair to say that most of the projects presented here applied a fabric first approach via the criteria set by the PassivHaus standard. Most teams used the PHPP software (PassivHaus Planning Package) to calculate the energy demand and comfort levels of their design. In summary, the PassivHaus criteria include:

- airtightness: 0.6 ACH @ 50 Pa (a comfort criterion)
- a surface temperature ≤ 17°C (a comfort criterion)
- a summer overheating limit of maximum 10% over 25°C (a comfort criterion)
- a ventilation rate of 30 m^2/hr/person (a comfort criterion)
- a heating demand ≤15 kWh/m^2/yr (an energy criterion)
- a primary energy demand ≤120 kWh/m^2/yr (an energy criterion).

The aim of this standard is to provide low-energy demand but also a very comfortable living environment for the occupants as most of the criteria above relate to 'comfort' rather than solely to 'energy' demand.

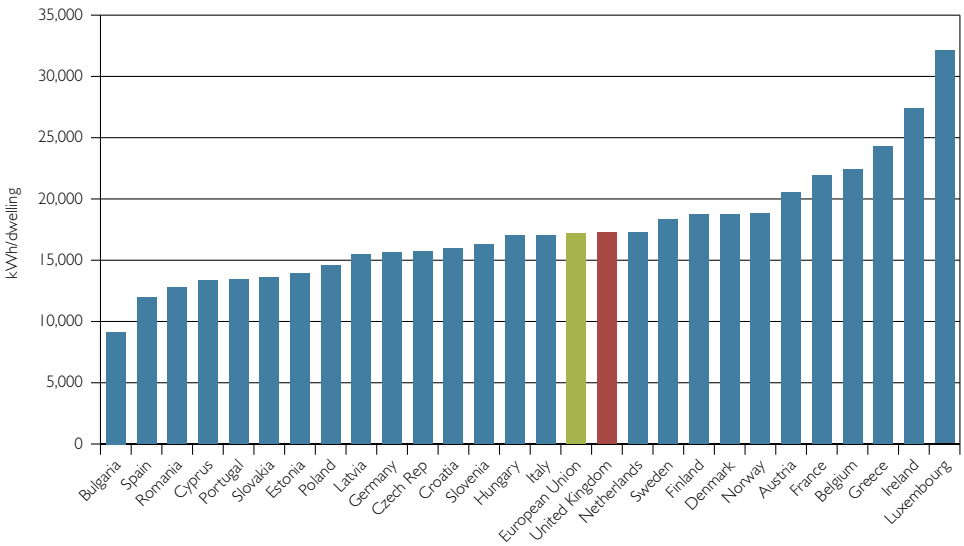
UK HOUSING STOCK IN COMPARISON WITH EUROPEAN HOUSING STOCK PROFILE

While the UK has a particularly old housing stock (see graph on p10), all other European countries are also facing similar issues and having to address the energy efficiency of their own domestic properties. Probably due to the age of its stock, on a climate-corrected basis, the UK is a higher consumer of energy per dwelling than the EU27 average, with two-thirds of countries having lower consumption per household in 2008 (see graph below).

While the UK has specific issues to address when considering retrofit (sash windows, for example), most other issues that practitioners will come across are common to all European countries, and we can hope that the lessons learned will gradually be shared across Europe. A 2019 report, 'Building Prosperity: 10 Policy Priorities to Achieve Growth and Social Value through Resilient, Healthy and Affordable Zero-Emission Buildings', reports improvement in household heating consumption between 2000 and 2018, mostly thanks to loft and cavity-wall insulation having been installed across many homes.[12] However, the rate of these installations has decreased sharply since their peak in 2012 due to the scaling back of government incentives.

Countries like Sweden, Norway, France and Germany have implemented robust policies and programmes that have significantly improved the energy performance of their housing stock, leaving the UK behind in this area. For example, Sweden has made significant strides with the widespread adoption of heat pumps, while Germany's KfW Efficiency House standard has led to substantial reductions in CO_2 emissions and energy costs for homeowners.

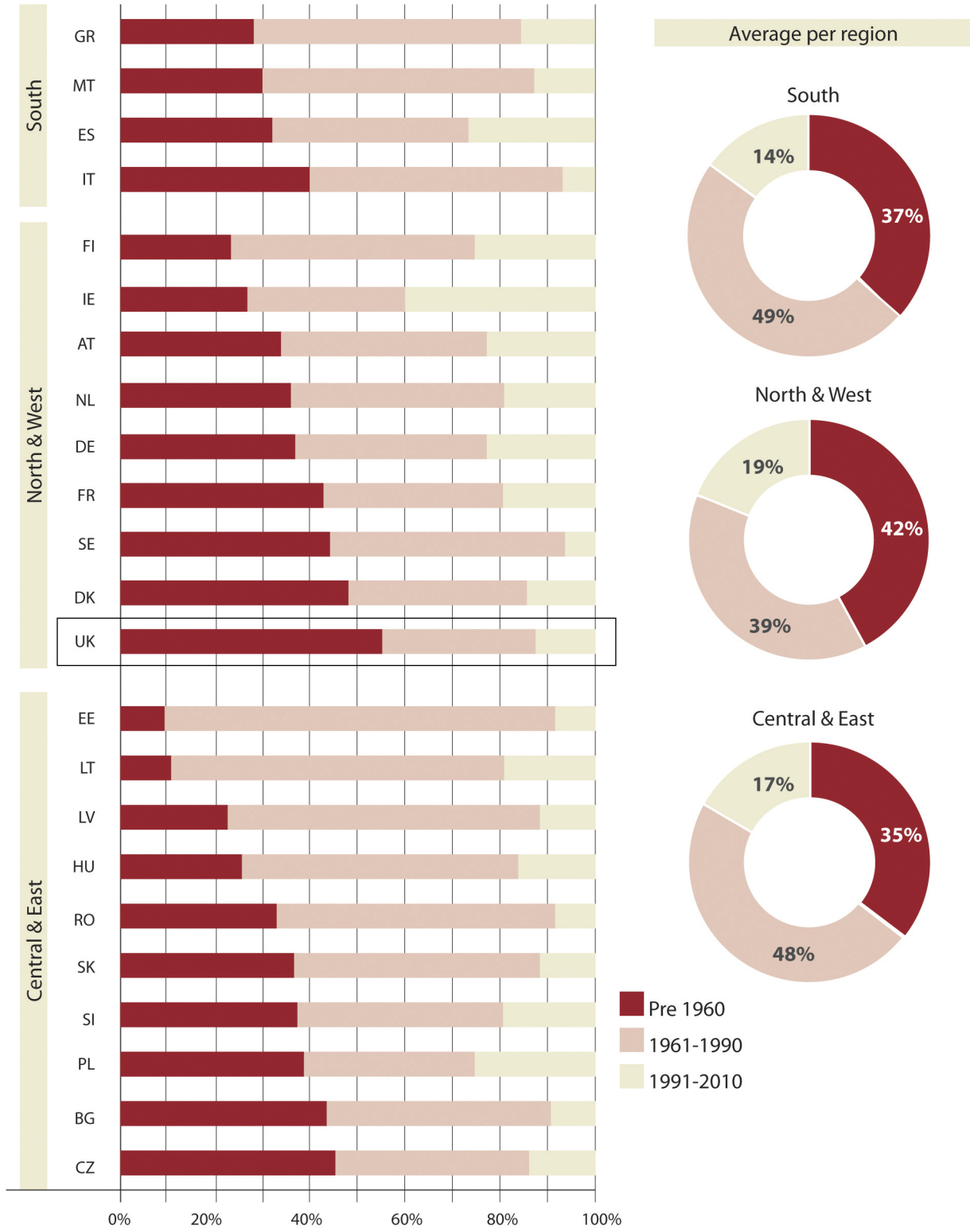
The UK's current housing stock needs substantial retrofitting to meet the government's net zero targets by 2050, and significant investments and policy changes are required to bring the UK up to par with its European counterparts.



Household heating consumption per m^2, drawn from Building Performance Institute Europe's 2011 report, 'Europe's Buildings Under the Microscope'

Age profile of residential properties

Source: BPIE survey



NOTES

BG: Based on estimations
EE: Data from 1951 onwards
GR: Data only till 2000
IT: Values exclude heritage buildings before the 1950
LT: Data from 1941 onwards
MT: Based on a sample survey with data until 2002
PL: Based on estimations
ES: Based on primary residences (i.e. excluding secondary houses)
SE: Data only from 1921 till 2005

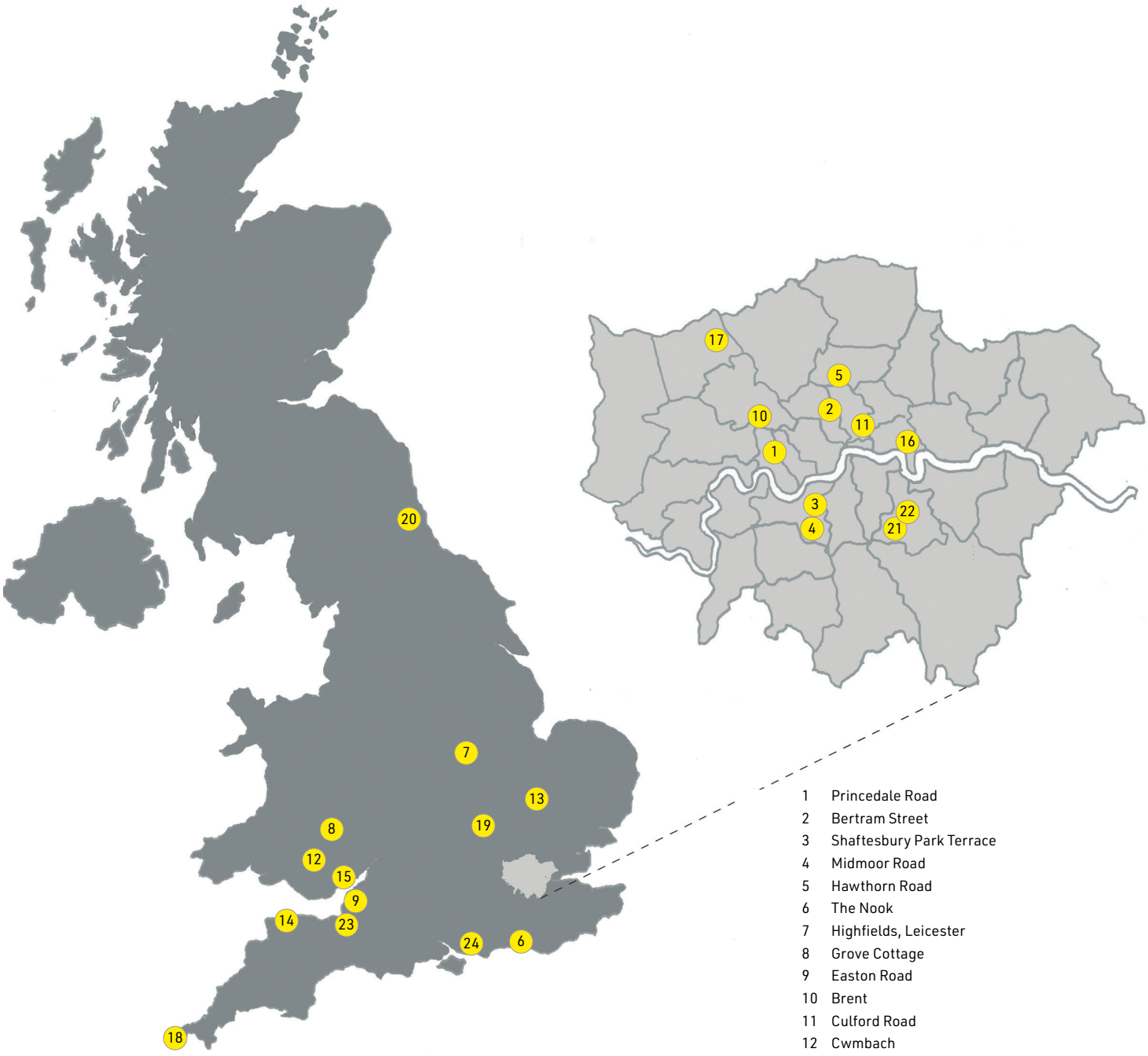
WHAT HAS CHANGED?

Since the original publication, there has been a growing interest in retrofit, including a keen desire to scrutinise the ongoing performance of these houses 10 years later. Have they performed? Do they still work? Are the fabric measures and services reliable and, most importantly, are the occupants happy and feeling comfortable? Considering the significant investment made and the non-negligeable disruption at the time of the retrofits for some, it was important to go back and see how they were doing.

Sustainability consultant, Julie Godefroy and Marion Baeli, co-lead this review work. Together with a team of 10 evaluators and the help of Innovate UK and Historic England, we embarked on a Building Performance Evaluation (BPE) exercise to investigate 10 deep retrofit properties in 2023, six of which feature in this book.

For each of these six case studies, you will find two additional pages summarising key findings from the BPE. We hope these insights provide valuable feedback on the long-term performance of deep retrofits and offer guidance on what to prioritise as retrofit measures are scaled up across the country.

PROJECT LOCATIONS MAP



1 Princedale Road
2 Bertram Street
3 Shaftesbury Park Terrace
4 Midmoor Road
5 Hawthorn Road
6 The Nook
7 Highfields, Leicester
8 Grove Cottage
9 Easton Road
10 Brent
11 Culford Road
12 Cwmbach
13 Byron Square
14 Lynton
15 Somerton, Newport
16 Passfield Drive
17 Stanmore
18 Penzance
19 Haddington Way
20 Coach Road
21 Hensford Gardens, London
22 Beaulieu Avenue, London
23 Wilmcote House, Portsmouth
24 Blaise Castle, Bristol

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CHAPTERS 2 AND 3: INTRODUCTION

With the exception of the five projects that were not in the Retrofit for the Future programme (Culford Road, Grove Cottage, Hensford Gardens, Wilmcote House and Beaulieu Avenue), the information and data presented in these chapters has been gathered from the final reports submitted by each team to the Technology Strategy Board upon completion of the built phase of each project. The 24 project teams also collaborated by providing additional information, such as images and post-occupancy data, and all have had the opportunity to comment on the final draft of this publication. In order to best compare the 24 case studies, they have been compiled according to an identical four-page layout.

PAGE 1 has some key information on the left-hand side. On the right is described the project's main characteristics in a short paragraph, in a second paragraph the author describes an aspect of the project that was found to be particularly interesting.

Notes:
The internal floor areas shown are GIAs (gross internal areas).
The primary energy figure pre-retrofit is based on the SAP modelling of each project, which each team submitted to the Technology Strategy Board.
Primary energy post-retrofit, as stated, is either 'calculated', i.e. in SAP, or 'measured' as per actual monitoring data.

PAGE 2 describes the energy-saving measures taken on the fabric, what kind of services were installed and if there were particularly interesting technology (often renewables) installed. The Vital statistics table gives the critical figures of the projects related to primary energy; space heating; airtightness; type of glazing and CO_2 emissions.

Note:
The data was provided primarily by the teams and by the TSB own analysis. All figures have been verified for accuracy as much as possible at the time of writing. As indicated, the data is also a mixture of predicted and monitored data and may contain a limited number of presentational errors. Please note that further data is available on the TSB website (www.ukgbc.org/resources/retrofit-for-the-future-innovate-uk).

PAGE 3 features an isometric detailed section illustrating how the fabric has been retrofitted.

Note:
It was not possible to illustrate for some projects all aspects of the energy-saving measures implemented on the fabric, in particular where different approaches have been taken for different facades. Please refer to the text description for more information. There are some cases where only the internal insulation detail has been shown; however, the project also includes external insulation on other external walls. The author has also deliberately not included manufacturers' names in order to place emphasis on the materials rather than the brands.

PAGE 4 presents a cost summary, monitoring data and project particulars.

Note:
Regarding the cost data, please note that the following are not incorporated: contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data); VAT.

As one-off designs incorporating many novel materials and technologies, the Retrofit for the Future projects are unlikely to have representative costs compared to replications involving larger numbers of properties. Although the cost of individual measures and their installations will be of interest, more useful are the details of the features that made the retrofit projects more or less expensive than expected. Focusing on these issues will help with potential replication projects, among others, in future. The TSB has published a separate report on the cost of the retrofit projects. The report is available online.

PAGES 5 AND 6 provide the Building Performance evaluation findings from the extensive research carried out in 2023.

CORE SCOPE FOR ALL 10 HOUSES:
- Site visits
- User survey: SOAP Retrofit
- Energy use audit based on one year (e.g. bills)
- One month of 'winter' monitoring:
  - Energy meter readings in more detail
  - T° and RH in a sample of rooms
  - CO_2 in the most-occupied room
    - SmartHTC
    - BTS mould risk indicator
- Airtightness testing: blower door and Pulse

ADDITIONAL SCOPE FOR FOUR HOUSES:
- Independent witnessing of airtightness tests (most homes)
- Thermal performance
  - Plate U-value measurement
  - Heat 3D U-value assessment
  - Thermal imaging
  - Independent expert advice
- Moisture
  - Moisture content of fabric
  - Fungal and allergen tests (ambient, after depressurisation and surfaces)
  - WUFI modelling
  - Expert advice

EVALUATORS: BPE EVALUATORS
Justin Bere – Bere Architects
Mike Roe – Warm
Nuala Flanningan – Warm
Helen Grimshaw – Carbon Coop
Ian Mawditt – Four Walls
Bob Prewett – Prewett Bizley
Tim Wilcockson – Qoda
Joe Jack Williams – Feilden Clegg Bradley Studio
Andy Macintosh – Feilden Clegg Bradley Studio
Lilija Oblecova – ECD Architects
Lizzy Westmacott – ECD Architects

BPE TESTING AND EXPERTS:
Build Test Solutions (BTS) – Luke Smith
Paul Jennings (airtightness testing)
Qoda – Tim Wilcockson
UK Centre for Moisture in Buildings – Valentina Marincioni and Toby Cambray

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CHAPTER 2

Pre-1919

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Princedale Road

Pre-1919
TSB-28

Internal floor area: **115 m²**

Primary energy
pre-retrofit calculated: **250 kWh/m²/yr**
post-retrofit measured in 2023: **128 kWh/m²/yr**
post-retrofit measured in 2024: **69.5 kWh/m²/yr**
EUI measured in 2023: **77 kWh/m²/yr**

Energy Use Intensity measured in 2024: **69.5kWh/m2/yr**

Client: **Octavia Housing**

Architect: **Studio PDP (Marion Baeli)**

Contractor: **Princedale EcoHaus**

Carpenter: **Eksalta Wondows and Doors**

Consultants: **Eight Versa; Qoda Energy; Pellings Ltd**

Front facade post-retrofit



This project is the first residential retrofit in the UK to be certified to the PassivHaus standard. It is a typical mid-19th century London terraced house located in a conservation area. The project features an internal wall insulation strategy; a unit combining MVHR, an exhaust air heat pump and hot water storage; solar thermal panels; prototype triple-glazed sash lookalike windows; and an underground labyrinth that tempers incoming ventilation air beneath the footprint of the house. The performance of the house has been monitored twice; in 2011 for one year and in 2023 for one month. Both sets of data are presented here.

From the outset of the project, the client had set the target to achieve full PassivHaus certification (EnerPHit standard did not yet exist). On inspection of the property built in 1840, this Victorian house was found to be in a very poor state of repair and in need of a significant upgrade. The extent of the necessary repairs to the fabric and the lack of original features inside suggested to the design team that an intrusive approach was justifiable.

Above and beyond the state of the fabric a critical part of the approach was the rethinking of the window and door design to satisfy planning and PassivHaus. The new windows needed respectively to: resemble the old Victorian single-glazed sash windows as closely as possible to maintain homogeneity within the streetscape and also have a minimal heat loss.[13]

Such windows didn't exist at the time of the project so the decision was taken with the client to design and manufacture them as an R&D project. The outcome was a 'look-alike' sash window very close in external appearance to the original Victorian one but formed of a fixed top light and a bottom casement opening inwards with three perimeter seals (picture below).

To produce these windows, the contractor was tasked with buying the necessary machine tools and setting up a workshop. This involved significant cost and time risks for the project overall; however, thanks to the ingenuity of the contractor, target costs and programme were achieved. The contractor, Eksalta Windows and Doors, and carpenter, Ainars Locswere given the copyright for the windows and doors produced and this undoubtedly incentivised their performance.

Sash look-alike casement window



Front facade during works with internal insulation layer



STRATEGY

FABRIC

The whole house strategy depends fundamentally on continuity of internal wall insulation and airtightness layer. The intrusive strategy included the removal of all floor structures and the chimney breasts. The new floor joists were hung on steel beams, which span from party wall to party wall and rest inside insulated pockets (photograph below). This measure helped to deal with risks of condensation around joist ends that may occur when insulating internally; it avoided a significant thermal bridge and enabled the insulation and airtightness layers to form a totally unbroken lining to the external walls. This arrangement subsequently showed that it achieved PassivHaus criteria such as: thermally bridge free design; airtight envelope and low space heat demand. The form factor of the house (see Chapter 4) was also a characteristic that enabled a low space heat demand.

SERVICES

The entire heating, hot water and ventilation system is combined into a central system (Genvex Combi). It's a unit the size of a tall fridge-freezer and contains:

- Mechanical ventilation with heat recovery (MVHR) unit as a balanced system that recovers the heat otherwise lost via the exhaust air;
- A small air source heat pump that prioritises the production of domestic hot water but will also provide top-up space heating when required;
- A 185 litre hot water cylinder.

This integrated system is also supported by a second hot water cylinder of 300 litres; solar thermal panels and a below ground labyrinth heat exchanger (see next paragraph for description).

Remarkably, no central heating system or radiators were fitted and the house is not connected to the gas network, an appealing aspect for the social housing landlord that limits the amount of specialist maintenance required.

RENEWABLES

As noted above, renewable energies are part of the services system. It includes the three drain-back solar thermal panels mounted on the south-facing butterfly roof, which together with the 300 litre hot water cylinder provide a large amount of stored hot water, making it particularly efficient in the winter when the volume stored could be sufficient for three days, getting occupants through a few cloudy days but still using the solar heat. In addition, an underground labyrinth made of concrete baffles (acting as air ducts) installed on top of a new concrete slab use the temperature of the ground (approx. 14°C) as a source of energy for pre-heating or pre-cooling the air, effectively providing free air conditioning in summer months.

VITAL STATISTICS

This project achieved a remarkable airtightness. It was enabled by the absolute simplicity of the air barrier strategy made of taped OSB boards (oriented strand board). The air pressure test at mid-project on the air barrier only (before dry lining installation and with window openings temporarily sealed) gave an air permeability of 0.2 m^3/m^2h @ 50 Pa and an air change rate of 0.19 AC, which is well below the required 0.6 ACH @ 50 Pa PassivHaus criteria. The final air permeability was measured to be 0.34 m^3/m^2h @ 50 Pa on completion.

Achieving an effective air barrier demands continuity from design to specification up to site installation. An airtightness champion was responsible in this project for checking the continuity of the installation and inspecting key interfaces and penetration seals before they were hidden (e.g. around soil vent pipes, electric cabling, ventilation ducts).

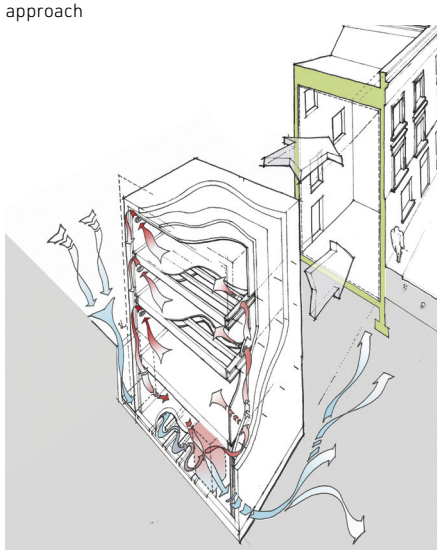
Vital statistics

Characteristics	Before	Target	Measured 2010	Measured 2023
Primary energy ($kWh/m^2/yr$)	250	120	128	–
Energy use intensity ($kWh/m^2/yr$)	–	–	48.5	62–77 (est.)
Space heating ($kWh/m^2/yr$)	120	15	10	–
Airtightness (m^3/m^2h @ 50 Pa)	–	0.6	0.34	1.45
Type of glazing	single	triple	triple	triple
CO_2 emissions ($kg\ CO_2/m^2/yr$)	70	17	20	–

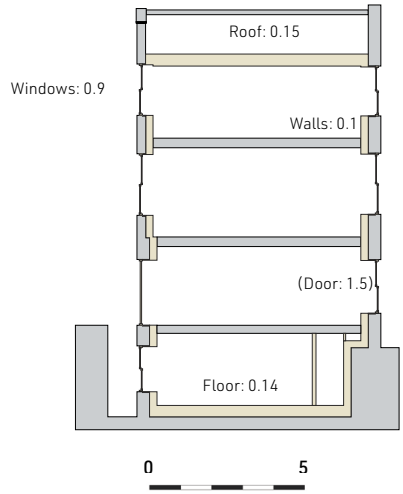
Floor joists detached from facade wall



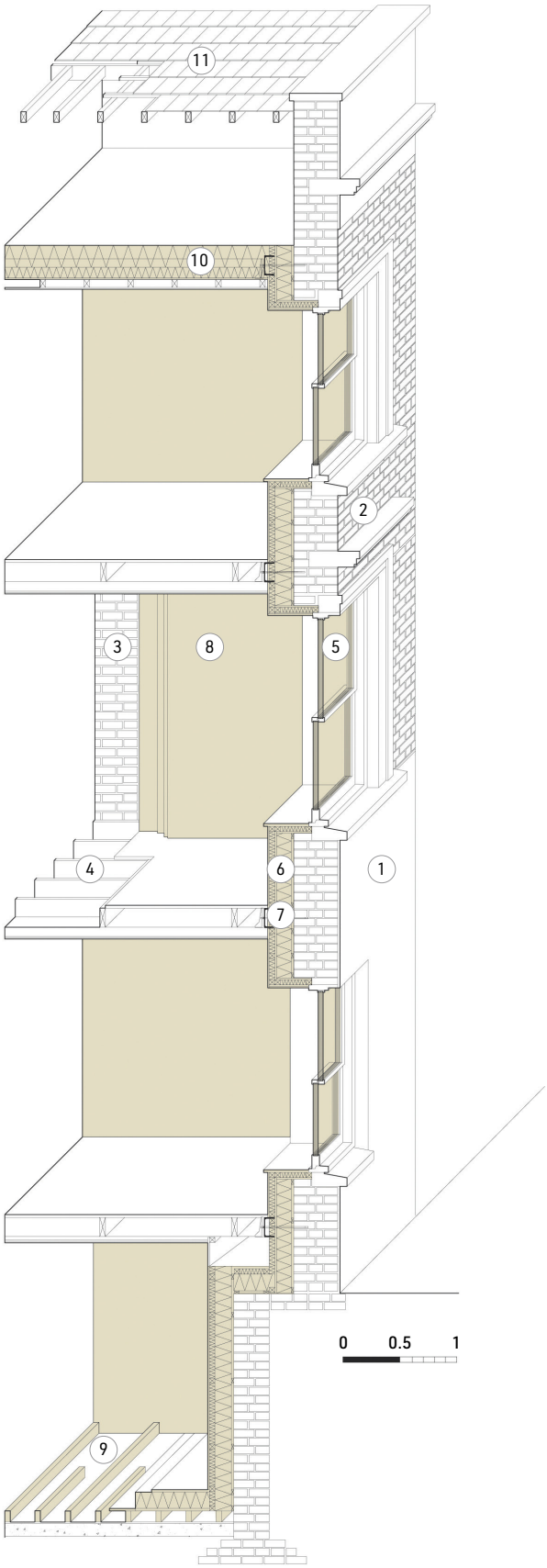
Ventilation strategy and whole-house insulation approach



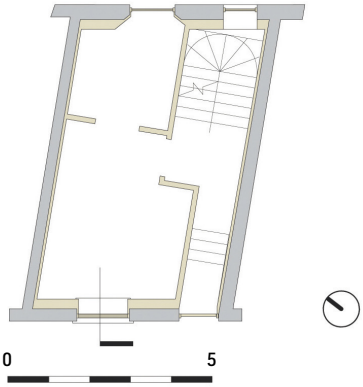
Fabric U-values post-retrofit (W/m^2)



Detailed section



Key ground-floor plan



1 Existing rendered façade

2 Existing exposed brick façade

3 Existing party walls

4 New timber floor structure, OSB and timber joists

5 New triple-glazed sash windows

6 New internal lining to external walls comprising:
25 mm vented cavity
150 mm PU foam insulation boards
12 mm OSB timber boards – airtight layer
50 mm PU foam boards (service zone)
15 mm DuraLine plasterboard

7 203 × 133 UB steel channel resting into party walls with Teplotie restraining the existing facade

8 New internal lining to party walls:
25 mm PU foam insulation boards
12 mm OSB timber boards – airtight layer
25 mm PU foam insulation boards
12 mm plasterboards

9 New underground heat exchanger comprising:
18 mm OSB timber board
150 mm PU foam insulation boards
18 mm OSB timber – airtight layer
67 mm concrete baffle / void (acting as air ducts)
15 mm screed under baffles (1:40 falls towards gutter)
125 mm new concrete slab

10 New roof insulation:
250 mm PU foam insulation
12 mm OSB timber board – airtight layer
50 mm battens – service void
12.5 mm plasterboard

11 Existing butterfly roof retained as existing

FURTHER DATA

COST

The cost of this project included a large amount for R&D for the contractor to create and produce the prototype triple-glazed sash look-alike windows (approximately £20,000), without which this project would not have achieved the PassivHaus certification. This investment has ultimately enabled the contractor to offer the market a specific UK-focused product that was lacking.

Having previously experimented with low energy and PassivHaus projects, the contractor also brought knowledge about the costs of low energy services to the project.

Costs 2010	
Fabric (insulation wall + ground + roof)	£25,230
Windows + doors (£20k R&D costs included)	£24,400
Services (MVHR and ductwork + labyrinth + solar and boiler)	£30,240
Other costs for retrofit	
Subtotal	£69,870
Non-energy-saving measures	£90,813
TOTAL	£180,683

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

MONITORING AND COMFORT LEVELS

An in-depth post-occupancy evaluation report has been carried out by Eight Associates, environmental consultants. The study looked at a full year of occupation, providing an indication that the house offers good indoor air quality with remarkably good CO_2 concentration with an average around 620 ppm; a relative humidity that stayed stable in the recommended bracket of 40–60%[14] and temperatures also stable, varying between 20˚C and 25˚C, even when the outside temperature went down to –4˚C.

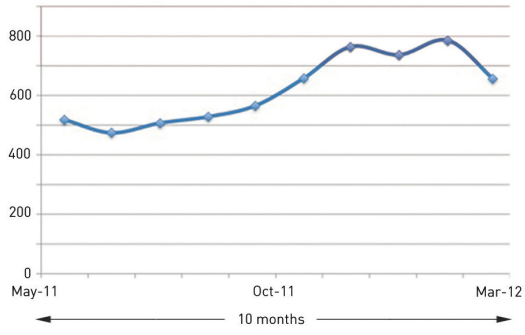
SPECIAL FEATURE

This project was part of a comparative monitoring programme looking at three Victorian terraced houses of similar layout and all located within metres of each other. It included this PassivHaus, a 'Decent Home Plus' house (50 mm internal wall insulation and double glazing) and a typical UK house (no insulation and single glazing). The post-occupancy evaluation report found that the demand in final energy for the PassivHaus was 63 kWh/m²/yr and 366 kWh/m²/yr for the typical UK house.

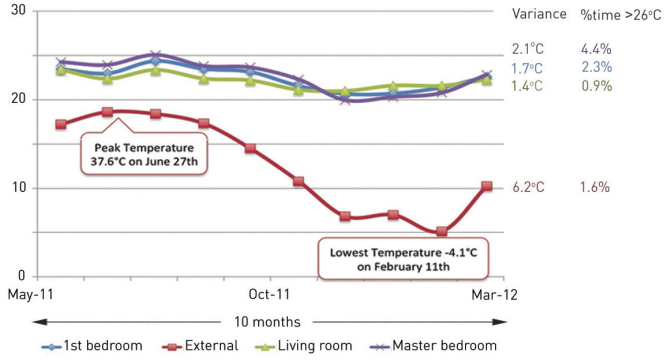
In other words, the PassivHaus consumed 83% less final energy than the 'typical house'.

The graph below shows that the final energy demand for the PassivHaus remains low and very consistent throughout the year while it increases sharply in the heating season for both the Decent Home Plus and the typical UK house.

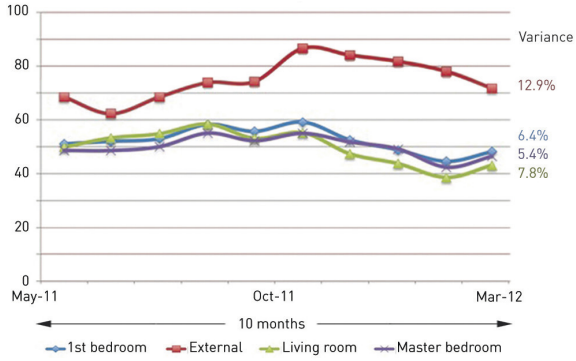
CO_2 concentration (ppm) – living room



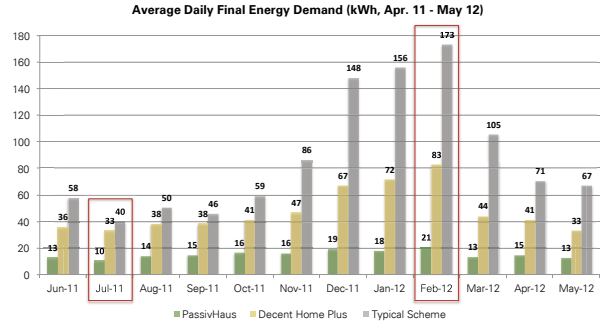
Average temperature (°C)



Relative humidity (%)



Average daily final energy demand (kWh, April 2011–May 2012)



RETROFIT REVISIT:

Princedale Road

SIGNIFICANT CHANGES SINCE THE ORIGINAL RETROFIT

Occupancy: Same tenant, overall occupancy still five (children now adults).
Building: No changes.

ENVELOPE

Overall fabric performance: Integrity of the fabric, windows and door remain in good condition, loft hatches remain well sealed.
Airtightness integrity: Differences in testing may explain a loss in airtightness. A slight movement over time may have affected joins in the rigid PU insulation, OSB layer and internal floor finishes. Airtightness is still exemplar compared to the existing stock and most new builds.
Further investigations: Increased heat loss may have occurred due to water from a blocked roof gutter penetrating the insulated roof/ceiling build-up (though not evidenced). Full access to the roof void is not possible so it is difficult to ascertain whether the OSB layer has been affected.
Rectifications needed: Some OSB boards above the insulation in the roof have been pulled aside due to the water ingress issue and may require attention. Regular building maintenance minimises risks to performance and to the building fabric – highlighted by the blocked roof gutter.
Windows and doors: Bespoke triple-glazed timber 'fake' sash window, operating with a tilt and turn mechanism (0.8 W/m^{2}K) and door (1.2 W/m^{2}K).
Insulation properties: Polyurethane (PUR) foam insulation used as vapour closed system with ventilated cavity. It is unlikely these materials would be specified now due to due to industry approach to all combustible insulation material.

SERVICES

Heating: The house has offered a comfortable environment for 12 years. However, in February 2023, before the BPE and monitoring took place, the Genvex combi MVHR fans failed, and the comfort level dropped. Due to the excellent heat retention of the fabric, the house could be heated in less than one hour with short bursts of a small 2-kW portable heater.
Ventilation: The tenant resorted to opening windows to obtain an acceptable air quality when the Genvex MVHR fans failed. Condensation was visible on the windows and walls; however, it disappeared when the MVHR fan was replaced and purged the house's humidity. This illustrates the benefit of the MVHR in an airtight and well-insulated house. Recommissioning, including control settings would be beneficial following repairs.
Hot water: Solar hot-water collectors, drainback and storage appear to have performed well with minimal maintenance. This was unexpected as this was a relatively unusual system at the time.

ENERGY PERFORMANCE

Poor access to data made the energy performance analysis difficult.
EUI: Best estimate of 62–77 kWh/m^2/yr (based on 2020 supplier estimate and cumulative average from meter). This is an underestimate as it doesn't account for solar thermal contribution. This is an increase on the EUI in 2012 (48.5 kWh/m^2/yr).
Gas: Not applicable.
Electricity: During March, there was an average use 24 kWh/day. The 2020 bill estimates 8,841 kWh/yr. Cumulative metering from 2011 allows a crude average of 7,093 kWh/yr, suggesting an increase from the 5,553 kWh/yr in the first year of occupation.

MVHR hot water, mini air source heat pump



Space heating demand: 10 kWh/m^2/yr estimate (assuming that June–September does not require space heating).
Solar thermal: This is not metered so its contribution is unknown. The original PHPP estimated the solar contribution to useful heat at 1,231 kWh/yr (14 kWh/m^2/yr).
Weather adjustment: Annual energy use per degree day of 10 kWh (using estimated space heating demand for 2020 of 1,199 kWh/yr, and heating degree day of 120).

The below-ground heat exchanger temperature at intake and exhaust into the MVHR is not monitored and therefore its impact is unknown. It may contribute to a lower temperature in the hot summer months, further monitoring would help clarify.

This PassivHaus retrofit has delivered a stable and comfortable environment for tenants over many years.

Future retrofits could consider active cooling and/or external shading (within the constraints of the conservation area).
Description of the BPE approach: Core methods including site visits, an occupancy survey and conversations with occupants, blower door and Pulse airtightness tests, SmartHTC and mould risk testing (including internal temperature and RH monitoring), and review of available energy data.

INDOOR ENVIRONMENTAL PERFORMANCE

Temperature: Average internal temperature during March was 18.4°C. In 2023, during the peak of winter, mid-week average temperatures in non-master bedrooms were 17.4–18°C, compared to 20.8°C in 2012. The MVHR system

Electric comsumer unit and meters; the old meter had not been removed



was operating sub-optimally during this period, with a replacement fan fitted after the monitoring period ended.
Relative humidity: 59.7% average in March. Despite sub-optimal MVHR, humidity levels managed in 'wet rooms' of the basement (peaks of 81% and 86%), returning below 60% within one hour. Average humidity higher on first and second floors (63%).
CO_2 concentration: Failure to record data (caused by operator/user error). The 2012 study reported an average CO_2 concentration of 620 ppm, rarely beyond 1,000 ppm.

COMMENTARY ON PHYSICAL FINDINGS VS USER FEEDBACK

Average temperatures align with occupant preference (17–18°C). Humidity aligns with feedback, with only incidences of condensation and mould when the MVHR failed.

SERVICES STRATEGY

Hot water: The solar thermal system was designed to provide the majority of hot water, with top-up by the Genvex heat pump. See also 'Renewables' section below.
Space heating: No modifications to space heating since the retrofit.
Electricity: No sub-metering and the tenant could not obtain weekly manual reads as the meters are housed in a high cupboard. Energy supplier issues meant it was not possible to get the smart meter data. Contributory factors included a change of supplier in the previous year, an energy debt issue and tenant difficulties accessing an online account. Investigations confirmed that the smart meter was working in smart mode. Despite this, attempts to access the data via SmartHTC were unsuccessful.
Ventilation: No measurements of flow rates or specific fan power available for this study. MVHR failed a few weeks before monitoring.
Renewables: The design team anticipated that the solar thermal system would be first to fail, but this appears to be performing well. The tenant is very satisfied with the availability and temperature of hot water. There is no sub-metering, so it is difficult to ascertain the contribution of solar thermal. The original PHPP estimated the solar contribution to useful heat at 1,231 kWh/yr (14 kWh/m^2/yr).

USER FEEDBACK

Questionnaire findings: Occupants expressed 'high' to 'very high' rates of satisfaction, especially in terms of winter comfort and noise. The SOAP survey (a survey questionnaire for retrofits set up by Dr Zachary Gill) scored 95% (rated 'great'). Constructive feedback related to comfort during hot summer periods and maintenance; the upper floors can feel too hot in heatwaves as there is no external shading.

The large, combined heating/hot water/MVHR unit has user controls that are complex and difficult to understand and operate efficiently. Whilst home user guides and demonstrations were rated highly, there would be value in revisiting this as settings have been tweaked (on MVHR control by residents) and maintenance knowledge and behaviours weakened.

Documentation from 2012 stated that regular filter replacement and cleaning of the heat exchange unit was occurring (by the landlord), but this did not seem to have happened for some time prior to the revisit exercise.

In terms of behaviour, the resident said that they opened windows and the back door during high temperatures (which may be counterproductive when outdoor temperatures are higher than inside). Sustained engagement on metering and energy consumption (initiated by the housing association) may have mitigated some of the current billing issues.

BPE TECHNIQUES: LESSONS LEARNED

Getting data from energy suppliers has been time-consuming. This is a significant risk to the BPE programme, and the availability of energy data should be investigated as early on as possible. In this case, there were several complex factors and a need to refer the resident on to external support services (such as Citizens Advice). Having early access to metering schematics and photographs would also be helpful, particularly where the original monitoring kit has been partially left in place.

The difference in airtightness value from the original retrofit and the revisited BPE may have occurred due to different calculations. Having visibility of the original calculations would enable a comparison of calculation methods. The problem of not being able to open up the fabric means that it is not possible to ascertain the condition of the various layers forming the building envelope.
Airtightness testing (blower door and Pulse): Volume calculations differed between original and current tests, so adjustments were made for comparison. Variations in MVHR unit sealing may have occurred, and testing investigations would have helped. The test method must be clearly defined in the scope, with equipment supplied if needed.
Views on methodology: SmartHTC data input was a learning curve, and felt more geared towards users of SAP/EPCs (e.g. generating a design HTC value).

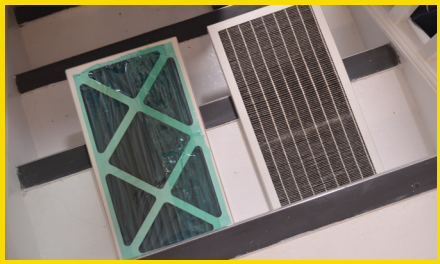
Hardware/software requirements could be smoother (e.g. lack of remote access to check data, need for manual upload, lack of compatibility of some software with common operating systems).

Energy supplier issues demonstrate the need to allow sufficient time for evaluation, how the reality of life impacts on data availability and the 'people' skills needed alongside technical knowledge.

MVHR fan and filters, left-hand fan has been replaced after functioning for 11 years



MVHR filters clogged with dust and particles



Access panel in MVHR unit; to change the filters requires a screwdriver to open



Bertram Street

Pre-1919
TSB-84

Internal floor area: **112 m²**

Primary energy
pre-retrofit calculated: **220 kWh/m²/yr**
post-retrofit measured: **129 kWh/m²/yr**

Client: **Camden Council**

Architect:

Contractor: **United House**

Consultants: **Sustainable Energy Academy; Cotality** (previously called Parity Projects)

This typical late Victorian three-storey terraced house is located in Camden. The occupants, a family of five, were enthusiastic about participating in the programme and remained in the house during the works. The team used the Home Energy Masterplan software (from Parity Projects) to inform the choice of energy-saving measures, which included an innovative patented and trademarked internal insulation system called WHISCERS™; the installation of vacuum glazing into existing windows; decentralised MVHR units to the kitchen and bathroom; limited insulation between floor edges; and photovoltaic and solar thermal panels.

Perhaps the most interesting feature of this project is the special process for retrofitting internal insulation.

Bertram Street was the first full-scale test of the process. Two of its aims were to save housing providers considerable costs in hotel bills and residents the inconvenience and stress of having to temporarily leave their homes.

There are six steps to this process:

1 A laser scanner is used to measure the internal dimensions of a room.
2 The data is forwarded to an off-site factory cutting machine.
3 The machine cuts the insulation boards (XPS insulation) with a high level of precision, thus minimising wastage.
4 The boards are then marked with their position (house number, room number, wall, orientation, etc.).
5 Then the boards are delivered to site.
6 Finally, the boards are fitted to the walls.

The aim of this approach is to reduce site installation of internal wall insulation to as little as two days and therefore enable the occupants to remain in the property, an attractive attribute for a retrofit process. The success of this system relies on the quality and level of detail of the survey, good labelling of the insulation boards and, most importantly, the quality of the installation, which includes taping all the boards to each other and sealing any gaps around the windows at floor and ceiling and to the existing party walls to ensure the maximum airtightness of the house.

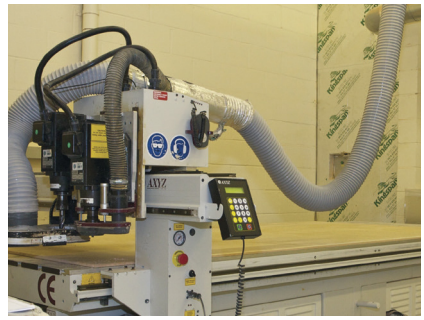
Front facade post-retrofit



Internal wall insulation



Insulation laser cutting machine



STRATEGY

FABRIC

The building fabric was enhanced internally with XPS thermal laminate insulation boards on all external walls and party walls using the WHISCERS™ process. The new layer of internal insulation created a deeper window sill, an arrangement that the tenants were content with. In fact, in the kitchen, where the window sits closer to the external wall, there is now a much appreciated window seat. Mineral wool was installed in the roof and at floor edges on the first and second floors to minimise cold bridging.

The potential issue of interstitial condensation between the existing brick wall and the new layer of insulation (potentially exposing timber joists to mould and decay) is being monitored by Parity Projects with moisture sensors positioned on the joist ends. Monitoring results (from Jan to Nov 2011) seem so far satisfactory to the team. This monitoring will help better understand the risk of installing a non-vapour open insulation material over timber joists, which is not yet well understood.

SERVICES

Hot water is provided by a new condensing gas boiler combined with a well-insulated heat store.

The ventilation strategy was achieved with decentralised heat recovery ventilation units located in the kitchen and bathroom. These ventilation units can be installed when the level of airtightness is below 3 m^3/m^2h @ 50 Pa; they are a good option when extensive ductwork cannot be accommodated. The manufacturer claims that these particular units can achieve 84% heat recovery.

RENEWABLES

The client partly chose this house for its large area of south-facing butterfly roof, which offered enough space (hidden from the street view) to fit 8 m^2 of solar thermal panels and 8 m^2 of photovoltaic panels.

The solar thermal panels were connected to twin coil cylinders for dual heating, satisfying most of the hot water demand in combination with the new condensing gas boiler. The photovoltaic panels aim to generate 1.1 kWp electrical power to the house. After the commissioning of the system, the site manager carried out a demonstration to the occupants and provided an operation and maintenance manual. As the occupants were present throughout the project, the handover went very smoothly.

VITAL STATISTICS

There were no architects involved in the project. Design decisions were developed and carried forward by the core working group with support from product specialists such as insulation manufacturers.

One example of collaborative thinking was the strategy chosen to enhance the window energy performance. At first, the existing single-glazed sash windows, a source of major heat loss (approx. U-value 5.4 W/m^2K), were envisaged to be refurbished, draught-proofed and fitted with Slimlite glazing (approx. 1.5 W/m^2K with a 6 mm cavity), Slimlite being a double-glazed unit that can be fitted into most standard astragals of existing timber sash windows. Further to discussion on planning issues, cost, delivery schedules and thermal properties, the team collaboratively agreed to switch to vacuum glass with enhanced energy efficiency (Spacia™ Pilkington 6 mm overall dimensions vacuum glazing U-value 1.4 W/m^2K).

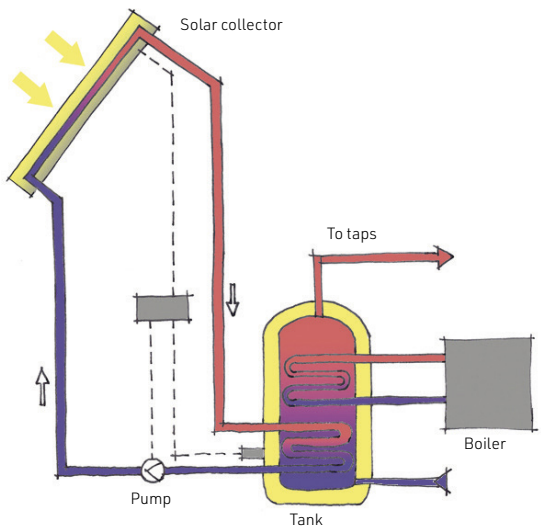
Vital statistics

Characteristics	Before	Target	Measured
Primary energy (kWh/m^2/yr)	220	51	129
Space heating (kWh/m^2/yr)	165	43.4	57.5
Airtightness (m^3/m^2h @ 50 Pa)	9.47	–	–
Type of glazing	single	Slimlite glazing	Spacia™ vacuum glazing
CO_2 emissions (kg CO_2/m^2/yr)	41	13.38	15.26

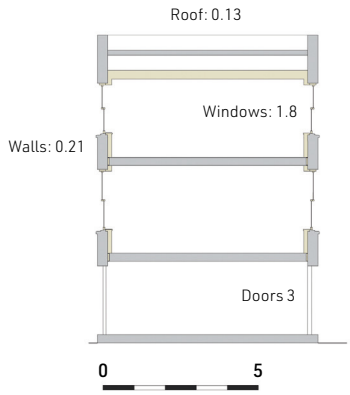
Internal insulation, window junction



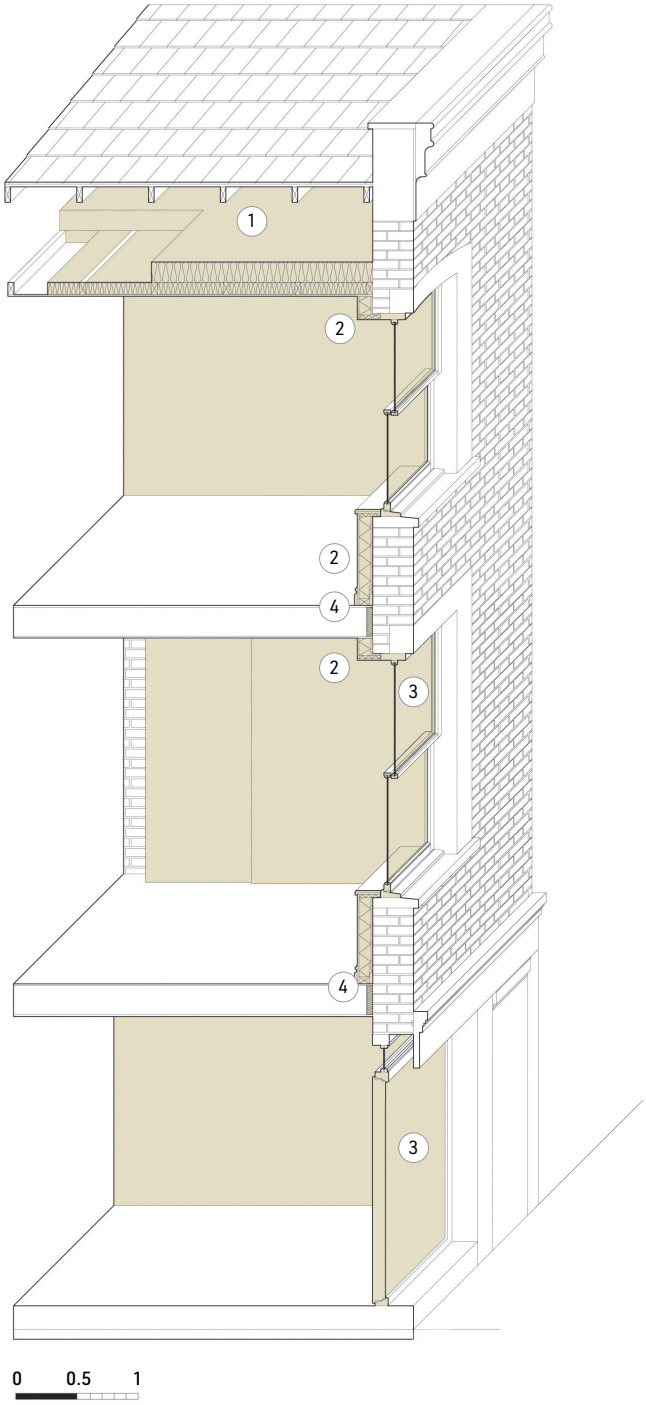
Services schematics



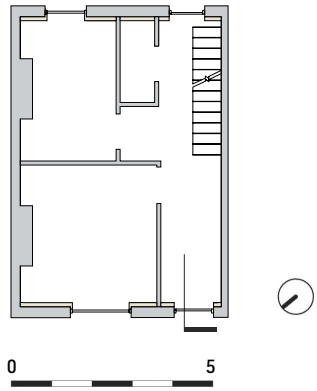
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
100 mm mineral wool between joists
170 mm mineral wool on top of joists

2 WALL
thermal laminated board with plasterboard face dot and dab on existing solid wall (62.5 mm XPS + 9.5 mm thermal laminate)

3 WINDOWS/DOORS
new vacuum-glazed windows
new high-performance door

4 INTERMEDIATE FLOOR
mineral wool insulation fill full height between deck and ceiling below minimum 30 mm thickness

NB The ground-floor was not insulated due to existing solid floor and low floor to ceiling height

FURTHER DATA

COST

The £16,000 for R&D for the WHISCERS™ system has been included in the 'other costs for retrofit' but it will obviously tail off as the process develops.

To monitor the property consistently for two years and collect and analyse the data, an additional cost of £8,676 has been spent on monitoring equipment and labour. As these ancillary costs will vary for each project they have not been included in the table below.

Costs 2010	
Fabric (insulation wall + ground + roof)	£18,600
Windows + doors (included in fabric)	
Services (individual MVHR + solar and boiler + PVs)	£15,800
Other costs for retrofit	£18,625
Subtotal	£53,025
Non-energy-saving measures	£17,500
TOTAL	£70,525

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

MONITORING AND COMFORT LEVELS

Parity Projects is in charge of the two-year monitoring plan to assess the performance of the house and its energy and water consumption. The monitoring programme includes monitoring of several areas of the building fabric (including sensors on the joist ends); the window movement opening and closing with sensors on the frames; the energy consumption, gas and electricity, internal comfort and relative humidity; and the temperature and CO_2 concentration.

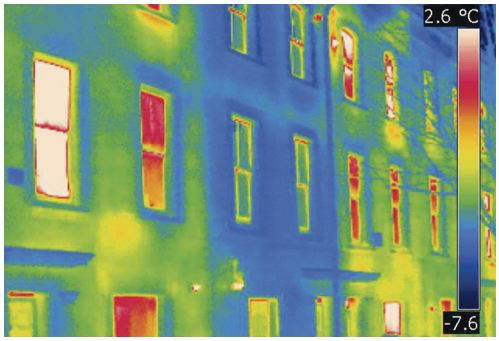
A thermal image of the front elevation of the house taken on a cold day illustrates quite well the difference in surface temperature of the external brickwork; it is much colder than its neighbouring properties because of the new layer of internal insulation, which prevents heat loss through the walls.

SPECIAL FEATURE

All windows were fitted with ultra-thin vacuum units, with the original boxes being retained and window frames fully draught-stripped. This ultra-thin unit is a Pilkington Spacia™ product, 6 mm thick (including glass and cavity). It consists of an outer pane of low-emissivity glass and an inner pane of clear float, with a vacuum rather than air or another gas in between. It has a low centre pane U-value (1.4 W/m^{2}K) but maintains a high solar energy transmission with a value of 0.67 (which compares with 0.87 for a single-glazed unit, 0.64 for double glazing with low e glass and argon gas and 0.50 for triple low e glazing with argon gas).

During the production of the vacuum glass units, a 15 mm diameter protection cap, which looks like a stainless steel button, has to be fitted on each panel. This can be an issue for conservation area officers. In this project, it was deemed acceptable by the local authority on the condition that windows were a 'like for like match in materials, dimension, fenestration patterns and other details'.

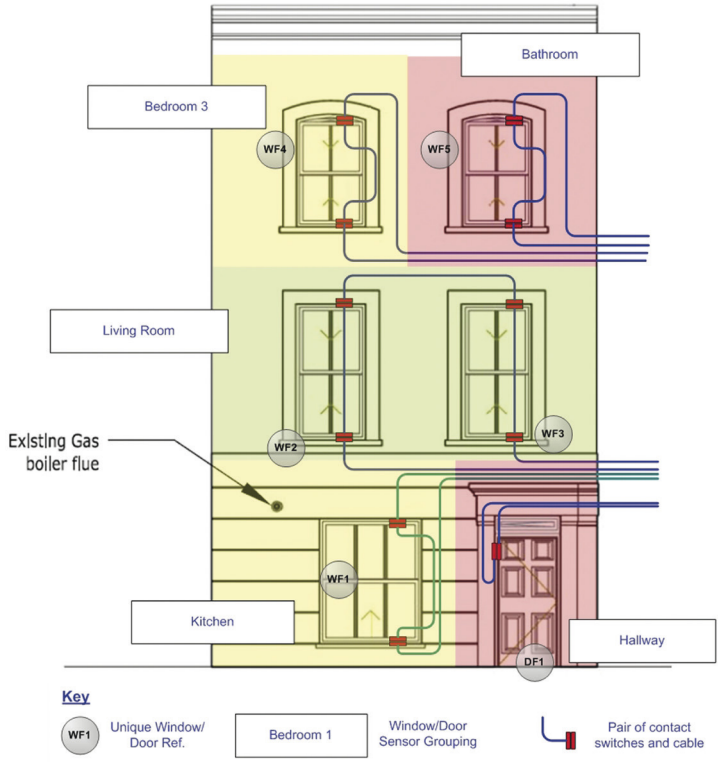
Thermal photograph of the front facade



Glazing detail of vacuum unit with protection cap



Monitoring equipment on front facade



Shaftesbury Park Terrace

Pre-1919
TSB-51

Internal floor area: **61 m²**

Primary energy
pre-retrofit calculated: **535 kWh/m²/yr**
post-retrofit measured: **129 kWh/m²/yr**

Energy use intensity measured 2023: **52.7 kWh/m²/yr**

Client: **Peabody**

Architect: **Feilden Clegg Bradley Studios**

Contractor: **Wates**

Consultants: **Max Fordham (Bill Gething); Rickaby Thompson Associates**

Front facade post-retrofit



The property is a mid-terrace, two-storey, two-bedroom house on the Shaftesbury Park Estate in a conservation area of the London Borough of Wandsworth. The house dates from approximately 1870. It has an L-shaped footprint, and is of solid brick wall construction with a pitched roof. Peabody, the owners of the house, embarked on this project with the aim of finding appropriate retrofit solutions to roll out over their 21,500 other homes in London. The main design challenge set by Peabody was that the retrofit needed to be implemented with the residents *in situ* for the majority of works. The strategy proposed was to improve the building fabric as far as possible in order to reduce the heat demand of the house to a level that could be largely satisfied by solar and internal heat gains. Works included internal insulation in the front wall; a mix of external and internal insulation at the rear; roof and floor insulation; solar thermal panels; and an experimental exhaust air heat pump integrated with a fan-assisted passive stack ventilation system in order to reduce ventilation losses and recover internal heat gains.

The client of this project requested that the residents should remain in situ, so the team looked for imaginative solutions for insulating the suspended timber ground-floor that avoided taking up the existing floorboards.

The option they took forward was to fill the floor void with expanded polystyrene (EPS) beads (more commonly used for retrofitting cavity wall insulation). The material has a good thermal conductivity (or lambda value) of 0.038–0.040 W/mK; it is resistant to water penetration and will not transfer water by capillary action.

The use of EPS beads required that services running under the floorboards had to be re-routed, in particular to avoid trapping the gas pipe in an unvented space, and also the electrical cabling that could overheat if surrounded in insulation. This was a learning process but the team rated the end result as a success.

The performance of the floor insulation is being closely monitored to evaluate its efficacy and to check that any build-up of moisture is picked up before it can cause a detrimental effect to the building fabric. If deemed a success, this relatively cheap approach could provide a generic solution for houses with suspended floors that could be effectively rolled out for future retrofits.

Internal ground-floor insulation detail

Floor void



Damp-proof membrane





Void filled in with beads

STRATEGY

FABRIC

The front facade was insulated internally; external insulation was not considered appropriate, this being ruled out due to the conservation area status. Aerogel (a very high-performance and thin insulant) was used to minimise space loss in rooms that were already quite small. This very efficient material (lambda = 0.013 W/mK) is expensive but its use can be justified at current costs where floor space is at a premium. The rear kitchen extension was externally insulated with 80 mm of polyurethane insulation and a timber rainscreen cladding finish with the remainder of the rear wall internally insulated with aerogel.

Windows were replaced with double-glazed sashes at the front (with trickle vents) and triple-glazed tilt-and-turn casements at the rear.

SERVICES

For the ventilation, the installation of an MVHR unit was assessed in the early stages but was rejected as it would take up significant space (in this small house), threading ducts through the existing structure was deemed problematic, and there were concerns that the level of airtightness achievable would not be sufficient to justify the system to be cost effective. Instead, concealed trickle ventilators within the new windows provide natural ventilation with a fan-assisted passive stack (illustrated below).

The existing condensing boiler of the house was retained and incorporated into a heat store system.

The heat store was heated by (in order) solar thermal, the extract air source heat pump and the boiler (using its central heating circuit).

Space heating is provided by pumping hot water from the store around the existing radiator circuit.

Domestic hot water is provided by heating mains water via a coil in the heat store. If this is hot enough, it goes directly to the taps, if not, it is topped up by the combi boiler using its water heating circuit.

RENEWABLES

Solar thermal panels were installed on the single-storey rear roof, which are anticipated to reduce the CO_2 emissions associated with water heating by approximately 50%.

Some low carbon R&D was also invested in this project in the form of a prototype fan-assisted passive stack ventilation system, incorporating a heat pump to recover heat from air extracted from the kitchen and bathroom. The recovered heat is fed into the thermal store to be used for domestic water heating. Further carbon savings are achieved with energy-efficient fixed lighting. Photovoltaic panels were not installed but quotations have been obtained for the future installation of panels with a peak output of approximately 1.26 kW, which would further reduce the CO_2 emissions for running the house.

VITAL STATISTICS

Being in a conservation area meant that the retrofit of new efficient windows needed to be discussed with the planners. It was agreed that the front existing single-glazed sash windows could be replaced with more efficient double-glazed ones without the need for a planning approval so long as they were of similar design. However the rear new triple-glazed tilt-and-turn casement windows needed planning approval, which was given on the basis of balancing the visual impact of the change against the benefits over alternative solutions.

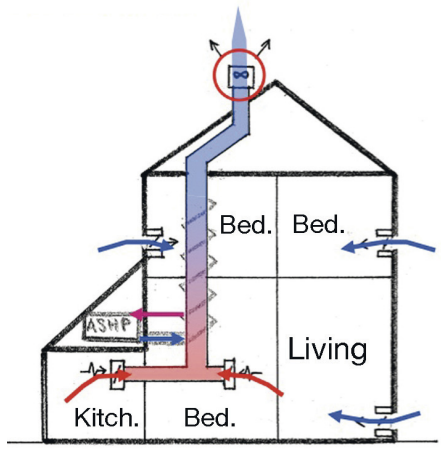
Vital statistics

Characteristics	Before	Target	Measured 2010	Measured 2023
Primary energy (kWh/m²/yr)	535	119	129	–
Energy use intensity (kWh/m2/yr)	441.10	–	83.49	52.7
Space heating (kWh/m²/yr)	–	43	–	–
Airtightness (m³/m²h @ 50 Pa)	–	5	5.92	7.58
Type of glazing	single	double/ triple	double/ triple	double/ triple
CO_2 emissions (kg CO_2/m²/yr)	76	25.4	23	–

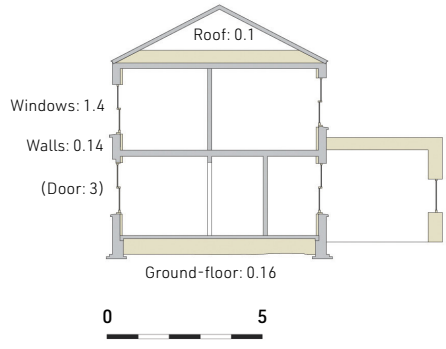
Rear facade post-retrofit



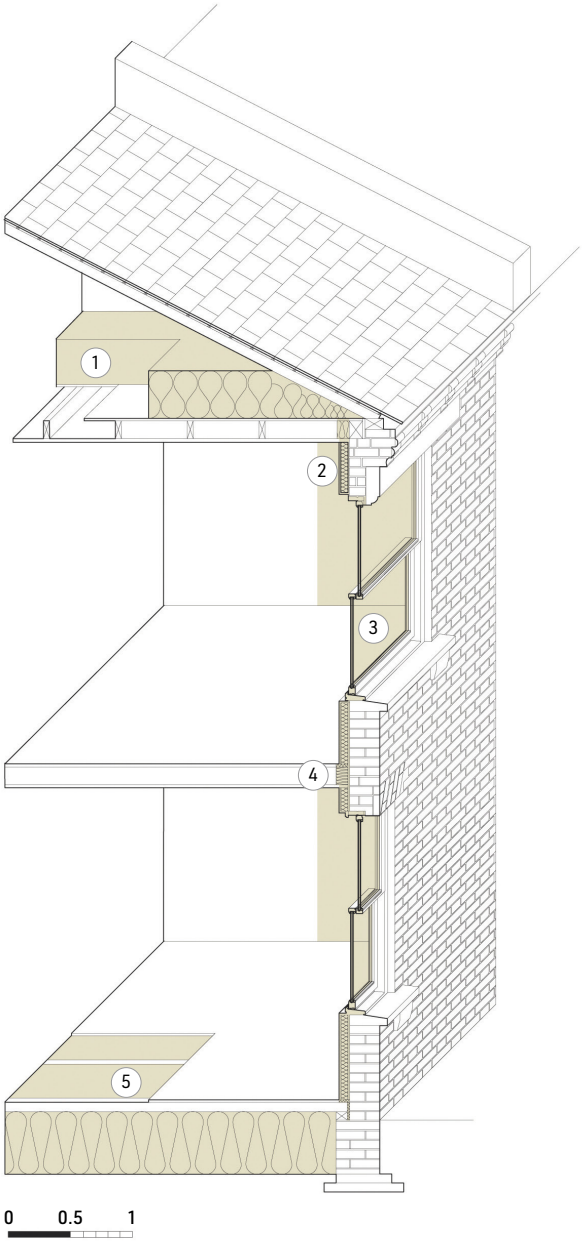
Ventilation strategy with fan-assisted passive stack



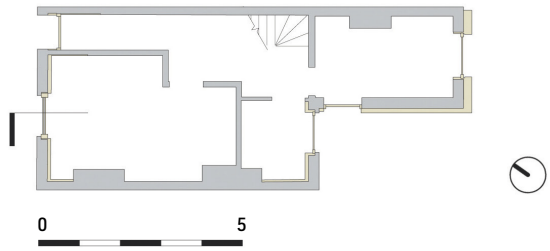
Fabric U-values post-retrofit (W/m²K)



Detailed section



Key ground-floor plan



1 ROOF
400 mm mineral wool in loft space

2 WALL
existing solid wall
plasterboard laminate adhered to external wall
60 mm aerogel insulation
plasterboard

3 WINDOWS
new double-glazed windows

4 INTERMEDIATE FLOOR
25 mm foam glass strip under lining
parge coat of lime plaster onto existing brickwork
one layer of 100 mm wood fibre insulation

5 GROUND
12 mm ply overlayer
existing floor board
vapour barrier
existing joists
entire void injected with platinum polystyrene cavity wall insulation

FURTHER DATA

COST

The cost consultant took on a gathering role for various pieces of information (e.g. supplier, sourcing, methodology) that was then handed over to the contractor, who scheduled the costs. Value engineering exercises (or 'efficiency driving') were employed to bring the initial cost down to the contract cost. Variations of around 10% from contract cost occurred in the final total amount included in the table below.

Costs 2010	
Fabric (insulation wall + ground + roof)	£23,620
Windows + doors	
Services (solar and boiler)	£51,056
Other costs for retrofit (consequential)	£4,200
Subtotal	£78,876
Non-energy-saving measures	£1,915
TOTAL	£80,791

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

MONITORING AND COMFORT LEVELS

Rickaby Thompson Associates analysed the metered energy data and the monitored internal conditions and initially provided a quarterly performance report for the project team.

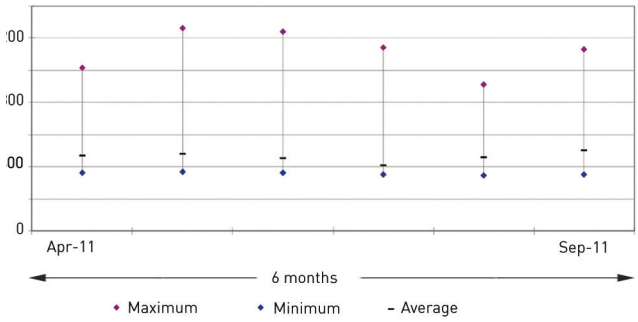
According to the six months of monitored data analysed so far, the house seems to be performing well. It is worth noting that collecting such data is not always a straightforward exercise. It is common for some of the equipment to be partly failing resulting in limited amounts of usable data. Consistent attention to the equipment's performance is essential.

The monitoring data of the concentration of CO_2 in the lounge (used as a proxy indicator of indoor air quality and ventilation quality in the property) is on average between 400 and 450 ppm, only just above ambient levels, with a maximum peak at 1200 ppm; this suggests that the indoor air quality is good.

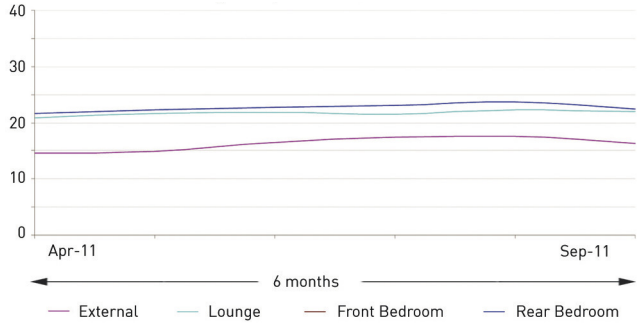
SPECIAL FEATURE

The house is part of a larger development built in the 1870s with the intention of providing decent accommodation for the working classes at a time when overcrowding and squalid living conditions were common. The project has aimed to develop solutions that will satisfy the original intention in line with the original ethos of providing economical and comfortable housing and allow its life to be extended for another 100 years, and this also applies to many other homes on this large estate.

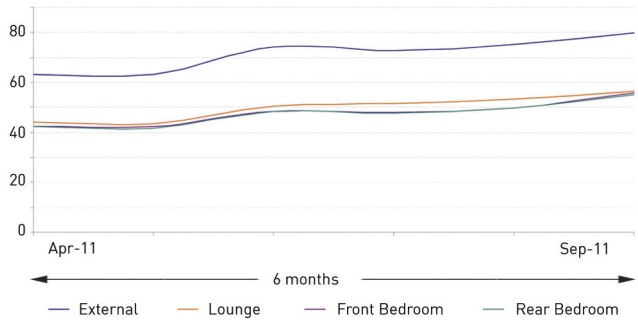
Average CO_2 concentration (ppm) – living room



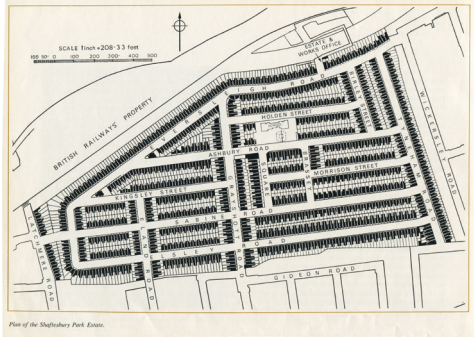
Average temperature (°C)



Average relative humidity (%)



1870s Shaftesbury Park Estate



RETROFIT REVISIT:

Shaftesbury Park Terrace

SIGNIFICANT CHANGES SINCE THE ORIGINAL RETROFIT

Occupancy: No changes.
Building: No changes. The rear bedroom is now used as a treatment room, rather than a bedroom.

ENVELOPE

Overall fabric performance: The airtightness is worse than measured following the original retrofit, and likely relates to the wear of elements, such as the windows.

Measured U-values for the walls had increased from 0.14 W/m^{2}K to 0.20 W/m^{2}K using heat flux plates, but were at 0.10 W/m^{2}K for the Heat3D measurement. The Heat3D also showed good uniformity, suggesting that either the initial calculation was wrong, or the aerogel performance is less than expected. Floor U-values were measured at 0.14 W/m^{2}K with a 0.04 uncertainty, which indicates that this is likely performing as well, or better, than expected, suggesting the method is durable.

Airtightness integrity: The airtightness had decreased since the original retrofit, from 5.92 m^3/m^{2}h @ 50 Pa to 7.58 m^3/m^{2}h @ 50 Pa using the blower door method. Pressurisation showed more leakage than depressurisation (9.5%), suggesting that outward openings were more of an issue.

The seals to the first-floor sash windows, between the panes, were either missing or significantly worn. The bathroom window would not shut fully, with a 'wobble' between the window and the frame. Both will have led to an increase in the air permeability.

The loft hatch rests on the seals with no way to pull it tightly shut. It is not possible to ascertain the extent of leakage from the hatch as no smoke testing was undertaken.

Further investigations: A further smoke test to determine the cause of air leakage is encouraged, enabling targeted fabric improvements.

Rectifications needed: The windows should be serviced with seals replaced and hinges adjusted throughout. Regular building maintenance minimises risks to performance.

Key lessons learned: The building fabric has aged well, with little damage or modification, and no signs of mould or damp. The study (carried out by UCL) reported that RH and particle counts were within acceptable limits. Fungal risk is deemed to be minor as Class A.

Airtightness has been significantly affected, but is still much better than the initial building.

High growth thermal performance assessment: There is a high possibility that timber degradation is occurring in the front and the rear elevations. However, the risk of freeze-thaw deterioration, potentially leading to brick spalling or face loss on those front and rear elevations, is low.

SERVICES

- **Heating:** The retrofit contained a comparatively experimental heating system, using solar thermal and a bespoke exhaust air heat pump (EAHP), which reclaimed the heat from the passive stack ventilation system to preheat the hot water in a cylinder. This is topped up by a gas boiler to more typical flow temperatures for heating (80/60). This provided two key issues for the residents:
- The boiler was an unusual unit from Germany, with little access to information and spares.
- The system was far too complex for simple maintenance by Peabody's maintenance team, creating frequent delays and increased difficulty in ongoing maintenance.

The resident noted that it was typical for the heating system to fail upon the first use in winter, leading to a nervousness about using the central heating.

During the revisit, the main gas boiler was not being used for heating.

Hot water: The hot-water system is fed from a central tank, but has had significant issues over the past 10 years. This has led to a reliance on the immersion heater to provide domestic hot water, despite the solar thermal system and EAHP. The resident was dissatisfied with the DHW control, largely due to the occasional outages.

Ventilation: The ventilation system has been running since the original installation with little additional maintenance. Local trickle vents are often closed to reduce drafts and heat loss, but there was no sign of condensation or mould growth within the property, suggesting that air quality remained good.

ENERGY PERFORMANCE (2022 VALUES)

- EUI: 52.7 kWh/m^2/yr
- Gas: 1,360 kWh/yr
- 1,857 kWh/yr

INDOOR ENVIRONMENTAL PERFORMANCE

Temperature (March 2023): No measured data.
Relative humidity (March 2023): No measured data.
CO_2 concentration: No measured data.

COMMENTARY ON PHYSICAL FINDINGS VS USER FEEDBACK

Due a logger misconfiguration no internal temperature or RH data was collected. Spot measurements of indoor temperatures around 18°C were recorded in the main living spaces, and 22°C in the second bedroom. The higher temperatures in the second bedroom were caused by a heater being used the previous day, passive solar gains during the visit day and the door being kept closed. This suggests that the improved fabric is reducing heat loss and contributing to the stability of conditions reported by the residents.

No condensation issues were reported in the home, but, over the winter, limited amounts were recorded for the first time on the north-facing bedroom windows.

SERVICES STRATEGY

Electricity: The house was rewired as part of the retrofit, with submetering installed for each circuit. Metering was extended to heat meters for the solar thermal, exhaust air heat pump, heating and hot-water circuits. This was all connected to a wireless monitoring station in the cloud, that unfortunately could not be accessed at the time of the revisit.

Renewables: The inclusion of the EAHP and the solar thermal as a preheat has not been possible to monitor. There have been reports of over-pressurisation within the hot-water tank, likely caused by the solar thermal providing too much heat with a sticky bypass valve. The complexity of the system has made maintenance and rectification of these types of issues more difficult than would have been hoped.

USER FEEDBACK

Questionnaire findings: Overall, the residents were satisfied, with positive feelings of comfort (both in summer and winter), low energy use and building appearance, balanced by concerns over the heating and hot-water systems, quantity of storage and the retrofit process itself.

The heating system has been a source of concern due to the difficulty in maintenance, with little trust in the system.

Due to space limitations, providing additional storage during the retrofit process would have been unlikely.

The use of IWI has reduced the available floor area. Despite the cost uplift of using aerogel, and additional embodied carbon, it will have minimised the impact on floor space due to its outstanding performance compared to other conventional insulation materials.

Good internal conditions were noted with the ability to rely on a portable electric heater over the winter months. Local thermostatic radiator valves (TRVs) were installed, but the resident has little trust in the overall heating system. The home felt environmentally stable, with no drafts or cold spots, and warmth being retained during the winter. Overheating was reported in the south-facing bedroom during the summer months, driven by the large window that replaced the original sash window. No condensation issues were noted, indicating the ventilation was working well.

From discussions with the residents, they were surprised how little follow-up had been undertaken on the home. In the period since the handover, the residents had little understanding of the works and the complex heating system. During the revisit, a simple pack of drawings, the original Retrofit for the Future case study report and a tour of the improvements was provided.

BPE TECHNIQUES: LESSONS LEARNED

Views on methodology: Moisture testing of the floor joists was quite invasive, but the home has coir matting and screwed floorboards allowing relatively simple access.

The U-value measurements were simple, but the Heat3D was much more appropriate for homes at scale, despite the reduction in accuracy compared to the heat flux plate measurements (±0.1 compared to ±0.04). However, Heat3D was able to visually show the variation in U-value across the wall, which provided an important context of the spaces between the heat flux plates.

For the ground-floor, the heat flux plates showed a large variance in the U-value, but the Heat3D equipment was not able to provide that additional context to support the reasons for the variance (a range of 0.11 to 0.17 W/m^{2}K likely caused by the floor joists within the insulation).

Generally, the tight timeframes for the study produced an incredibly focused research piece, and the close deadlines kept the pressure on the team to deliver the study. A year-long study would be more appropriate to draw out detailed conclusions, but the pressure helped to realise the outputs more readily.

Midmoor Road

Pre-1919
TSB-58

Internal floor area: **106 m²**

Primary energy
pre-retrofit calculated: **470 kWh/m²/yr**
post-retrofit measured:

Client: **Family Mosaic**

Architect: **Prewett Bizley Architects**

Contractor: **Manby Contracting**

Consultants: **The Green Building Store (Andrew Farr MVHR); Brian Cheery (gutter); ALDAS (Peul Jennings airtightness); Nick Grant (DHCW pipe sizing)**

This project was designed by the same team who carried out the Culford Road project. As well as developing some of the approaches trialled previously, the team were also keen to work in a less invasive manner. Demolition was avoided as much as possible and replaced with a stripping back approach, where all the plaster of this Edwardian three-bedroom house was removed to exposed brick and timber skeleton. This provided the opportunity to repair the primary structure as required and then construct an airtight insulated new layer from scratch. The whole house retrofit approach included both internal and external wall insulation, insulation to the floor and roof, new windows with double- and triple-glazed units, a new boiler and an MVHR unit.

The front facade was internally insulated: a decision driven by planning requirements and the wish for the existing attractive streetscape to remain consistent. At the rear, however, the house elevations were more workaday and there was less consistency along the terrace.

Taking this into consideration, as well as the tight internal planning of the rear of the house, an external insulation system was selected for the rear. This decision was not taken lightly though as it required the coordination of a number of other issues.

First, existing waste pipework needed to be moved. Dealing with the existing SVP was fairly straightforward but a more expensive knock-on effect was where the 280 mm external wall insulation encroached on the inspection chamber in the yard space, the result being that inspection chamber and underground drainage had to be moved.

Resolving the eaves/verge detail at the top of the wall demanded a little more ingenuity. One obvious option was to extend the eaves of the roof and to reposition the gutter in front of the new insulation layer. This can be done but it is an expensive process. Considering that the roof had been re-slated only a few years before, the architects opted for a more innovative approach. They designed a special gutter (see below right), that acted like a a giant stop bead for the insulation below. This has been developed since and used on a number of other projects. It is hoped that it will be commercially available as a standard component soon.

Front facade post-retrofit



Rear facade post-retrofit



Prototype gutter to fit over external insulation



STRATEGY

FABRIC

The front wall is internally insulated with phenolic insulation and aerogel in the window reveals and the rear walls externally insulated. The architect paid particular attention to eliminating cold bridging wherever possible, through careful detailing. Where this was impractical, extra insulation 'socks' were extended over the fabric or into the ground to reduce the effect of the bridge as much as possible. Most of the interfaces were modelled with THERM software to help gauge the approach. The airtightness layer comprises a combination of OSB boards on the internal insulated surfaces and plaster on the external insulated walls, with the existing plaster made good.

SERVICES

The team spent a lot of time on site ensuring a high level of airtightness was achieved to minimise leakage and ensure the effectiveness of the MVHR system. The MVHR system was designed and commissioned by Andrew Farr of the Green Building Store (one of very few suppliers offering design and support services) in combination with the architect. The architect (who acted as lead contractor on this project) installed the duct connections to the heat exchanger personally so as to develop his experience for future design work. The ventilation system runs 24/7 and can be boosted by either of two buttons located in the kitchen and bathroom, respectively.

The domestic hot water system was designed with AECB water standards in mind. As well as incorporating flow restrictors, careful thought was given to making the arrangement as compact as possible. The resulting short pipe runs were all well insulated. Furthermore, as the house was found to have an incoming supply of 3 bar pressure, small bore pipework was used to further reduce 'dead leg' wastage of lukewarm water when taps are opened.

As well as heated air supply (by means of a hot water battery) there are only four small radiators in the house – in the bathroom, kitchen and the two front rooms, which only have double glazing. The heating system is controlled by a central thermostat that allows the tenants to choose the temperature of the house. Each room can be additionally controlled by TRVs on each radiator.

RENEWABLES

No renewables were included within this project.

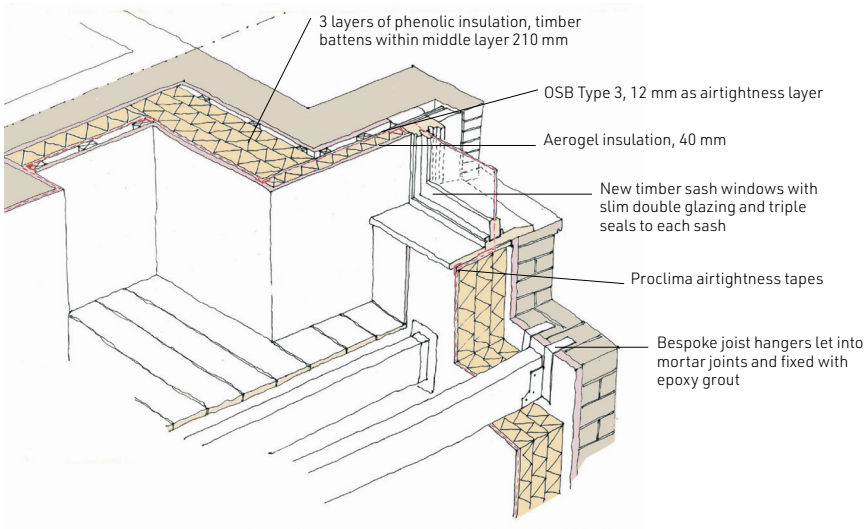
VITAL STATISTICS

The final airtightness test achieved 1.2 m^3/m^2h, similar to the result the team had previously achieved at Culford Road. This followed a previous test of 0.8 before all the windows were installed and provides a salutory lesson about maintaining high standards through a project.

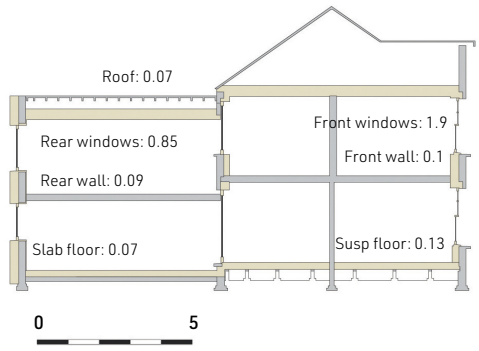
Vital statistics

Characteristics	Before	Target	Measured
Primary energy ($kWh/m^2/yr$)	470	155	–
Space heating ($kWh/m^2/yr$)	–	25	–
Airtightness (m^3/m^2h @ 50 Pa)	–	1	1.2
Type of glazing	single	double/ triple	double/ triple
CO_2 emissions (kg $CO_2/m^2/yr$)	77	32.5	–

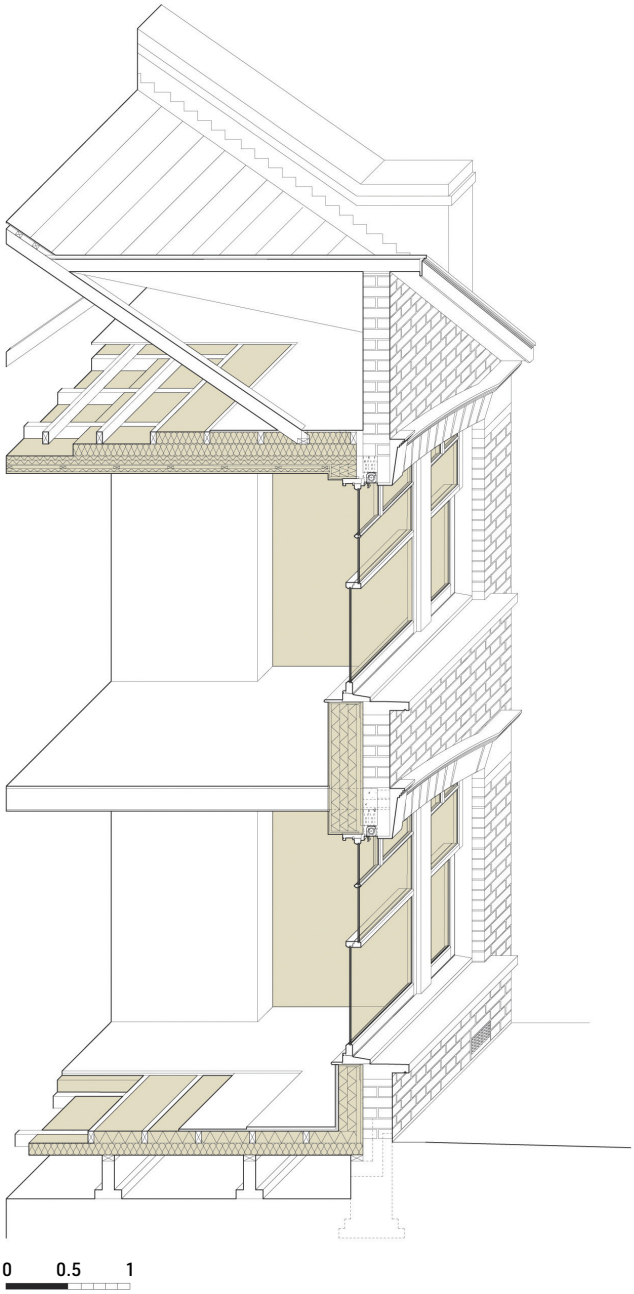
Internal insulation to front facade



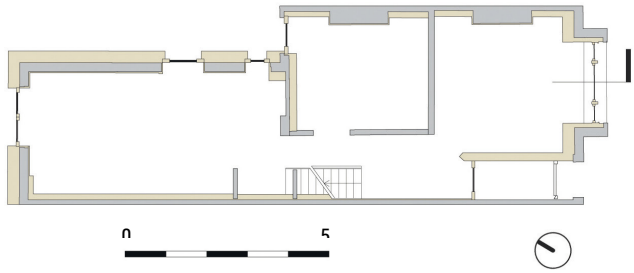
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
new 200 mm mineral wool above existing joists
new rigid insulation (2 × 35 mm) below existing joists
airtight layer 12 mm OSB, taped at all junctions
25 mm batten zone
plasterboard and skim finish

2 WALL EXT
existing solid wall
30 mm galvanised battens/ventilation gap
210 mm (3 layers) rigid insulation including battens
12 mm OSB board
15 mm plasterboard and skim finish

3 WINDOWS/DOORS
high-performance double-glazed windows with quadruple draught strip
new airtight triple-glazed timber door with fixed glazing above

4 GROUND
floor finish
3 mm hardboard (to protect the airtightness layer)
18 mm T&G chipboard
100 mm rigid insulation between battens
100 mm mineral wool insulation between existing joists laid over breather membrane

FURTHER DATA

COST

This project retained most of the existing building's fabric, so as to focus as much of the funds as possible on energy efficiency. Leaving in existing joists and so on did present challenges in respect of airtightness. The deep strip of the fabric also revealed various rotten timber elements that required careful making good. Of the £127,000 spent only £63,000 was associated directly with actual installed energy efficiency measures. The remaining funds were spent on professional fees, statutory fees, making good damage uncovered during the works and research and development.

Costs 2010	
Fabric (insulation wall + ground + roof)	£36,000
Windows + doors	£16,800
Services (MVHR and ductwork + solar and boiler)	£10,400
Other costs for retrofit	
Subtotal	£63,200
Non-energy-saving measures	£64,200
TOTAL	£127,400

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

MONITORING AND COMFORT LEVELS

Tenant feedback on comfort levels has been positive. The mother of the house, who had previously suffered with asthma in her previous dwelling, reported in the first year that all her symptoms had abated.

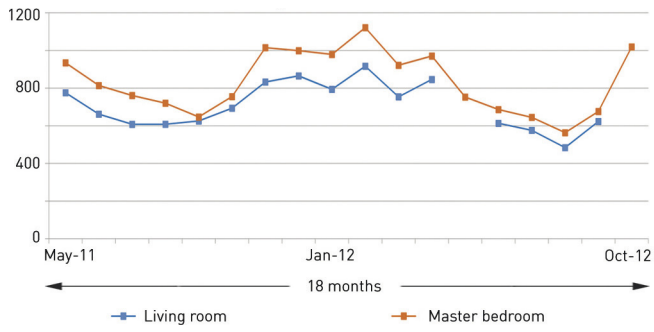
Indoor air quality monitoring data shows both very stable relative humidity and relatively low CO_2 concentrations within the house. The data presented a mild relief to the designers as the system was designed and commissioned for an occupancy closer to three than the actual occupancy of five to six during the first year. Indoor temperature monitoring also indicates that the occupants enjoy consistent indoor air temperature in the low 20s Celsius during the colder months and averaging up to 25°C during the warmer months. Some modest periods of overheating do seem to have occurred. The design team believe this is in part due to large front windows facing south. While solar shading had been designed in, this would have had to be funded by the client, who decided against it.

PROJECT PARTICULARS

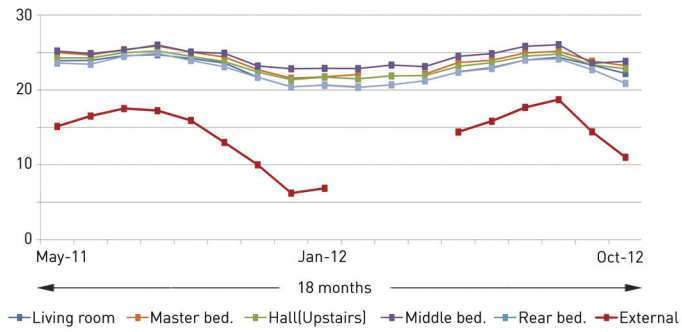
As well as the design and development of the gutter system described already, a special joist hanger was prototyped and trialled. This was designed to make it easier to cut out joists from external walls and re-hang them in the wall in such a way as to reduce the risk of their decaying following the installation of internal wall insulation. Conventional hangers are almost impossible to fit onto in situ joists. The new type was modified so that it could be offered onto the joist from below and slid into position.

The new sash windows were also designed by the architect. They replicate the originals that were replaced around 10 years prior by a very poorly designed UPVC system (daylight was visible between the fixed and sliding elements). While the new sashes provide only a modest U-value of around 2 W/m²K, (based on double-glazed units that have a centre pane U-value of 1.5 W/m²K), crucially, they have been carefully detailed to be virtually airtight when locked shut.

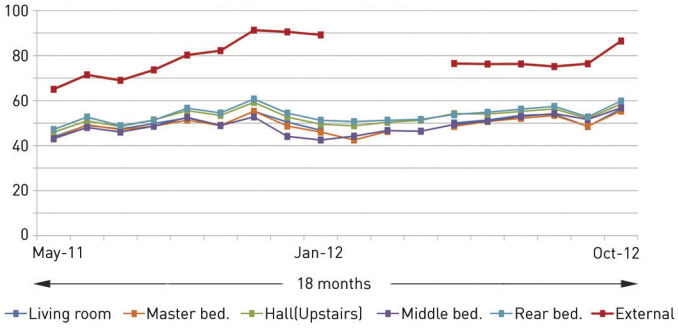
Average CO_2 concentration (ppm)



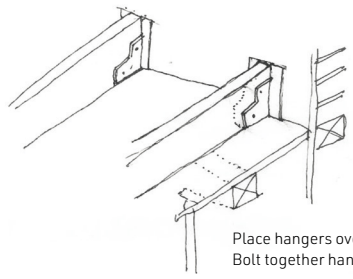
Average temperature (°C)



Average relative humidity (%)



Re-hanging of joist ends



Place hangers over joists.
Bolt together hanger and joists

Hawthorn Road

Pre-1919
TSB-59

Internal floor area: **109 m²**

Primary energy
pre-retrofit calculated: **807 kWh/m²/yr**
post-retrofit measured in 2023: **244 kWh/m²/yr**

Energy Use Intensity
post-retrofit measured in 2024: **106 kWh/m²/yr**

Client: **Metropolitan**

Architect: **Anne Thorne Architects LLP**

Contractor: **Sandwood Design and Build Ltd**

Consultants: **Eight Associates (now Eight Versa), King Shaw Associates, UCL Consultants Ltd (Ben Croxford)**

This mid-terraced Edwardian house is owned by a client already experienced in retrofits. Via a Neighbourhood Investment Unit (NIU) structure, they have already refurbished nearly 300 of these hard-to-treat homes in the same borough. This project provided the opportunity to test retrofitting strategies and target 80% CO_2 emission cut. The team aim was to avoid an over-complicated technological solution that relied heavily on the end user understanding complex and confusing systems and controls, it was also to approach the whole house insulation strategy with a strong focus on natural materials. The property had been divided into two one-bedroom flats but as a result of the retrofit, it was de-converted into one three-bedroom dwelling as part of the client's programme of providing large family units in North London.

The project was extensively modelled by the architects using the PassivHaus Planning Package 2007 (PHPP) software. It enabled them to fine-tune the specification of products and materials to ensure the energy required to keep the home at an internal temperature of 21°C remained very low.

The modelling of the house revealed that the property's limitations (which stem from the thermal fabric, orientation and form of the existing building) meant that the aim to achieve full EnerPHit criteria for space heating at 25 kWh/m²/yr was beyond the scope of this retrofit. The main difficulty was meeting the airtightness criteria (1 m³/m²h @ 50 Pa), which would have required removing and replacing the staircase – neither practical nor economical. Additionally, after installing the Rotex and MVHR units, the airtightness test on the services room sealed shut came in at 1.2 m³/m²h @ 50 Pa, so the teams knew then that 1 m³/m²h @ 50 Pa would not be achieved in this house.

However, the proposal still achieves a considerable improvement on space-heating demand (87% reduction) with 52 kWh/m²/yr.

The design team's desire to use breathing/natural materials was determined from the outset of the project for the following reasons: these materials sequester carbon, they have low embodied energy, and they are better able to deal with moisture within the construction fabric and internal atmosphere of houses thanks to their open cell and hygroscopic characteristics.

Front facade post-retrofit



Rear facade post-retrofit



Installation of airtight layer



STRATEGY

FABRIC

The insulation strategy is external at the rear of the house and internal at the front of the house, driven largely by external appearance requirements.

The front walls were retrofitted with two layers of sheep's wool insulation, within a timber-frame structure. To mitigate any thermal bridging of the timber battens as they cross, the insulated framing was lined with a wood fibre insulation board. This layer of insulation brought the U-value to target and protected the airtight membrane within the build-up from being unintentionally punctured. The internal walls were finished with a layer of lime plaster applied on the wood fibre insulation boards.

The rear facade was insulated with a thick layer of EPS external wall insulation. On completion of the project, the team came to the view that external insulation was a particularly successful measure. It was fairly easy to install and didn't compromise the internal floor space. This is one measure that the client felt they could afford to incorporate into appropriate standard works for their other houses.

SERVICES

The ventilation strategy included an MVHR unit with ductwork supplying fresh air to the living room and bedrooms and extracting stale moist air from the kitchen and bathroom. Fitting the unit and the ducts in the house required careful planning and detailing. The team chose to use a full-size cardboard mock-up of the MVHR unit to better assess its space requirements and assist coordination with other equipment: overall, a helpful trick to ensure a smooth installation process.

Domestic hot water is produced by a combination unit (described below). Small radiators were also installed to top up the space heating on the coldest days.

RENEWABLES

The Rotex 'GasSolarUnit' combination unit providing domestic hot water is the size of a large fridge-freezer. Being an integrated unit, the equipment could be managed with a single control panel. Providing simple controls for the tenants was paramount in this project to ensure that they would not need extensive training to use their house to its full potential.

VITAL STATISTICS

The designed performance of the house has been pushed to its maximum potential considering budget and priorities. The completed house achieves high U-values as per section below. The airtightness strategy included several materials: an Intello membrane for the internal wall insulation and roof; a DPM installed on top of the new concrete floor wrapped upwards to the Intello membrane; a layer of internal plaster on the walls for the rear part of the house where external insulation has been installed.

These measures resulted in considerable improvement from an airtightness of 17 m^3/m^2h @ 50 Pa down to 2.54 m^3/m^2h @ 50 Pa after a first test and 2.4 m^3/m^2h @ 50 Pa after adjustments and second test. This was a good result considering the complex 'L' shape of the house and multiple materials used to form the air barrier.

High levels of airtightness enable maximum benefit from heat recovery provided by the ventilation system; prevent draughts occurring in the house and heat loss through gaps in the fabric: all contributing to ultimate comfort.

Vital statistics

Characteristics	Before	Target	Measured 2010	Measured 2023
Primary energy ($kWh/m^2/yr$)	807	88	244	–
Energy use intensity (kWh/m2/yr)	617	–	52	106
Space heating ($kWh/m^2/yr$)	617	30	52	7.45
Airtightness (m^3/m^2h @ 50 Pa)	17	1	2.53	3.64
Type of glazing	single	triple	triple	triple
CO_2 emissions ($kg\ CO_2/m^2/yr$)	138	17	39	–

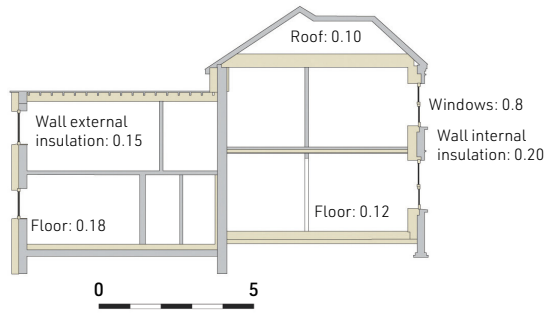
External insulation on rear facade



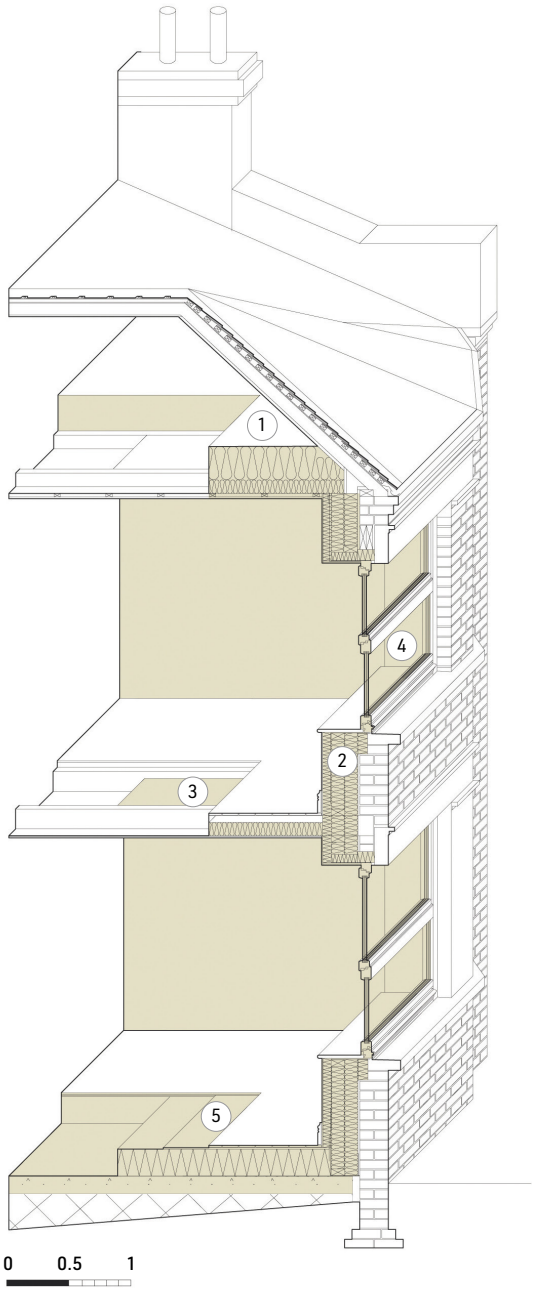
Ventilation unit (MVHR) with insulation over primary ducts



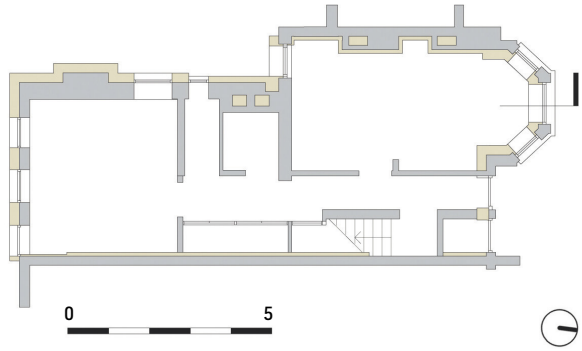
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
existing roof slates on softwood battens and cross battens with breather membrane/roofing felt
OSB boards fixed to u/s of rafters to contain insulation and maintain roof ventilation
250 mm cellulose insulation above joists
airtight membrane/vapour control layer fixed to u/s of existing joists above ceiling board finish
25 mm timber battens to allow service that prevents the airtight membrane being punctured

2 WALL
100 mm × two layers sheep's wool insulation fitted between two layers of 50 × 100 mm timber battens
airtight membrane to wall protected behind wood fibre insulation
60 mm wood fibre insulation to minimise thermal bridging of timber battens
lime plaster finish

3 INTERMEDIATE FLOOR
100 mm sheep's wool between existing joists for sound insulation

4 WINDOWS/DOORS
timber-framed triple-glazed window

5 GROUND
OSB floor
200 mm EPS floor insulation
new concrete floor slab replaces existing suspended timber floor

FURTHER DATA

COST

The high figure identified in 'other costs for retrofit' includes costs for additional labour that were not anticipated. The high cost of the 'non-energy-saving measures' includes a large sum that reflects the cost of renovation following a serious fire and for converting the two flats back into one house.

Annual utility costs (gas and electricity combined) are £855, as compared with an estimated £2,283/yr pre-retrofit: a significant saving (63%).

Costs 2010	
Fabric (insulation wall + ground + roof)	£31,300
Windows + doors	£10,600
Services (MVHR and ductwork + solar and boiler)	£26,000
Other costs for retrofit	£22,190
Subtotal	£90,090
Non-energy-saving measures	£99,000
TOTAL	£189,090

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

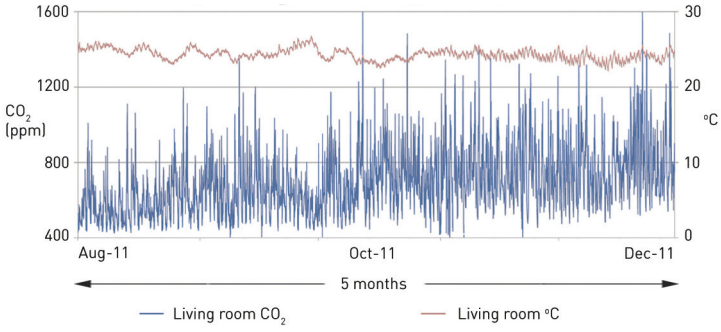
MONITORING AND COMFORT LEVELS

The monitoring strategy for this house was established by Dr Ben Croxford of UCL Bartlett School of Graduate Studies. His analysis of the results shows that the house overall achieves a drastically lower energy demand than pre-retrofit. The temperature is very stable, day and night, winter and summer. More hot water is used than expected and at a higher temperature (the occupant didn't like the temperature restrictor and had it removed; apparently this is a common request made to plumbers). The MVHR system is working well. CO_2 levels are generally below 1,000 ppm and humidity levels are kept between 40% and 60% RH. Electricity consumption is higher than expected; this is due to more appliances and gadgets being used by the householders than anticipated. Halving this standby usage of electricity (approximately 250 W) by switching more appliances off overnight could lower the annual electricity consumption by around 20% (approximately £110 per year).

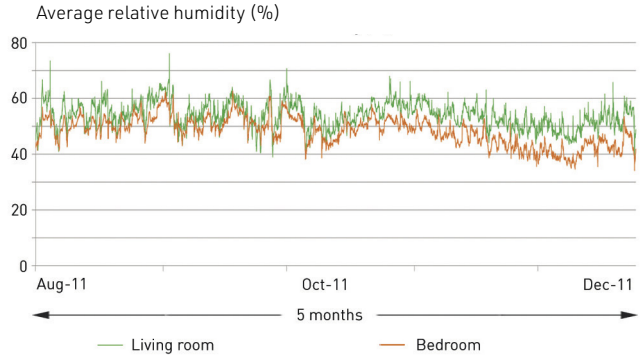
SPECIAL FEATURE

Thermal bridges were extensively assessed on this project. The architects used THERM modelling software to inform the detailing necessary to minimise cold bridging. This was a particular issue on the ground-floor: cold bridges were identified where internal partitions had been built off the concrete slab. The analysis found that a 60 mm layer of insulation installed on both sides of the ground-floor partition would mitigate the cold bridge and avoid any potential surface condensation occurring on the partition and floor.

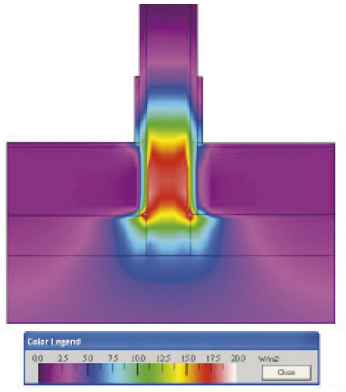
Living room CO_2 concentration (ppm) and temperature (°C)



Average relative humidity (%)



Thermal bridging modelling to internal partition and ground-floor junction



The cold bridge is very obvious. Psi-values 0.269 W/mK
Adding 50mm insualtion on each side gets the Psi-value down to 0.174W/mK (picture below). With 100mm, we reach 0.143 W/mK



RETROFIT REVISIT:

Hawthorn Road

SIGNIFICANT CHANGES SINCE THE ORIGINAL RETROFIT

Occupancy: The same residents, increased occupancy due to birth of a child.
Building: No significant changes but deterioration of the fabric to the north facade and ad hoc repair of failures to guttering and brickwork; breakdown of solar thermal element for the ROTEX Gas Solar Combi Unit requiring spare part and maintenance.

ENVELOPE

Overall performance: The EWI to the south side (rear) elevation is generally in good condition, albeit with signs of hairline cracks at junctions. There are brick mortar joint repairs to the north side, where cement rather than lime has been used, with consequent evidence of deterioration of the north-facing brickwork. Ongoing poor repairs and the inadequate maintenance of guttering to the north bay window has resulted in a build-up of moisture and moss growth, and severe brick deterioration. This may be further exacerbated by levels of IWI preventing the timely drying out of bricks. There are many hairline cracks in the mortar, generally to the north facade, requiring re-pointing.
Airtightness integrity: Blower door test demonstrates that the airtightness has been compromised compared to the original test, although the difficulty in installing the blower door in the doorframe may have had some impact on the results.
Further investigations: Smoke tests may help identify more clearly where air leakage occurs.

Thermography required to check the integrity of the wall, roof and floor insulation. WUFI analysis modelling is being used to assess whether levels of internal insulation are contributing to cold and damp brick deterioration on north-west walls.
Rectifications needed: Guttering and mortar repairs to the brickwork need urgent attention to prevent further deterioration. MVHR in need of rebalancing.

SERVICES

Heating: The ROTEX Gas Solar Unit powers small radiators to top up space heating on the coldest days. No change or maintenance schedule.
Hot water: The solar thermal circuit stopped working over two years ago after a parts failure. Spare parts and a maintenance engineer have proved difficult to arrange. As a result, there has been no renewable energy contribution to the home's needs for over two years.
Ventilation: The MVHR is in need of rebalancing and cleaning: it is noisy in the bathroom and sounds as if it is on boost setting while very low flows are felt in other areas. A volume flow metre test would be useful here.

ENERGY PERFORMANCE

Refer to page 49 table.

INDOOR ENVIRONMENTAL PERFORMANCE

Temperature: Generally comfortable and even temperatures. Average 20.1°C, which is also the occupant's stated preferred temperature in the SOAP survey; with an average minimum of 18.0°C and an average maximum of 23.3°C. The minimum temperature recorded was 17.2°C.

The hottest temperature recorded during the month of March was in the ground-floor WC, which is shared with the plant-room cupboard, and measured 27.1°C. In terms of more generally occupied space, the kitchen was the next hottest, with a recorded maximum of 26.5°C. The average temperature difference across the house is 2.21°C. From bottom to top, this ranges from 20.97°C to 18.76°C.

Relative humidity: Generally stable humidity levels with an average across the house of 50.7% RH. Average minimum recorded: 48.35% and average maximum: 53.37%. Highest RH recorded during the month of March was in the kitchen at 73.5%. Average RH differences across the house of 3.17%. From bottom to top of house ranges from 50.20% to 53.37%. The minimum RH recorded was 34.0%.
CO_2 concentration: The CO_2 sensor in the sitting room gave an average daytime (7:00am to 11:00pm) level of 613 ppm over a period of 27 days with a minimum of 418 ppm and a maximum of 1,854 ppm recorded. The maximum night-time (11:00pm to 7:00am) recorded 1,068 ppm. This level is regarded as 'good' and within the recommended range, suggesting that the MVHR strategy is working well.

COMMENTARY ON PHYSICAL FINDINGS VS USER FEEDBACK

Occupants are generally happy with property, but maintenance is a serious issue. Degradation in airtightness may be down to hairline cracking in the mortar and brickwork. More obvious declines are through doors and windows, but these retain good seals or are rarely opened. There are possible additional heat losses as some occupants are smokers and leave doors open while outside. Controls on the ROTEX Gas Solar Combi Unit appear complex, but the house tends to run at comfort levels so there is no need to adjust. The occupant of bedroom two often finds the bedroom very hot, but evidence suggests that bedroom one gets

Light moss and weathering on external wall insulation render



Rear elevation external wall insulation in good condition with very few hairline cracks in render



warmer due to being on the south side, however there were no complaints from that occupant. In both cases, internal venetian blinds appear to be down most of the day reducing solar heat gains (even in winter months).

Although the house is comfortable, there is great concern by the tenant and evaluator about the increasing deterioration of the north facadefacade brickwork and contributing drips from the poorly maintained gutter above.

While the overall running costs are deemed reasonable and keep the house at a comfortable 18–20°C as designed, the loss of contribution from the solar thermal array is unfortunate as it would appear that it could be resolved by the replacement of a faulty part.

Results of annual energy use suggest higher costs than previously achieved, but increased internal temperature requirements may be a reason for this.

A tumble dryer is used in winter to stay on top of household laundry, but otherwise drying racks outdoors in the garden are used. Moths are reported as an issue throughout the property with evidence around the MVHR filter inlet/plant room cupboard. No moths were observed in sheep's wool insulation in the roof space.

SERVICES STRATEGY

Space heating: ROTEX Gas Solar Combi unit has been reliable (unfamiliar/ complex controls means there has been less adjustment of settings), however maintaining the solar elements and the servicing of the unit has proved difficult as it is not a widely used item in this country.

The heating booster in line with MVHR ducting was used in the early days but proved expensive to run and generally unnecessary so advice was to turn off the switch operating this element.

Electricity: Provided on meter. A 10 minute power cut was recently experienced as there were insufficient funds in the account. This raises the concern of fuel poverty, which is mostly counteracted by low energy usage and a fabric first building strategy, but highlights that it is also important to maintain solar, which would offer free energy too.

Ventilation: MVHR filters are changed annually, or at times more frequently when UCL's Professor Ben Croxford visits with student study groups. This may be a cost issue or not seen as the responsibility of the tenant. Responsibility has never been clarified between the housing authority and the tenant. On first visit the evaluator witnessed existing filters, which looked over-soiled and therefore not working as effectively as they could in keeping air quality to a high standard.

The MVHR is noisy in the bathroom and overall seems out of balance, needs cleaning and a performance overhaul. However, the ventilation function still maintains stable humidity levels with an average across the house of 50.7% RH.

Renewables: The solar connection has been faulty for some two years. The tenant and housing association have reported difficulty getting replacement parts and suitable engineer. This may be due to unusual manufacturer for the UK market.

USER FEEDBACK

Questionnaire findings: The property has very few issues and the whole house (deep retrofit) is generally performing well. It is rated 'great' at 82% compared to benchmark scores, with little negative feedback from the residents.

Residents are very satisfied with comfort levels generally, although the house can overheat in summer. A user guide was provided along with an introduction to the various aspects of running the home.

Showers estimated at 20 per week and seven baths. Energy costs for the past year are stated as £1,700 and water costs at £400. There are no visible signs of condensation or mould internally.

BPE TECHNIQUES: LESSONS LEARNED

A fabric first approach had been adopted in the original specification to ensure a warm, comfortable home that is easy to operate. To check comfort levels and risks of mould growth, humidity and temperature readings are needed over a winter month. Relative humidity and internal temperature sensors were installed at the beginning of March 2023 to establish some benchmark performance data. A CO_2 data logger was installed in the sitting room to determine indoor air quality. Anonymous user feedback helped to provide context and user satisfaction levels. Blower door and Pulse tests helped determine the relative airtightness/leakage of the building over time and therefore the quality of the build, or to highlight defects in performance or building maintenance. Internal and external inspections of the fabric were carried out. Mould and damp testing was additionally performed by a specialised UCL unit.

The original building analysis and implementation work has generally stood the test of time, but a lack of maintenance schedule has eroded some of the performance, with cracking in mortar courses evident and where tackled, poorly re-done. Long term, this leads to higher overall remedial costs than a few essential repairs done regularly and with correctly specified materials.

Airtightness testing (blower door and Pulse): There was a technical difficulty in securing the blower door inside the narrow doorframe elements. The Pulse test was more practical to execute in this location.

Views on methodology: There is some concern that there was insufficient analysis of insulation thicknesses around the cold, north-west wall area, which may be contributing to the brick deterioration. UCL monitoring of this area may give further information not yet received.

Front elevation showing impact of leaky gutter on brickwork



Freeze-thaw damage at high level as a result of faulty rainwater goods



Moss on front elevation brickwork



The Nook

Pre-1919
TSB-90

Internal floor area: **177 m²**

Primary energy
pre-retrofit calculated: **316 kWh/m²/yr**
post-retrofit measured: **115 kWh/m²/yr**

Client: **Two Piers Housing Co-operative**

Architect: **BBM Sustainable Design**

Contractor: **Earthwise Construction**

Consultants: **Green Building Store**

This late-19th-century detached property is a house in multiple occupation (HMO) housing six adults. It is located in Brighton within Preston Village, an article 4 conservation area, which put some additional constraints on the upgrade strategy of the front facade. The design team developed a very comprehensive whole house retrofit, which included the following measures: internal wall insulation on the front facade; external wall insulation for the sides and rear facades; ground-floor insulation; triple-glazed windows on the side and rear elevations and double-glazed sashes to the front bay windows. The M&E services included an MVHR unit; a condensing gas boiler with insulated hot water tank and a solar thermal system.

The team also decided from the outset that the occupants should be able to remain in their accommodation for as long as possible during the retrofit. With careful planning, the residents were able to remain on site for all but three weeks of the period when the most invasive works were undertaken.

Overcoming planning hurdles in this project was a challenging and time-consuming process. Although not listed, the building falls within a conservation area with an 'article 4 direction', which meant that additional town planning controls on permitted developments (such as the replacement of windows) applied to the front facade.

During the feasibility stage of the project, the design team opted to replace all of the windows in the house with the best affordable triple glazing on the side and rear elevations. Unfortunately, due to the additional constraint of article 4, the team had to opt for double-glazed units on the front elevation.

After two planning submissions and considerable effort from the architect to gather convincing technical information about the energy performance of various options and present in-depth work on the details, the windows were eventually granted an approval.

Discussions with the conservation officer delayed the start on-site by four months with serious knock-on effects to the project as a whole, highlighting the challenges and conflicting agendas of low environmental impact design and heritage concerns.

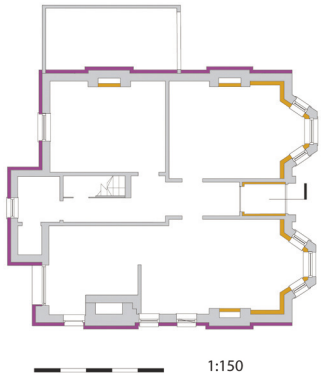
Front facade post-retrofit



Front facade pre-retrofit with single-glazed windows



Insulation strategy due to planning constraints (IWI orange; EWI purple)



STRATEGY

FABRIC

The team's original idea was to insulate the building entirely on the outside, however planning restrictions meant that this was not possible and replicating details would have been cost prohibitive. The resultant strategy combines external wall insulation on the rear and side elevations and internal wall insulation to the front. This hybrid strategy raised a number of technical considerations and detailing problems such as cold bridges. The ground-floor was also insulated. To avoid digging out the existing solid concrete slab, a thick layer of PUR insulation was installed, which lost the first step of the staircase requiring the newel post to be moved and a few of the ground-floor door lintels to be raised.

Windows were replaced with triple-glazed casement units for the side and rear elevations and double-glazed sliding sash for the front elevation facing the street.

SERVICES

The house has been fitted with a gas condensing boiler connected to two roof-mounted evacuated tube solar thermal arrays on the east-facing roof (Thermomax DF 100) and a 376-litre highly insulated twin-coil hot water tank. This system provides both domestic hot water and top-up space heating, reusing the existing radiator network.

In order to keep the heating demand low and the house well ventilated, the house is also fitted with an MVHR unit and associated ductwork (Paul Novus (F) 300 DC unit). The controls are simple and located in the main hallway in an easily accessible location.

RENEWABLES

The solar thermal panels installed are located on the east-facing roof, and while this is not the optimal orientation, the designers claim that nevertheless, they will satisfy a significant proportion of the hot water demand. The layout of the pipework was carefully considered to ensure a compact design and minimise deadlegs. All the pipework has been lagged.

The house is also fitted with an A++-rated fridge and compact fluorescent low energy lighting throughout. LED lighting (which can be a very efficient form of lighting) was considered, but the costs could not be justified compared to simply replacing all the bulbs with compact fluorescents.

VITAL STATISTICS

The thermal efficiency of the building fabric has been drastically improved to levels that are close to U-values commonly required to achieve PassivHaus standard.

The reduction of primary energy from 316 kWh/m^2/yr down to just 115 kWh/m^2/yr is extremely impressive and illustrates the high efficiency of the building fabric, together with what is likely to be an efficient hot water design. The tenants, who lived on site throughout the project, may have become sympathetic to the spirit of the project and consequently used energy with consideration and attention.

Occupant behaviour affects energy use, so homes must be easy to operate. Tenants should be informed about the house's functioning and essential maintenance – like changing MVHR filters – to ensure optimal energy efficiency and maximise savings.

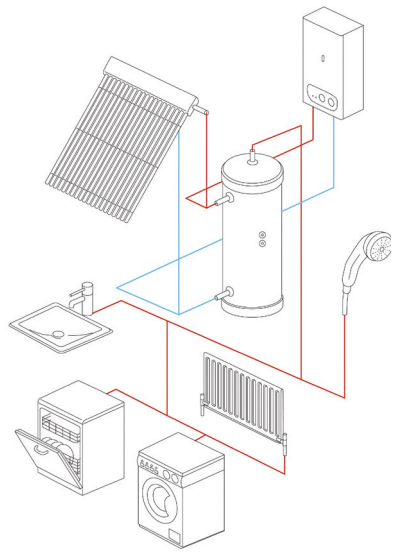
Vital statistics

Characteristics	Before	Target	Measured
Primary energy (kWh/m^2/yr)	316	114	115
Space heating (kWh/m^2/yr)	–	40	–
Airtightness (m^3/m^{2}h @ 50 Pa)	–	–	3
Type of glazing	single	double/ triple	double/ triple
CO_2 emissions (kg CO_2/m^2/yr)	107	23	19

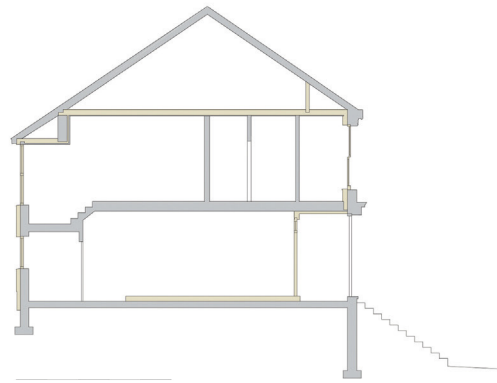
Installation of the external wall insulation



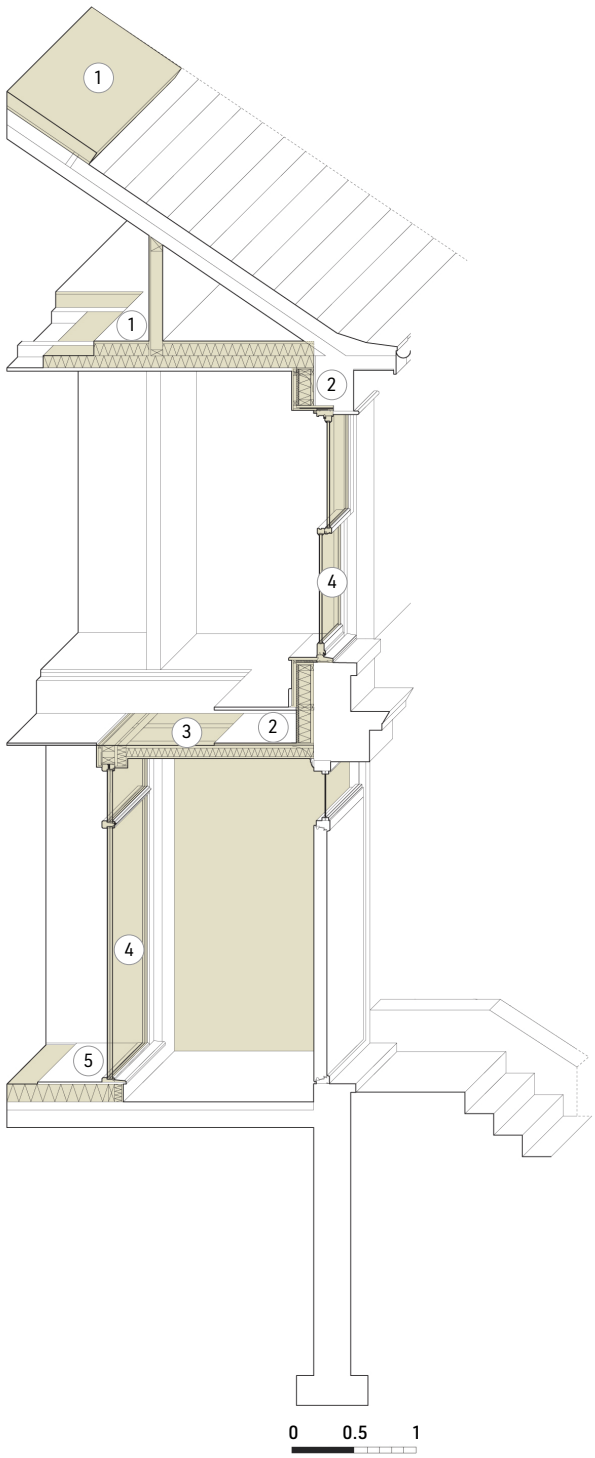
Production of domestic hot water schematic



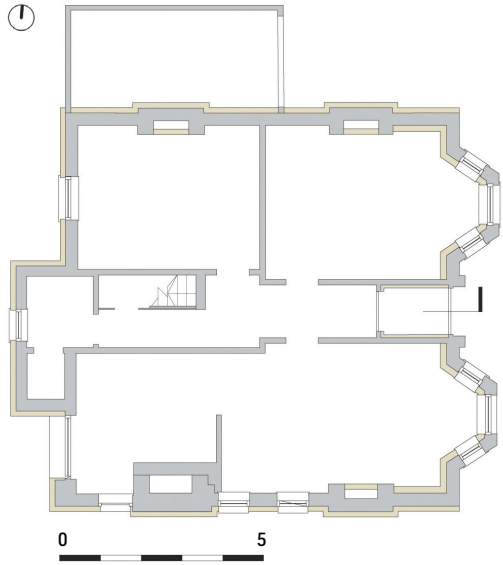
Fabric U-values post-retrofit (W/m^{2}K)



Detailed section



Key ground-floor plan



1 ROOF
roof-mounted solar thermal panels
100 mm rigid PUR insulation with bonded T&G flooring grade chipboard 22 mm
100 mm PUR insulation cut between joists and loose laid
fully taped vapour control layer draped in between joists and cut around joists where joins vertical vapour control layer
wattle and daub existing ceiling

2 WALL
existing wall
25 × 50 mm treated softwood batten
100 mm rigid PUR insulation
25 mm rigid PUR insulation
25 × 25 mm treated softwood batten
-15 mm wallboard and skim
insulation taken through existing floor void to face of existing ceiling

3 INTERMEDIATE FLOOR IN ENTRANCE
25 × 50 mm treated softwood batten
rigid dry-lining PUR insulation bonded to plasterboard and skim

4 WINDOWS/DOORS
new paint finished timber sliding sash double-glazed window to suit existing
new painted thermally broken triple-glazed single timber door and fanlight

5 GROUND
150 × 22 mm timber floorboard
vapour control layer
140 mm rigid PUR insulation
DPM
existing floor

FURTHER DATA

COST

In this project the cost related to fabric efficiency measures is relatively high. This is partly due to the rather large size of this property with 177 m^2 of floor area, but also to the detached form of the house. There is a large amount of external surface area to insulate in comparison with a terraced house of the same floor area, which inevitably adds to the cost and quantity of insulation material required.

The team found that external wall insulation was an easy and effective way of insulating the property and caused fewer problems than internal wall insulation of the front facade. However, even if the front facade could have been wrapped with external wall insulation (e.g. if the house had not been located in a conservation area), it would have brought further costs such as reinstating architectural features, which was estimated at the time to cost around £15,000, although there are now new products that would make this much cheaper.

MONITORING AND COMFORT LEVELS

Monitoring data indicate very good indoor air quality overall. The CO_2 concentration average curve is located around the 800 ppm mark with a peak in the winter months of January and February; however, these are still perfectly acceptable values (refer to ASHRAE Standard 62.1-2010, 'Ventilation for Acceptable Indoor Air Quality'). Temperature curves are constant, hovering around 20°C, and vary very little in comparison with the outdoor temperature curve. Relative humidity varies between 45% and 75% and is higher in the living room (between 60 and 70%), probably due to the kitchen's open plan arrangement, which leads directly into the living room.

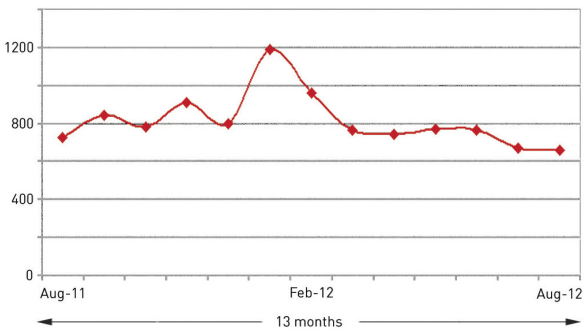
Costs 2010	
Fabric (insulation wall + ground + roof)	£70,250
Windows + doors	£30,300
Services (MVHR and ductwork + solar and boiler and tank)	£22,950
Other costs for retrofit	-
Subtotal	£117,750
Non-energy-saving measures	£5,200
TOTAL	£122,950

SPECIAL FEATURE

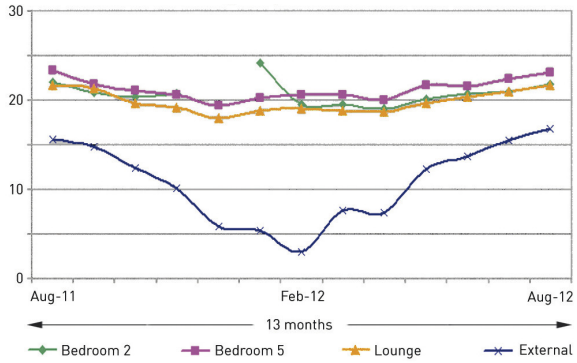
It is normal for adjustments to be made in between a scheme's design and completion. In a retrofit project, this is often due to the unknown condition of the actual building fabric prior to soft-strip works and can sometimes involve changes to the moisture behaviour of the fabric. In this project, only small changes occurred: asbestos was discovered in two locations and was removed. There were other minor changes: for example, the team used two layers of 60 mm boards of insulation for the external insulation instead of one layer of 120 mm boards originally specified. The manufacturer's website stated that 120 mm deep boards were standard products, but this was only the case for very large volumes. The additional fixings and installation of the insulation in two layers added expense to this aspect of the project.

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

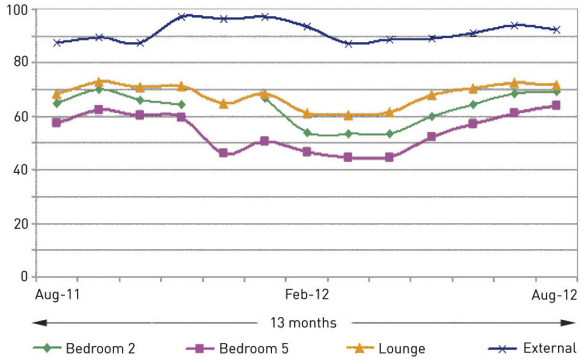
CO_2 concentration (ppm) – lounge



Average temperature (°C)



Average relative humidity (%)



External wall insulation



Highfields, Leicester

Pre-1919
TSB-57

Internal floor area: **70 m²**

Primary energy
pre-retrofit calculated: **638 kWh/m²/yr**
post-retrofit measured: **154 kWh/m²/yr**

Client: **East Midlands Housing Association**

Architect: **Gordon White Hood**

Contractor: **Aqua Interiors Limited**

Consultants: **EnviroHomes Limited; Institute of Energy and Sustainable Development; De Montfort University**

To reduce the energy consumption significantly and provide high levels of comfort, the principles of fabric first were followed. The upgrade of the external walls was carried out entirely internally due to conservation area constraints. As a result of the internal wall insulation being installed, floor and living space was lost. This led the team to propose an additional bedroom within the existing roof space, adding value to the house. To expedite the on-site process for building this additional room and ensure the good quality of the new space, the loft room was built as a prefabricated unit in a factory and then lowered into position on site. It was installed in just one day.

Retrofitting a Victorian house to a high level of energy efficiency requires knowledge, precise detailing and skilled site installation to coordinate new elements with the existing fabric. While the traditional on-site process for the construction of a loft space would have been feasible, it was felt by the team that an off-site solution built under factory conditions would have a better chance of achieving precise detailing, in particular for the installation of the airtightness membrane and the layer of insulation. The precision of the prefabrication methods enabled adaptations to be made in light of the constraints: the loft pod, made mostly of steel elements, had exceptional tolerances and fitted into the site very well. The precision of the detailing of this pod, which ensures optimum airtightness and reduces cold bridges, is one of the successes of this project.

The speed of the pod's on-site installation was another appealing aspect for the team. While a traditional approach would probably have required four to five weeks' work on site in uncertain weather conditions, the off-site solution here allowed the pod to be manufactured in factory conditions and the new volume installed on site in just one day. This is a significant benefit for a project with a tight schedule, minimising time on site.

The creation of an additional room greatly helps justify the retrofit costs, as it offers a replicable solution and adds value to the house.

Front facade post-retrofit



Rear facade post-retrofit



Prefabricated top floor and roof



STRATEGY

FABRIC

In spite of the substantial building works that have taken place, from the outside little appears to have changed

The new 'loft pod' insulated structure was designed to replicate the existing roof shape and the whole house was insulated internally, the only visible change being the replacement windows, which have profiles very close to those of the original sashes.

The upgrade of the house's thermal envelope was achieved by the addition of a new interior lining on all external walls comprising 100 mm of PIR insulation fixed directly to the brickwork; followed by an airtight membrane taped and sealed; then a further 50 mm of PIR insulation held in place by timber studwork and filled in with a further 50 mm of rockwool insulation finished with 13 mm plasterboard and skim. As a result, the airtight membrane was set as far back from the wall finish as possible to minimise the chances of accidently perforating it with fixtures or fittings. Plumbing and electrical services also run behind the studwork. Both the insulation and the membranes were designed to join with the new 'loft pod' to ensure the continuity of the energy-efficiency strategy throughout.

SERVICES

The ventilation system installed is a small MVHR unit located in the loft pod volume. The rectangular ductwork ('flat') is located within the floor and wall thickness. The location of the ventilation unit is important to ensure the maximum efficiency of the system. In a small house the retrofitting of equipment is often a challenge. The team located the MVHR in a space of low value with low headroom at second-floor level. This created rather long duct routes to the ground-floor level, therefore reducing the efficiency of the system, but it was a necessary compromise for this house.

RENEWABLES

Hot water and heating is provided by a condensing system gas boiler, topped up by roof-mounted solar thermal panels. To control these systems, an innovative adaptive (Wattbox) unit was included. This observes and adapts to the behaviour of the household occupants, which removes the need for users to set timer clocks. It is estimated that it saves around 10–15% of heating energy for typical usage. Simple up/down controls achieve occupants' preferences and provide a rapid heating response. The team also targeted further savings with the use of a 'V-phase' voltage optimiser control system, which stabilises the incoming voltage to ensure that electrical appliances run efficiently at the correct voltage.

VITAL STATISTICS

The airtightness achieved was 2.8 m^3/m^2h @ 50 Pa, above the targeted figure of 1 m^3/m^2h @ 50 Pa. According to the team, this may be due to the sliding sash windows and multiple and complex junctions of the airtightness membrane, in particular at first-floor level where the membrane was cut around each floor joist end and other awkward junctions. Initially, triple-glazed sliding sashes were installed at the front and triple-glazed casements at the rear produced by the same mainstream manufacturer (Jeld Wen). The sliding sashes were then replaced by sash look-alike casements manufactured by a local joinery company due to the difficulty the tenant had in operating the heavy triple-glazed sashes. In order not to disrupt the airtightness layer sealed on window frames, the new casements were installed within the existing frames.

Vital statistics

Characteristics	Before	Target	Measured
Primary energy ($kWh/m^2/yr$)	638	82	154
Space heating ($kWh/m^2/yr$)	389	28.1	9
Airtightness (m^3/m^2h @ 50 Pa)	15	1	2.8
Type of glazing	single	double/ triple	double/ triple
CO_2 emissions ($kg\ CO_2/m^2/yr$)	120	17	24

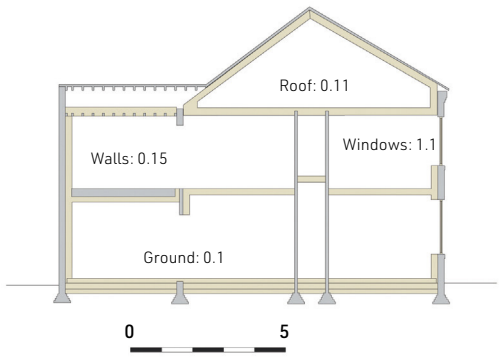
First-floor bedroom with internal wall insulation



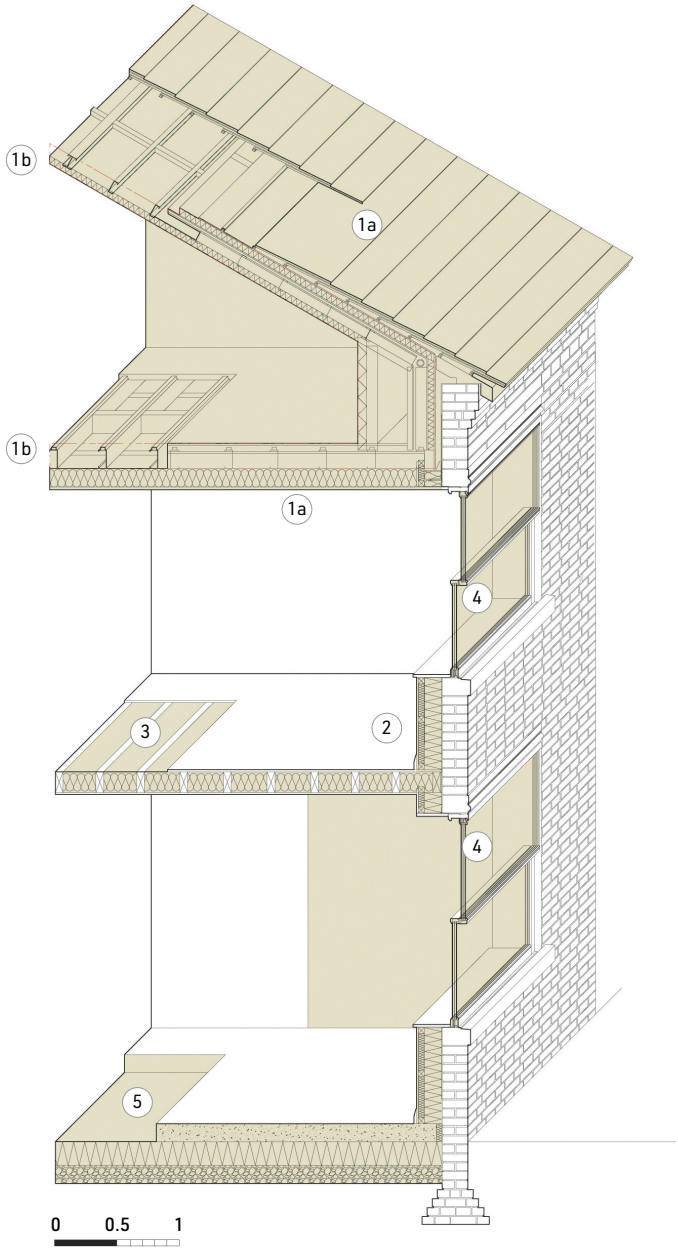
Ventilation unit (MVHR)



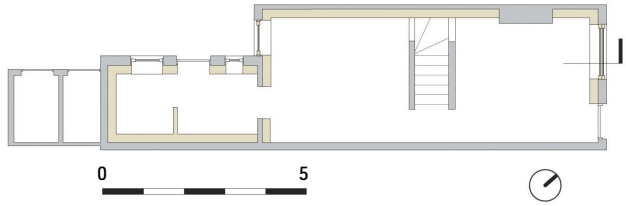
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1a ROOF
new fibre cement slates to match existing
25 × 38 mm tanalised s.w. battens at gauge on roofing felt
roof joists
airtight membrane overlapped and sealed at all junctions with proprietary sealants, sealed into the side of the new pod
150 mm mineral wool insulation provided between the joists

1b ROOF
loft pod – new prefabricated off-site roof section
9 mm sarking
75 mm PIR insulation between joists
100 mm LGSF (light gauge steel framing)
60 mm XPS insulation boards factory bonded with wall board
18 mm chipboard flooring (faced with thermosetting resin impregnated paper)
150 mm LGSF

2 WALL
existing solid wall
vapour permeable membrane (Solitex)
150 mm PIR insulation (Celotex)
air sealing membrane (Intello plus)
50 × 50 mm timber studs with mineral wool insulation
13 mm plasterboard and skim

3 INTERMEDIATE FLOOR IN ENTRANCE
150 mm mineral insulation between joists

4 WINDOWS/DOORS
triple-glazed timber windows

5 GROUND
22 mm T&G chipboard floor
225 mm PIR insulation
100 concrete slab
DPM
150 mm sub-base

FURTHER DATA

COST

Although it forms part of the fabric improvement measures, the cost of the loft pod has been identified in the table above as a distinctive feature of the project.

On completion, the overall cost of the project was found to be £18,000 above the original budget. This overspend resulted from three particular areas of difficulty: the procurement of the loft pod; additional labour and unforeseen problems with the building integrity; and expanding the scope of works.

Costs 2010	
Fabric (insulation wall + ground + roof)	£18,563
Windows + doors	£6,737
Services (MVHR and ductwork + solar and boiler)	£14,310
Loft pod	£16,701
Subtotal	£56,311
Non-energy-saving measures	£34,000
TOTAL	£90,310

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

MONITORING AND COMFORT LEVELS

CO_2 concentration levels inside the house are a little higher than for other projects, hovering around 1,000 ppm. The relative humidity graph shows a stable average between 40% and 50% within recommended values.

Internal temperature averages are very stable between 22°C and 25°C, but probably driven by tenant preferences.

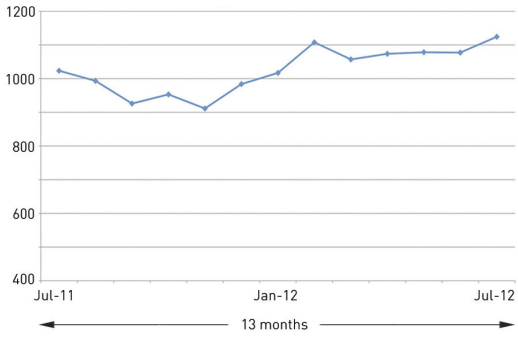
Tests were also done in this property to determine the volatile organic compounds (VOC) emitted (can be from building products; human-made and naturally occurring chemical compounds). All results were reported to be normal.

SPECIAL FEATURE

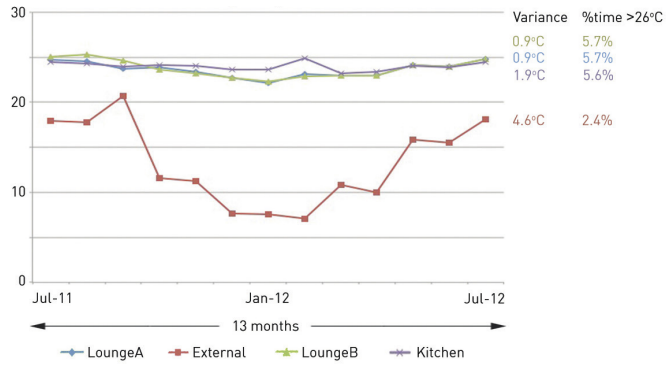
Overall, the team felt that the project was delivered very successfully. When queried on what they would definitely do again in another retrofit project, the team stated that the off-site solution had great benefits for the project and they would reuse this approach. They felt it proved to be very accurate, offered quality and benefited the programme. They would, however, allow more time for the development of the design so that manufacturing costs could be controlled.

The team also felt that reducing energy consumption through passive measures such as high levels of insulation and airtightness rather than relying on renewable technology to generate a supply creates a more robust solution that is easier to install and less reliant on specialist installation contractors. The only point of advice on the passive measures would be to prepare well and train to achieve a really good level of airtightness.

Average CO_2 concentration (ppm) – indoor



Average temperature (°C)



Average relative humidity (%)



Prefabricated roof in factory



Grove Cottage

Pre-1919
(not part of Retrofit for the Future)

Internal floor area: **135 m²**
Primary energy
pre-retrofit calculated: **284 kWh/m²/yr**
post-retrofit measured in 2023: **120 kWh/m²/yr**

Energy Use Intensity
post-retrofit measured in 2024: **79 kWh/m²/yr**

Client: **Andrew Simmonds, Lorna Pearcey**

Architect: **Simmonds Mills Architects**

Contractor: **Eco-DC**

Consultants: **David Olivier, EAA (various), Alan Clarke (PHPP / heating design), Green Building Store (Andrew Farr for MVHR), BJSE Consulting (Bob Johnson for structural engineering), Thermal Inspection (thermal images), ALDAS (Paul Jennings for airtightness)**

This project was completed in 2009 and preceded all others in this publication. It was presented as an exemplar project at the Retrofit for the Future programme launch in 2010. It is the first EnerPHit certified project in the UK built to the PassivHaus refurbishment standard, which was developed in 2011 by the PassivHaus Institute (PHI) in Germany. It follows the same principles as PassivHaus, but with less demanding criteria for airtightness (1 ACH instead of 0.6 ACH) and space heating (25 kWh/m2/yr instead of 15 kWh/m2/yr).

The property was a two-bedroom detached cottage in Hereford, built in 1869. The pre-retrofit construction featured painted solid-brick walls with a 30-m2 unheated basement. The house was entirely retrofitted, and an existing extension was reworked and further extended with an additional 40 m2 of floor space, including two additional bedrooms. The main energy-saving measures implemented in this project included external insulation, minimal thermal bridging, high levels of airtightness, thermal mass, triple-glazed windows and doors, salvaged materials and a chain of custody for timber sourcing, MVHR system and green roofs on the extension at the rear of the property.

Prior to refurbishment, the property had a timber ground-floor with a cellar space. Because the cellar was damp and funds did not allow for a conversion, the team decided to thermally separate it from the rest of the house, while still allowing door access.

The modifications to the existing building fabric included an extensive remodelling of the ground-floor structure with the insulation and airtightness elements installed underneath the floor in order to avoid disruption and cost related to existing partition walls and floor finishes.

Because of the unusual nature of the floor build-up, some modelling was carried out to help ensure that the details were as free of cold bridges as possible and that the surface temperatures would be high enough to prevent any mould growth (THERM and WUFI software were used). This study indicated a small degree of risk, but the use of a vapour variable membrane combined with continuous mechanical ventilation in the house meant that the project team felt the long-term risk was acceptable.

Front facade post-retrofit



External roof insulation on site



Air vapour barrier installation



STRATEGY

FABRIC

The concept behind the upgrade of the fabric of this solid-masonry-walled construction was to adopt a whole house external insulation strategy, including the roof above the existing rafters. This approach of wrapping the house from the outside has the advantage of creating a continuous and uninterrupted insulation layer. The only difficult area to resolve was the cold bridge at the foot of the existing facade wall created by the external wall insulation and the insulation fitted in the suspended ground-floor. Insulating and load-bearing cellular glass blocks were retrofitted in the existing masonry wall to minimise this cold bridge. The narrow gap (25–40 mm) between the north gable wall abutting the neighbour property was insulated using a DIY PU expanding foam injected from holes drilled in the house's internal walls. All windows were replaced with new triple-glazed timber units and adequately taped to the new airtight parge coat.

SERVICES

The ventilation strategy included a MVHR system providing fresh warm air for the house, and also a new efficient gas boiler (the existing radiators were retained). Hot water is provided by a twin coil hot water cylinder, heated by a gas boiler.

To avoid any unnecessary energy loss, all hot and cold water pipes were well insulated in line with advice provided by AECB.

RENEWABLES

A roof-mounted platform, which could support 4.5 m^2 of solar thermal panel was built. However, the panels were ultimately not installed as it was found during the build process that the efficiency of the other measures (extra tank insulation, low water use generally and insulated pipework) made solar thermal only a marginal benefit at present.

Other systems such as biomass were investigated but this was not considered an appropriate fuel because of the resultant air pollution issues (particulates etc.) in a residential area, and also because of the high capital costs associated with biomass equipment (considering the relatively low heat demand in this house).

Additionally, in order to avoid using electrical power to light the internal spaces, the architect carefully designed the window arrangement to take advantage of the south-facing orientation in both the existing house and the new extension. These windows allow some solar gain and high levels of daylight to all rooms to reduce the need for electric lighting. Daylighting was further maximised through the internal colour scheme, which favours light, off-white colours.

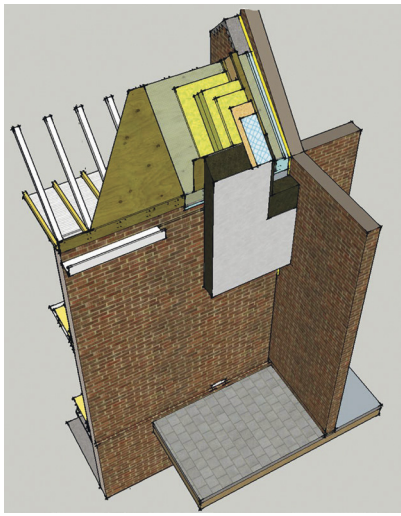
VITAL STATISTICS

The airtightness strategy for the existing house consisted of a new parge coat on the external face of the existing brick walls (a thin layer of cementitious material was used). On the new extension, internal plaster was used for all blockwork walls in combination with air-vapour barriers in the ceilings and some limited wall areas where a timber frame was required above brick/blockwork. This was all well sealed and taped, especially around the window openings. The results that this strategy achieved are excellent. The tests undertaken revealed a first result of 1.56 m^3/m^2h in March 2009; after the identification of a few issues (including in the door frames), the final air permeability measured was 0.82 m^3/m^2h in July 2010. This result is a considerable improvement and meets the airtightness target (1.0 ACH @ 50 Pa) set for the EnerPHit standard.

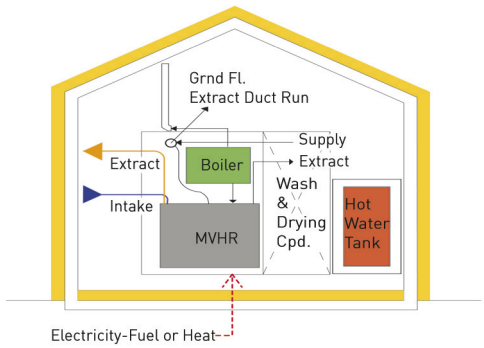
Vital statistics

Characteristics	Before	Target	Measured 2010	Measured 2023
Primary energy ($kWh/m^2/yr$)	284	88	120	–
Energy use intensity (kWh/m2/yr)	204	–	80	113
Space heating ($kWh/m^2/yr$)	–	30	35	7.45
Airtightness (m^3/m^2h @ 50 Pa)	–	1	0.82	1.37
Type of glazing	double/ single	triple	triple	triple
CO_2 emissions ($kg\ CO_2/m^2/yr$) operational	138	17	25	–

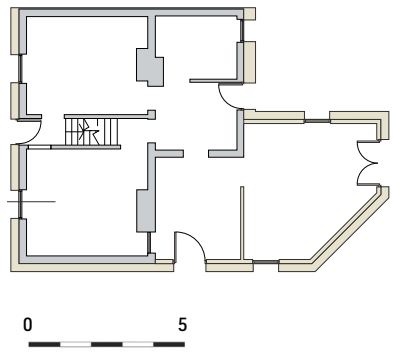
Front facade and roof build-up



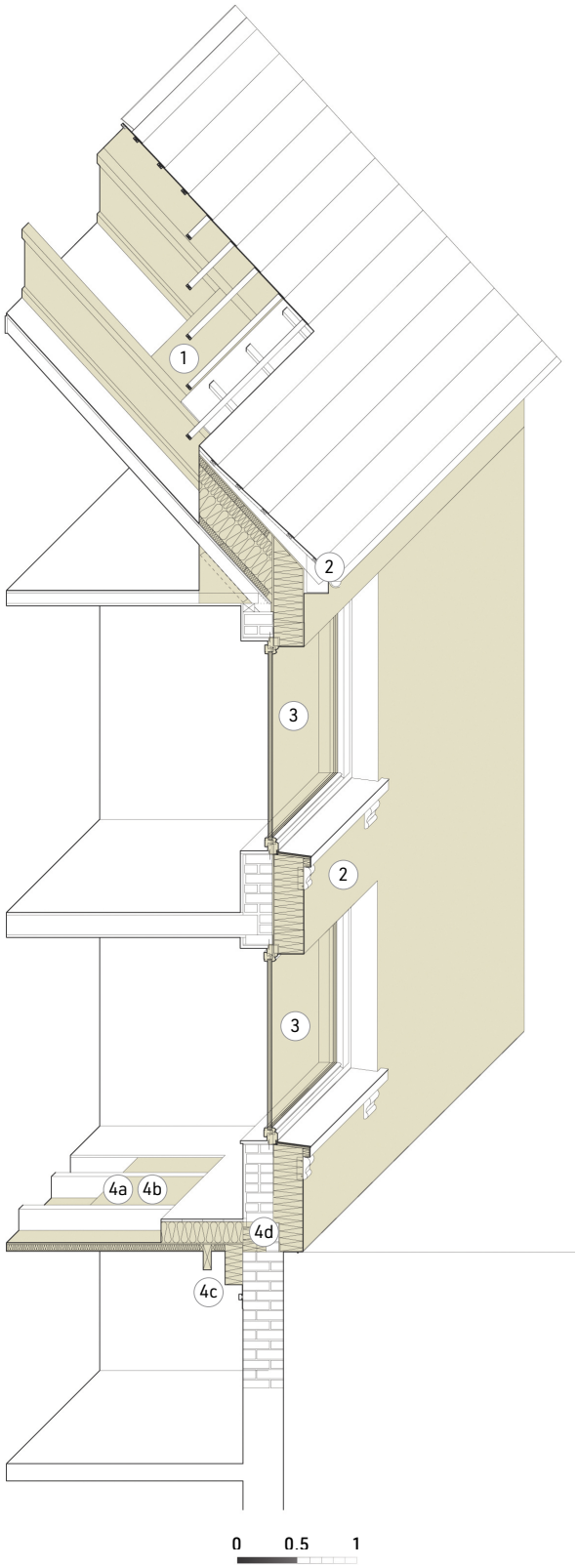
Services strategy



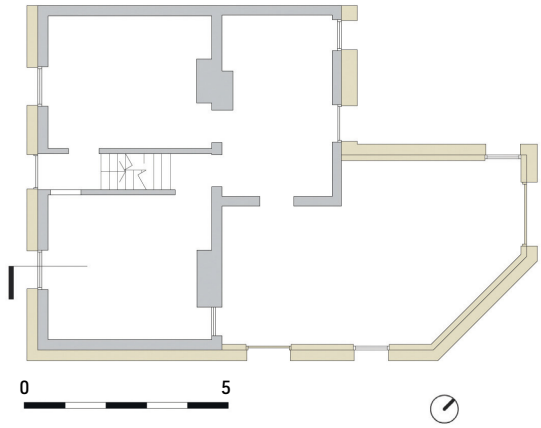
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
slates on battens, 50 × 25 mm counter battens
low vapour resistance sheathing membrane and 9.5 mm OSB sheathing
new 400 mm deep I-beams screwed via bottom flanges through air-vapour membrane and 20 mm T&G timber sheathing to connect I-beams
fully fitted mineral wool between beams
existing attic joists
triangular plywood gussets fixed one side of each joist

2 WALL
render
250 mm EPS insulation
existing wall

3 WINDOWS/DOORS
new high-performance triple-glazed

4 GROUND: main house
From top to bottom:
a-175 mm sheep's wool insulation between existing suspended floor joists
b-50 mm sheep's wool insulation between battens
c-vapour variable membrane for vapour control layer (Intello)
d-load-bearing cellular glass block

5 GROUND: (other areas not shown in this illustration)
- existing extension with solid floor
liquid DPM on top of existing floor slab
dry concrete mix self-levelling compound
100 mm of polyurethane foam board
vapour variable membrane for vapour control layer (Intello)
two layers of glued and screwed WBP plywood
floor finish (thin travertine stone on flexible adhesive).
- new build extension
200 mm reinforced concrete slab
DPM
250 mm EPS
50 compacted MOT
subsoil

FURTHER DATA

COST

This project was mostly self-build where the architect was also the owner and occupier of the house and highly engaged in the site supervision, working very closely with the contractor. He also installed most of the MVHR system himself. This arrangement resulted in fast decision-making, confidence-building within the contractors' team and saving significantly on the overall cost.

2010 post-retrofit energy bills were £698 (£384 gas; £314 electricity). Pre-retrofit costs are estimated above the £2,000 mark to achieve the same temperature.

Costs 2010	
Fabric (external insulation @ £80/m²)	£8,000
Windows + doors (delivered costs – not installed)	£12,500
Services (MVHR and ductwork delivered – not installed)	£5,000
Other costs for retrofitting the main house	£19,500
Subtotal	£45,000
Non-energy-saving measures (new build extension + attic conversion + external works)	£95,000
TOTAL	£140,000

MONITORING AND COMFORT LEVELS

The mean internal temperature measured during the heating season was a comfortable figure of 21°C. The minimum internal temperature measured was 18°C in one of the bedrooms.
Potential reasons may be found in the characteristics of this bedroom, which has no radiator, two exposed walls and a first-floor west-facing window. However, overall, the graph below illustrates very stable internal temperatures throughout the house.

It is worth noting that there are only four radiators in the house – two on the ground-floor, with a towel rail and small bedroom radiator on the first floor, and none on the second floor.

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

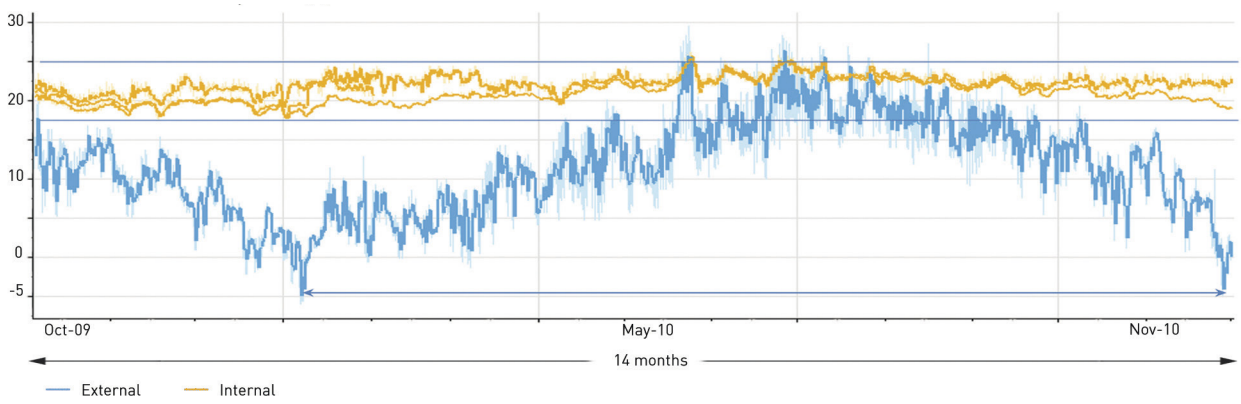
SPECIAL FEATURE

Thermal Inspections Ltd produced the house's thermograph.

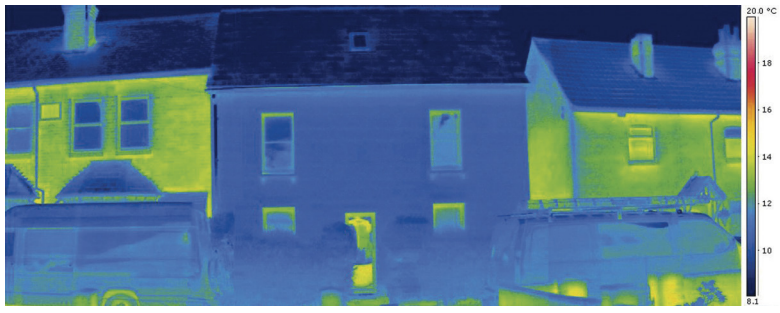
The thermograph below illustrates the externally insulated front facade. There are no noticeable heat losses. The neighbouring house shows a warmer surface temperature: this is significant and probably due to lack of insulation. However, whether this is the case cannot be confirmed by this thermogram alone (the material of the facade could also affect the image).

This image indicates that the strategy for the upgrade of the building fabric has been very effective.

Temperature (°C)



Thermal image of the front elevation



Front elevation post-retrofit



RETROFIT REVISIT:

Grove Cottage

SIGNIFICANT CHANGES SINCE THE ORIGINAL RETROFIT

Occupancy: No changes.
Building: No significant changes reported, other than the remedial works described below.

ENVELOPE

Overall performance: The fabric still performs well and its performance in the retrofit revisit was similar to the design calculations.

In the years after the retrofit, a precautionary measure was taken to address moisture-related risks. Specifically, some of the sheep's wool fitted between the joists on the suspended floor was removed at the point where the floor meets the external wall. This decision followed the discovery of localised timber decay affecting a single joist parallel to the exterior south gable wall, which was set off from the masonry (without a damp-proof course) by less than 25 mm. It was also to allow the injection of a hydrophobic brick cream, DPC, into the mortar joints of the solid wall, a measure the homeowner regrets not taking during the retrofit. The combination of basement wall condensation wetting, leading to vertical capillary movement of moisture ('rising damp') behind the airtightness membrane of the suspended floor, and the increased temperature, resulted in one of the timber joists rotting. New insulation was installed with a tapered angle.

Airtightness integrity: The airtightness integrity has reduced. This seems to be from now-defective door seals and because the airtightness membrane for the suspended floor has not been reattached to original retrofit levels.

Further investigations: Fungal biomass quantification testing (air sampling) was carried out in one room with the suspended ground-floor (living room) and one room under the roof (bedroom). The results indicate high fungal levels. This may be interstitial rather than surface mould and may be connected with the water damage from a leak in a heating system expansion vessel.

Rectifications needed: Airtightness membrane at suspended floor needs reattaching.

SERVICES

Heating and hot water: Some radiators have been removed from the original retrofit. The boiler expansion vessel burst and caused a small flood, resulting in remedial works to the hallway and bathroom areas and part of the suspended-ground-floor edges.

Ventilation: The visit found that the MVHR unit has stopped supplying fresh air but is still extracting as expected; investigations are ongoing to discover the cause.

ENERGY PERFORMANCE (2022 VALUES)

EUI: The total EUI is 113 kWh/m^2. Exported PV electricity is not metered so the actual energy used may be lower than this figure.

Gas: Gas usage has increased since the original retrofit, but this appears to be from shower usage and the metered data supports this (based on the increase is summer gas consumption).

Electricity: No significant changes reported.

INDOOR ENVIRONMENTAL PERFORMANCE

The monitored data indicates a good indoor environment in terms of air temperatures, CO_2 levels and RH. Occupant feedback confirms the indoor environment feels comfortable. There were no complaints of stuffiness despite the MVHR fault.

Temperature: The mean internal temperature was above the set point of 18°C.

Relative humidity (March 2023): The mean relative humidity ranges from 58% to 61% for the bedrooms; 51% for the upstairs bathroom; 51% for the living room; and 55% for the kitchen. The ideal range is between 40% and 60% RH.

CO_2 concentration: The CO_2 monitor was in the living room, which is the most consistently occupied space. The CO_2 levels seemed to stay below 1,250 ppm for most of the monitoring period, with a few dates rising above 2,000 ppm.

COMMENTARY ON PHYSICAL FINDINGS VS USER FEEDBACK

The user feedback is consistent with the physical findings.

Internal temperatures and relative humidities were considered comfortable. No mould or condensation issues were identified by the occupants. Hot water temperatures were considered too high.

SERVICES STRATEGY

Hot water: Provided by gas system boiler and storage tank. The boiler runs a legionella cycle once a day (assumption based on spike in gas usage between 10:30am and 11:00am).

Space heating: Three radiators supplied by the gas boiler in the building. No reports of maintenance issues. There were more radiators, but they were removed due to heat rising upstairs and making it too uncomfortable.

Electricity: The average electricity use, post-retrofit, was slightly lower (4,037 kWh/yr) than the pre-retrofit usage (4,954 kWh/yr). In 2017, a PV installation was added, but this did not meter the exported electricity. As a result, it is difficult to compare more recent electrical consumption figures.

Ventilation: Mechanical ventilation system with heat recovery (MVHR). The MVHR unit is a Paul 200 thermos. The unit was installed as a prototype originally and has worked reasonably well. Whilst checking the flow rates, the supply air wasn't working properly. Further inspections are required to determine if this is from a blockage in the system or whether the fan has stopped working.

Renewables: PV was added after the retrofit in 2017. The total output of PVs is metered, but how much is used by the home is unknown (exported electricity from PV is not metered and instead is paid a set amount).

USER FEEDBACK

Questionnaire findings: The occupants are knowledgeable professionals who designed the retrofit and have been very thorough in keeping the building maintained to a high quality. The SOAP score is 95% (rated as 'great').

Feedback is generally above benchmark values except for control of services and storage space. Energy use and comfort were rated highly. There are a few minor elements that the occupants would like to change, such as having a higher level of control for the heating, ventilation and lighting. The main areas that need immediate maintenance are the door seals and the ventilation system. The ventilation system and boiler have worked well, with minimal maintenance required over the years. There was no correlation between occupant feedback and faults with the MVHR.

The new house (extension) is reported as being warmer compared to the retrofitted areas; this may be a result of fewer thermal bridges in the new build compared to the retrofit. The extension includes the kitchen/dining room.

BPE TECHNIQUES: LESSONS LEARNED

Core BPE scope and detailed BPE: This property was selected as the ground-floor was of interest due to it having an insulated timber floor above a cold basement. The scope was to test the moisture content of the floor insulation between joists for risk for mould. Heat flux U-value measurements and thermal imaging were also completed.

We attended the site at the start of the monitoring period to set up, answer any questions the occupant may have and complete the building survey so we could determine which detailed tests should be carried out and where they were required. There also would have been greater control over where the sensors were placed and whether any additional meters could have been read.

Airtightness testing (blower door and Pulse): We could not conduct a pressurisation test at 50 Pa on the blower door test, due to concerns by the homeowner this may damage the airtightness membrane.

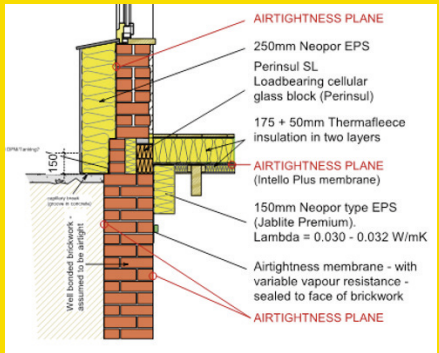
One-off retrofit and extension works between 2008 and 2009



Air/vapour barrier installation



Section detail



Easton Road

Pre-1919
TSB-98

Internal floor area: **78 m²**

Primary energy
pre-retrofit calculated: **439 kWh/m²/yr**
post-retrofit measured: **192 kWh/m²/yr**

Client: **Self Help Housing Association (SHHA)**

Architect: **White Design Ltd**

Contractor: **Mears Group PLC**

Consultants: **Arup Structures & Services, Carnego Systems Ltd**

This Victorian two-bedroom mid-terrace house with solid wall construction is typical of approximately 50% of Bristol's housing stock of 162,000 households. The house is in Lawrence Hill, which is the most deprived area in Bristol and falls in the most deprived 1% of all areas nationwide. In the ward, overall 54% of housing is socially rented, and in Easton Road 92% of children live in income-deprived households. Designed according to the guidelines of PassivHaus (but not certified), this whole house retrofit features high levels of internal and external insulation, a combi boiler, an MVHR system, solar thermal panels, triple-glazed casements, and an experimental sash and casement window module to suit the Victorian street frontage.

This project had two distinct, but intrinsically linked, aims. The first was to deliver the required cuts in energy use by focusing on the building fabric, structure and energy systems; the second was to gain an in-depth understanding of occupant behaviour and psychology, identifying technologies and processes that facilitate low-carbon lifestyles and decision-making.

In order to best ensure that the levels of comfort and energy savings would be achieved as designed, a Building User Guide was produced. The document was designed to be comprehensive yet relatively simple. The guide includes explanations in plain English of how to use the house, what to do to control the air (both hot and cold) and the hot water, and also extensive information on a low-carbon lifestyle: climate change, fossil fuels, population growth impacts and energy costs. It even encourages occupants to get involved with local groups with a commitment to sustainable living. It can be intimidating to live in a low energy retrofit. Finding others going through the same experience will definitely help occupants to engage with the aims of a project of this type. Being located in Bristol, a city with a great interest in low energy retrofits and an increasing number of projects, one can hope that such a network may be realised.

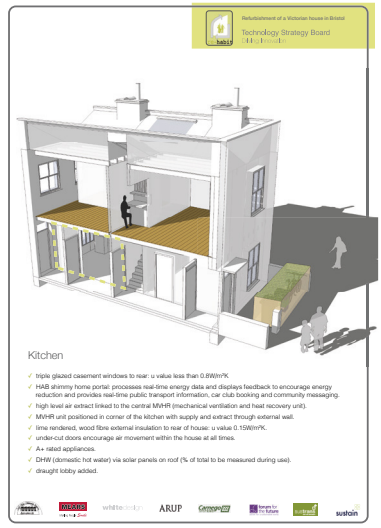
Front facade post-retrofit



Window detail on front facade



Building User Guide extract page



STRATEGY

FABRIC

The thermal performance of both external facades was vastly improved. The rear facade was retrofitted with external lime-rendered wood fibre insulation and the front facade with internal mineral wool wall insulation. The roof received 260 mm of mineral wool insulation. The whole house was made more airtight with taped orientated strand board (OSB) on the internal wall build-up of the front facade and an airtight membrane (Proclima Intello) on the internal service void of the rear facade.

The installation of internal wall insulation for the front facade was chosen in order to retain the character of the Victorian terraced street and avoid having to apply for planning permission. To achieve the low U-values of 0.15 W/m^{2}K, 250 mm of insulation was added to the internal face of the front solid brick facade. Concerns over the dew point and condensation risk led the team to include a vapour control layer. Also, a new lime render was applied to the external front facade to protect the masonry wall from significant rainwater penetration. This breathable render will reduce rain penetration and allow any moisture trapped in the brick wall to dry out. The joist ends resting inside the brick wall are potentially exposed to risks of condensation. They were temporarily removed and injection treated with a preservative that has a 60-year warranty then refitted with the addition of probes to monitor moisture content in the timber and better assess the risks of the joist ends rotting.

SERVICES

Following the fabric first approach, which provides a well-insulated, airtight shell, an MVHR system was installed. A 'Hab shimmy portal' was also installed. This device is a simple flat screen located in the kitchen that processes real-time energy data and displays feedback to encourage energy reduction in homes. The portal also combines this data with other sustainability information such as real-time public transport information, car club booking and community messaging.

RENEWABLES

Solar thermal panels were installed to partially satisfy the hot water demand. Some low-tech measures were also implemented to further encourage the occupants to save energy: for example, a clothes dryer positioned over the bath to provide an alternative to the use of an electric dryer or the inconvenient drying of clothes in other habitable rooms; a covered bike store to encourage cycling; a recycling area; and food-growing opportunities with seating/planters in the rear garden.

VITAL STATISTICS

In order to address effectively the thermal bridge problem between the existing window and the new layer of internal wall insulation, the team designed a bespoke unit.

It replaced the windows facing the street with a module made of a double-glazed sash (positioned in place of the existing) and a double-glazed casement (aligned with the new layer of internal wall insulation). The resultant quadruple-glazed unit eliminated cold bridges and achieved the same PassivHaus U-values and airtightness criteria. As it was such a unique piece it was manufactured by a joinery company.

On the rear facade, all windows were new triple-glazed casements produced by a mainstream window manufacturer.

Vital statistics

Characteristics	Before	Target	Measured
Primary energy (kWh/m^2/yr)	439	120	192
Space heating (kWh/m^2/yr)	–	22	–
Airtightness (m^3/m^{2}h @ 50 Pa)	8.14	1	4
Type of glazing	single	triple	triple/ quadruple
CO_2 emissions (kg CO_2/m^2/yr)	79	17	30.7

Installation of internal insulation



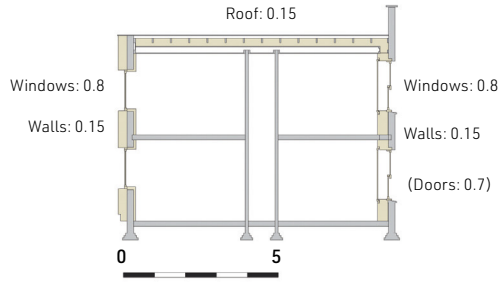
Real-time energy monitor

Roof-mounted solar thermal

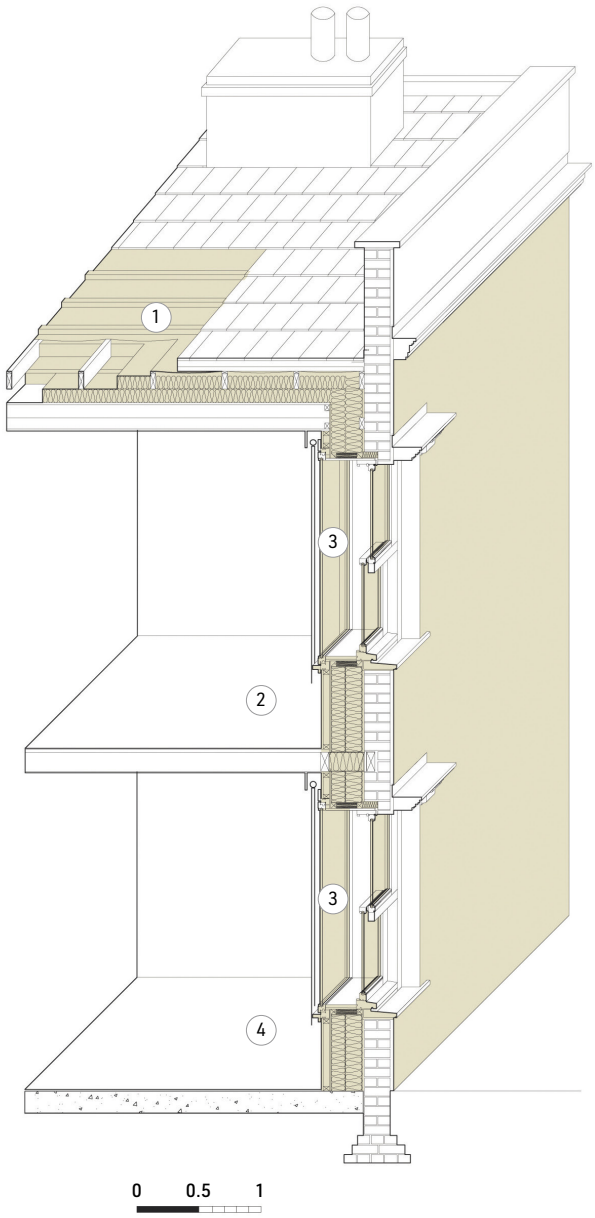




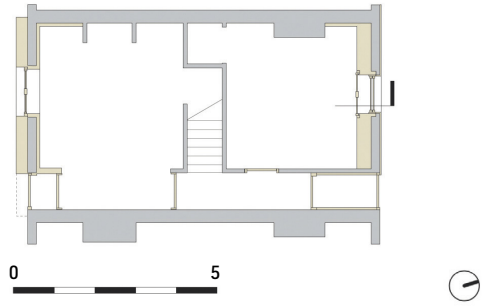
Fabric U-values post-retrofit (W/m^{2}K)



Detailed section



Key ground-floor plan



1 ROOF
existing tiles kept where possible
new battens
continuous lapped breather membrane fixed below battens with 15 mm sag to allow any moisture to run down below battens and escape at bottom of tiles in gutter
new counter battens
new 150 mm joists
260 mm mineral wool insulation between rafters
100 mm of mineral wool fixed against party wall to counteract any cold bridging effect of neighbour's loft space being unheated
vapour barrier run continuously under loft insulation, taped and sealed to maintain airtightness
OSB

2 WALL
three layers of hydro lime-based render (lime green natural finish or similar) + reinforcement mesh
existing solid wall
internal render retained
120 mm and 140 mm layers of mineral wool insulation between 600 mm support joists
15 mm OSB layer taped at every joint and edge with vapour barrier to form airtightness layer
50 mm battened out service zone, plasterboard and skim

3 WINDOWS/DOORS
bespoke double-glazed sash window unit combined with double-glazed casement windows internally, site-measured and factory-sealed to create airtight window box unit

4 GROUND
DPC laid over existing concrete slab to protect insulation, lapped up wall and taped

FURTHER DATA

COST

The cost for the ventilation system was £9,509 including the commissioning but could be reduced if a number of properties were to be considered at once. The cost of treating the joist ends was relatively low at £405; it was considered a 'reasonable' approach in comparison with the option of cutting the joists back to provide a ventilated cavity between the insulated lining and the potentially damp brickwork. The project team considered this such an invasive process that most landlords and homeowners would not view it as a viable option.

Costs 2010	
Fabric (insulation wall + ground + roof)	£14,047
Windows + doors	£13,603
Services (MVHR and ductwork + solar and boiler)	£22,400
Other costs for retrofit	
Subtotal	£50,050
Non-energy-saving measures	£99,950
TOTAL	£150,000

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

MONITORING AND COMFORT LEVELS

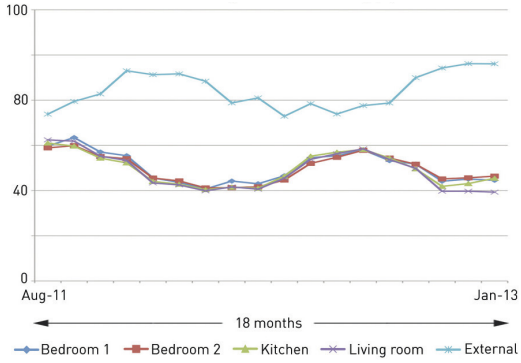
The monitored relative humidity (RH) shows a curve of averages between 40% and 60%. In the summer months, the RH measured indoors is close to external RH, probably due to the occupants opening the windows. In the winter, the RH is very different to outdoor levels as the MVHR system extracts the moisture outside.

The monitored average temperatures per room show a very comfortable environment with temperatures between 20°C and 25°C. Individual room temperatures are also very consistent and vary very little in comparison with outdoor temperatures.

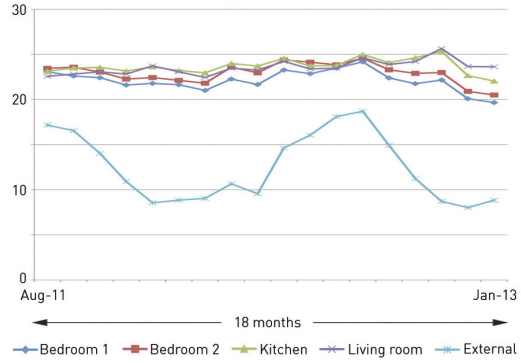
SPECIAL FEATURE

In order to provide the required environmental upgrade while also maximising opportunities for added value, the team looked for additional architectural design opportunities. Considering the extent of the work required on the roof, one of the opportunities identified was to create a new floor with a third bedroom and a dedicated plant room. This would also address the wider national and local policy, which demands more family housing in central Bristol. A planning application to Bristol City Council was refused on the basis that increasing the height of the house was unacceptable as it would break the terrace's roof line. It was felt that this was a key missed opportunity for the project. But lessons were learned: the planning department explained that a combined application to modify the entire terrace in this way might have been considered more positively. A full street approach would bring other challenges such as dealing with multiple ownerships, however it is an efficient approach worth considering where feasible.

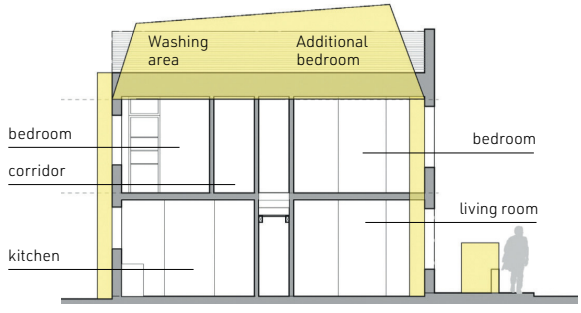
Average relative humidity (%)



Average temperature (°C)



Sketch option for a roof extension



Brent

Pre-1919
TSB-65

Internal floor area: **116 m²**

Primary energy
pre-retrofit calculated: **634 kWh/m²/yr**
post-retrofit calculated: **89 kWh/m²/yr**

Client: **London & Quadrant Housing**

Architect: **Green Structures Ltd**

Contractor: **Green Structures Ltd**

Consultants: **n/a**

The house is a typical two-bedroom, two-storey, late 19th-century brick-built mid-terrace. The team decided to upgrade the thermal envelope by applying external insulation to all facades and replacing all windows with triple-glazed casement units. Other measures included the installation of an MVHR unit in combination with a solar accumulator heat store.The retrofitting works were undertaken with the tenant in residence throughout.

This project is not located in a conservation area and, clearly, the insulation layer applied externally has changed the appearance of the house from the street. This approach sets the project apart from other London houses as the team did not need to overcome the hurdles of planning approval for retrofitting this Victorian terraced house. The team demonstrated that externally insulating a Victorian house with bay windows is possible and, while the streetscape is undoubtedly affected, the change was deemed acceptable by the client, given the radical improvement in the energy performance of the property.

The external insulation used was a non-structural cladding system, installed by an 'approved' specialist subcontractor and made up of a base coat, 100 mm of phenolic foam boards, 1,200 mm × 600 mm boards overlapping, a render base coat and a final decorative finish.

Choosing external wall insulation brought various benefits: it enables the occupants to remain in their house while the new insulation layer is being applied and technically, it enables all structural elements to remain within the thermal envelope, thus avoiding many potential cold bridges; complex airtightness junctions and concerns over interstitial condensation around timber joist ends. As a one-off, however, this approach still leaves cold bridges via party walls, but this could be avoided if the whole terrace was retrofitted.

The project raises the question of pragmatism versus cultural heritage and suggests that maybe, as a society, we need to decide whether this is a necessary compromise if we are to retrofit Victorian housing on a larger scale without having to incur the costs of relocating occupants each time.

Front facade pre-retrofit



Front facade post-retrofit



Internal ventilation ductwork



STRATEGY

FABRIC

To complete the upgrade of the thermal envelope of the house, the rear facade was also retrofitted with external insulation, adding an extra 120 mm of phenolic foam rendered boards, and the roof was insulated with a mix of measures including a 100 mm layer of rockwool within the ceiling joists, a 75 mm layer of phenolic foam between rafters and a layer of multifoil insulation with 25 mm air gap on both sides.

The suspended timber ground-floor has been insulated with applied sprayed foam. It was originally intended that the foam be applied via a remotely operated vehicle [ROV] procured from China, however administrative difficulties with banks prevented the purchase of the necessary equipment on time.

SERVICES

The way this property is designed is quite unique. The solar-powered heat storage system uses an experimental passive solar heating system combined with a thermal accumulator and a warm air distribution system. The choice of this solution was based on its future potential cost relating to economies of scale.

The heat demand of the house is kept low and is met partly by heat recovery from the MVHR unit, and partly via a connection of the unit to the two heat stores. It can also be topped up by an electric in-line duct heater. The hot water demand is met entirely by the solar thermal tube collectors connected to the heat stores, which are designed to keep three days' worth of hot water and help cope with days of poor solar radiation.

RENEWABLES

One of the key issues in utilising solar thermal power (and indeed most forms of renewables) is the variability of supply. Green Structures Ltd has developed a heat storage solution, incorporating phase change materials. They claim it will allow any solar energy to be used directly to contribute to the building's heating or hot water requirements, as with any conventional solar thermal installation, while contributing to longer-term heat storage. Once charged, the heat store (installed in the roof void) is designed to hold in excess of three days' requirement, thus buffering the supply against demand.

VITAL STATISTICS

The house is 'designed' to use 89 kWh/m^2/yr of primary energy, an 86% reduction from pre-retrofit. The 'actual' demand will largely depend on the balance between the performance of the system and how practical it is for the system to interact with it adequately. In this project, the tenant insisted on opening windows in winter months despite repeated attempts to explain that this would work against the building's insulated and airtight design, and that it would effectively guarantee no heating in the building. Consequently, the tenant received high electricity bills and decided to remediate the issue by turning off the system, apart from brief periods in the morning and evening when the immersion heater would run to provide hot water. This isolated the electrical supply to the loft and all the equipment therein including the in-line duct heater, the solar thermal system circulation pump, the BMS and, not least, its embedded data-logging system.

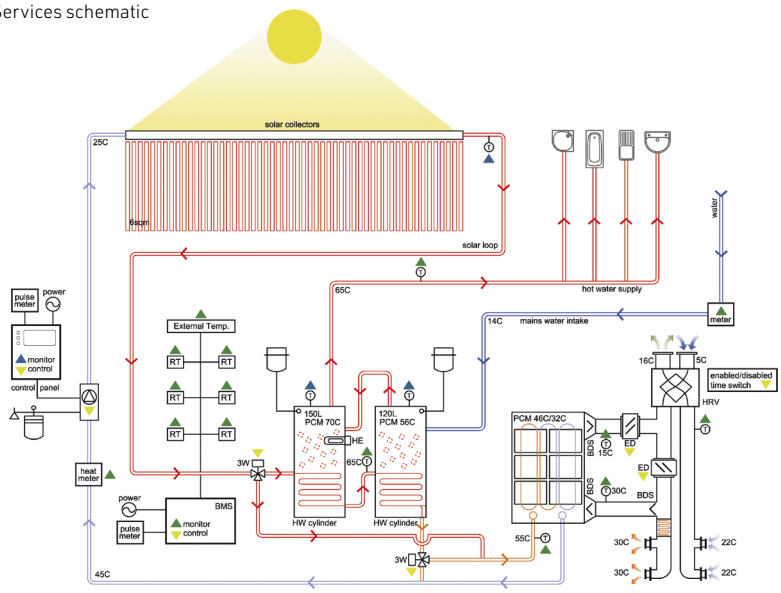
The design team however reported that the situation has much improved since and the occupant has become more understanding.

This case illustrates the impact occupant behaviour can have on energy use, comfort and satisfaction. Further research and design development to encourage behaviours and habits that reduce energy use is essential.

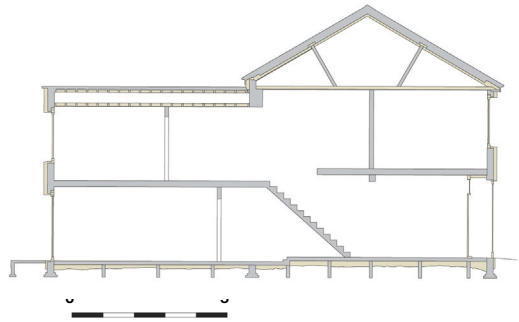
Vital statistics

Characteristics	Before	Target	Measured
Primary energy (kWh/m^2/yr)	634	89	–
Space heating (kWh/m^2/yr)	283	29	–
Airtightness (m^3/m^{2}h @ 50 Pa)	–	2	–
Type of glazing	single	triple	triple
CO_2 emissions (kg CO_2/m^2/yr)	–	17	–

Services schematic



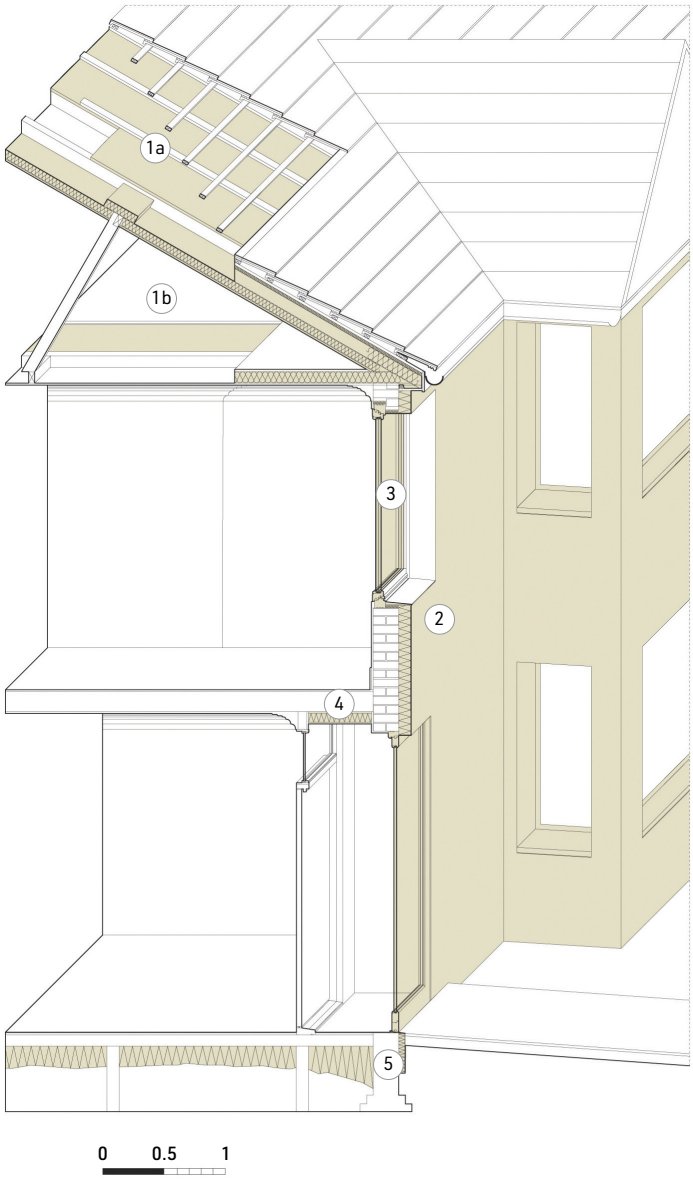
Fabric U-values post-retrofit (W/m^{2}K)



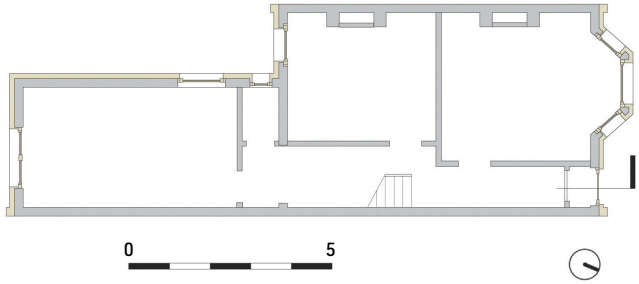
Thermal accumulator unit



Detailed section



Key ground-floor plan



1a ROOF
existing concrete tiles
roof felt
battens
counter battens providing 25 mm air gap
multi-layer insulation
existing rafters
airtight membrane
75 mm phenolic foam with plywood finish

1b ROOF (LOFT SPACE)
chipboard
100 mm mineral wool between joists
plasterboard

2 WALL
render
100 mm phenolic foam insulation
external insulation overlapping window frame by 25 mm
existing solid wall

3 WINDOWS/DOORS
new timber-frame triple-glazed argon-filled windows
new timber-frame double-glazed entry door

4 INTERMEDIATE FLOOR OVER ENTRANCE
plywood finish
75 mm phenolic foam insulation

5 GROUND
new floor finish
new floorboard
spray insulation foam
perimeter 50 mm external polystyrene foam cement rendered

FURTHER DATA

COST

Total cost was £227,900 all inclusive (VAT, monitoring, prelims, design and management fees, and some R&D for the thermal accumulator storage). Although the overall costs are alarmingly high, the costs associated with fabric improvements only are similar to many other projects. The high cost is largely due to the number of innovative systems estimated to have cost £51,900 overall, but those will hopefully inform future opportunities, following analysis of the monitoring data.

The team report that some costs could have been avoided by better planning, such as the relocation of the soil stack within the building envelope, which in this project led to the complete refit of the two toilets, bathroom and kitchen.

MONITORING AND COMFORT LEVELS

Period of monitoring: February 2011 – August 2012.

The relative humidity data show values for room 1 largely between 40% and 60%, with peaks up to 70% and troughs down to 30%. This graph illustrates much more varied measurements, as it has not been taken from averages, unlike most other projects here.

Temperatures vary between 18°C and 26°C for rooms two and three, while room one shows higher temperatures of up to 32°C in the peak summer months when the outdoor temperature reached 36°C. However, the temperatures overall are shown to be quite stable in comparison with outdoor temperature variations.

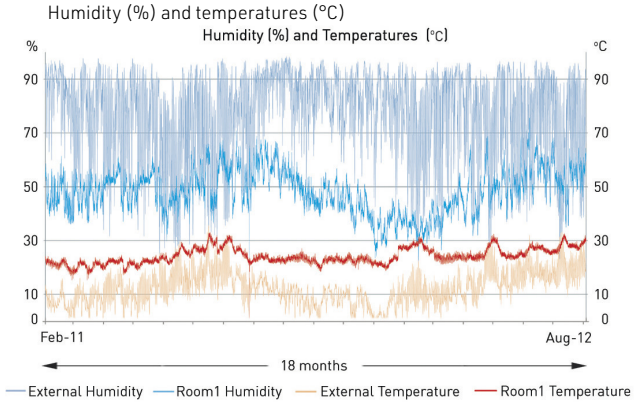
Costs 2010	
Fabric (insulation wall + ground + roof)	£35,700
Fabric (windows + doors only)	£11,000
Services (MVHR and ductwork + solar and boiler)	£43,000
Other costs for retrofit	£45,000
Subtotal	£134,700
Non-energy-saving measures	£23,000
TOTAL	£157,700

SPECIAL FEATURE

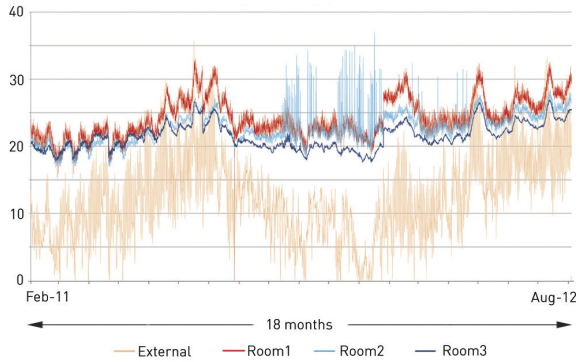
The aesthetic of the facade has been significantly altered: the sash windows have been replaced with tilt-and-turn timber casements and the existing brickwork covered with a rendered finish for the bay windows and timber cladding for the main facade. This creates a somewhat bold architectural statement version of the Victorian aesthetic that, applied on a whole-street scale, may be an option worth considering to revitalise old streets in non-conservation areas and create comfortable homes that are affordable to heat with minimum disruption and reduced technical challenges.

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

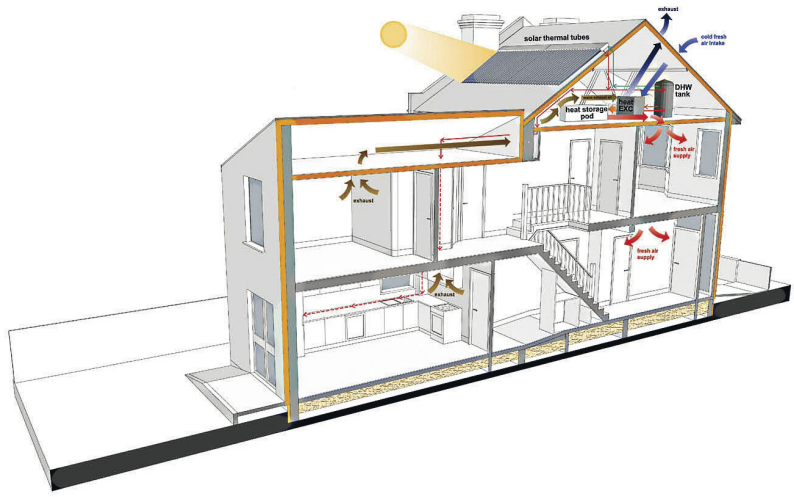
Humidity (%) and temperatures (°C)



Temperature (°C)



Whole house/external wall insulation and services



Culford Road

Pre-1919
(not part of Retrofit for the Future)

Internal floor area: **106 m² (pre-building works)**
121 m² (post-building works)

Primary energy
pre-retrofit calculated: **357 kWh/m²/yr**
post-retrofit measured 2010: **77 kWh/m²/yr**
(PV contribution excluded)

Energy Use Intensity post-retrofit measured 2024:
post-retrofit measured 2024: **51 kWh/m²/yr**

Client: **Dr Robert Cohen and Ms Bronwen Manby**

Architect: **Prewett Bizley Architects**

Contractor: **Dave Manby**

Consultants: **Paul Jennings (airtightness tests)**

Front facade post-retrofit. The double glazed sash windows were carefully designed to match the originals, but provide very good airtightness



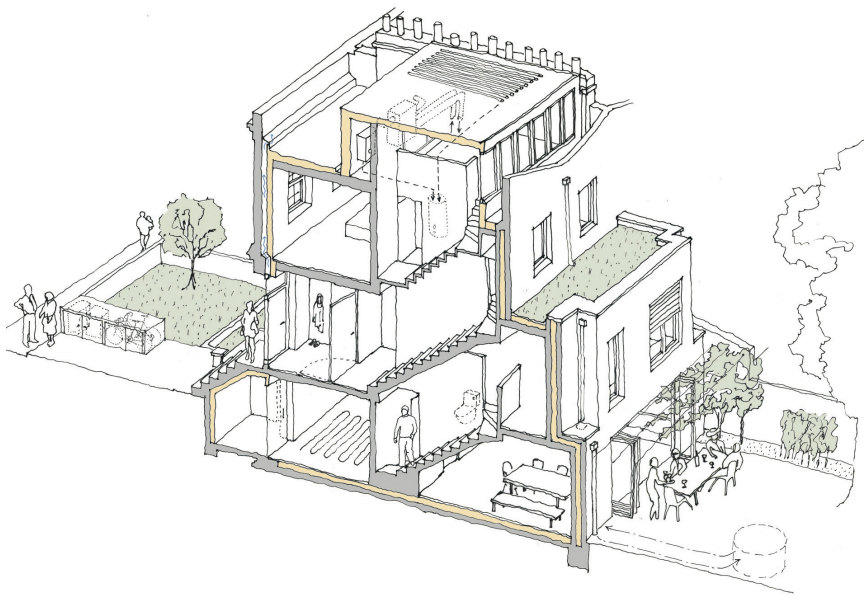
This project was designed in 2007 for a private client who wanted to see if an 80% carbon reduction was possible. Situated in De Beauvoir Town, Hackney, London this mid-terrace house was constructed around 1830 according to a masterplan characterised by wide streets and short terraces of houses. The area became a conservation area in the 1970s. The house was reorganised internally and externally with extensions at roof level and at the rear of the house. Energy-saving measures included internal insulation to the front facade, new super-insulated cavity walls to the rear, double and triple (where possible) glazing, an MVHR system, a photovoltaic array and an efficient gas boiler. On-site works commenced in 2009 following extensive negotiations with the local planning authority during 2008 regarding the full-width two-storey rear extension. The clients moved in at the start of 2010 and the solar PV was installed in March 2010. The owners occasionally open the house to visitors for open day events such as those organised by the Super Homes network.

Typically for developments of this period, the original house was planned very economically. Later additions such as WCs, bathrooms and boiler room had compromised the original layout and had led to some rooms, such as the kitchen, feeling rather dark. The client's brief, therefore, called for an improvement in the internal layout as well as making the property as energy efficient as possible. Both of these issues needed to be resolved while working within the constraints imposed by the conservation area guidance.

The team decided that the best way to address this dual challenge was to add a full-width – but only half-depth – extension at the rear at lower-ground and upper-ground-floor level. This had the advantage of adding just enough space and light to completely transform the existing rooms at the rear while adding minimal external surface area through which heat could escape. Similarly, the roof extension was built as a compact simple form so as not to be visible from the street.

The approach to achieving all this involved the demolition of the rear facade, the roof and all internal studwork partitions. This was seen as the most practical approach to avoid clogging the site with temporary works and ensuring maximum constructional quality and airtightness.

Whole-house insulation strategy – axonometric view



STRATEGY

FABRIC

The front elevation was left intact but insulated internally with a system of insulated studs (at the time being developed by Knauf) in-filled with glass wool and then clad with OSB and plasterboard. This system included two important features:

- A small ventilated cavity between the brickwork and insulation – to allow any moisture that may collect at this interface to evaporate out or drain out under gravity.
- The replacement of wall plates and bond timbers with concrete – to guard against cracking if these timbers were to decay.

Steel beams were installed at each floor level to support new floor joists, an approach that was deployed with greater refinement at Princedale Road. The new rear wall was rebuilt as a cavity wall with an aerated blockwork inner leaf, a 200 mm cavity fully filled with glass wool insulation and an external leaf reusing the original stock bricks. Insulation was added to the ground-floor (130 mm styrene) and to the roof (180 mm rigid PIR board). Foamglass blocks were installed at the base of cavity walls to avoid thermal bridges. The front windows were replaced with authentic replica sash windows that include real astragal bars only 20 mm wide. Individual panes of Slimlite double-glazed units (4 mm outer pane, 6 mm argon-filled cavity and 4 mm low-e inner pane, with warm edge spacer). The sashes had quadruple draught stripping which provided very good airtightness during the pressure tests. The front door was replaced with a highly insulated and airtight new door and the fan light above was triple-glazed. At the rear it was possible to install standard timber triple-glazed casements.

SERVICES

Space heating is provided by an underfloor system on the lower-ground-floor and by two towel warmers in the main bathroom on the first floor. Heating and hot water are generated by a condensing gas boiler.

Ventilation during the colder months is provided by an MVHR. The primary intake and exhaust ducts were kept as short as possible and were insulated using a flexible closed cell insulation. The distribution ductwork is very straightforward and economic in order to minimise pressure losses, noise and fan power.

Electricity is provided by both the national grid and roof-mounted photovoltaic panels.

RENEWABLES

The photovoltaic (PV) panels qualify for 25 years of feed-in tariff income. This modestly sized array (1.26 kWp) provides over two-thirds of the electricity use in the house (note: the vital statistics below ignore this contribution). While this is admirable considering the size of the house (120 m^2), this is partly predicated by a relatively low occupancy level of two working adults.

VITAL STATISTICS

An eventual airtightness value of 1.1 m^3/m^2h @ 50 Pa was recorded when the project was commissioned. The architect believes that this positive result is due to the following reasons:

- clear approach to the air barrier;
- level of stripping back before works began;
- a committed contracting team.

In all, four tests were carried out during the works, at each stage revealing areas for further work or making good.

Net annual utility costs are £100 less than the feed-in tariff income.

Vital statistics

Characteristics	Before	Target	Measured 2010	Measured 2023
Primary energy ($kWh/m^2/yr$)	357	134 (EnerPHit)	77	–
Energy use intensity (kWh/m2/yr)	–	–	51.3	51.2
Space heating ($kWh/m^2/yr$)	182	25 (EnerPHit)	23	–
Airtightness (m^3/m^2h @ 50 Pa)	10–15 (est.)	1.0	1.1	1.52
Type of glazing	single	triple	double/ triple	double/ triple
CO_2 emissions (kg $CO_2/m^2/yr$) operational	65	–	9 inc. PV	–

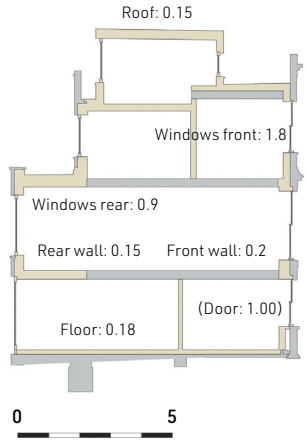
Internal view during site works, showing just how extensive the works were



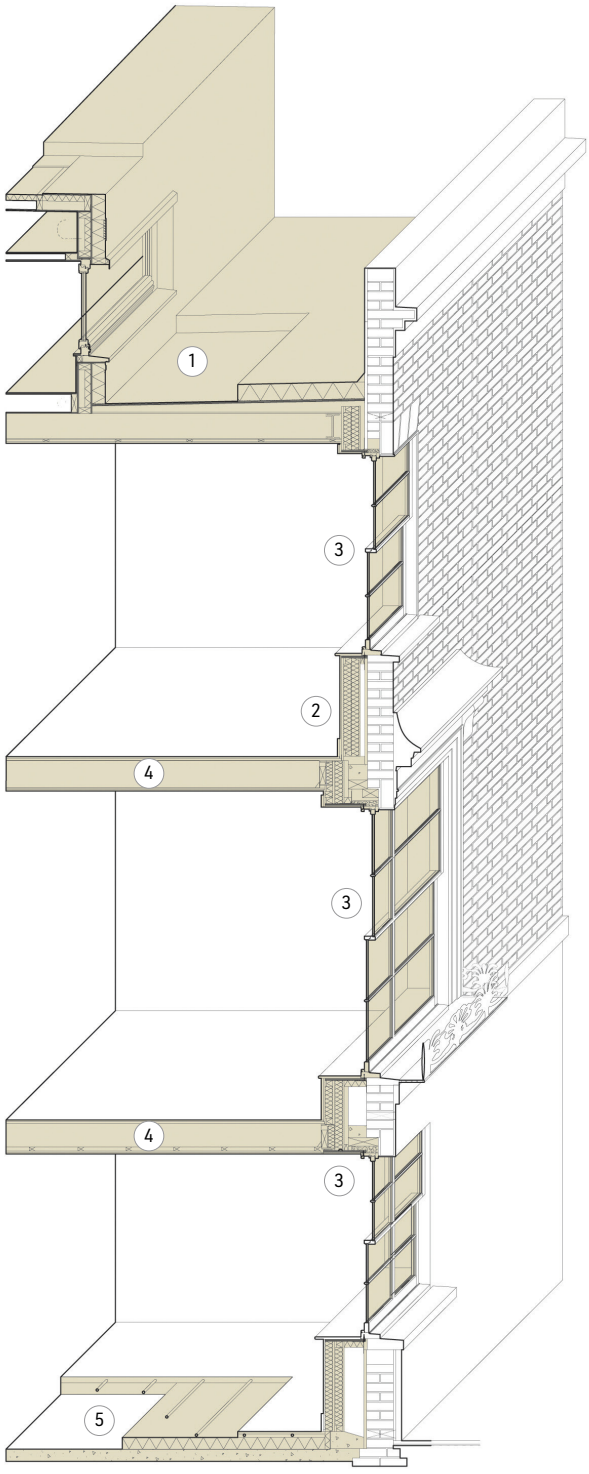
MVHR on top floor level



Fabric U-values post-retrofit (W/m^2K)



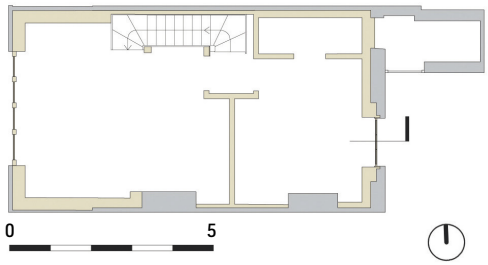
Detailed section



0 0.5 1

CULFORD ROAD
1:50

Key lower-ground-floor plan



1 ROOF
EPDM rubber waterproof membrane
180 mm rigid urethane insulation; 50 mm insulation to upstands
polythene vapour barrier continued up masonry walls to bond with DPCs
plywood sheathing over 175 mm joists
12 mm OSB as airtightness layer
12 mm plasterboard ceiling on softwood battens with plaster skim

2 WALL
existing 330 mm stock brick wall with external stucco finish up to upper-ground-floor level
15 mm sand/cement render applied to inner face to seal gaps
minimum 25 mm air gap ventilated via weepholes and airbricks
25 mm aluminium top-hat sections screwed to brickwork at 400 mm centres
12 mm OSB sheathing
70 × 50 mm vertical rigid insulation spacer battens at 400 mm centres with 65 mm glass mineral wool insulation in between
18 mm OSB airtightness layer with all joints taped
70 × 50 mm horizontal rigid insulation spacer battens at 400 mm centres with 65 mm glass mineral wool insulation in between
12 mm OSB sheathing
12 mm foil-backed plasterboard internal lining with plaster skim coat

3 WINDOWS/DOORS
new bespoke softwood sliding sash windows with four seals at all sash edges. Micro-double-glazed units consisting of 4 mm outer, 6 mm argon-filled cavity and 4 mm low-e inner pane
window lining: 18 mm WBP plywood box fixed to outside of window frames on all sides prior to installation and sealed with two silicone beads. DPM liquid applied to rear face of plywood and window frames. Inside edges of plywood sealed to surrounding construction with airtightness tape. Expanding foam to fill all gaps between frame and masonry

4 FIRST AND SECOND FLOOR
150 × 20 mm T&G pitch pine recovered floorboards secret-nailed to plywood. 18 mm T&G plywood screwed to joists
203 × 102 mm × 23 kg UBs (universal beams) spanning between party walls
new joists fixed to UBs with joist hangers to eliminate cold bridge
two layers 12 mm plasterboard ceiling on softwood battens with plaster skim coat

5 Ground-floor
existing floor removed and ground excavated 150 mm
20 mm slate screed replacement tile finish
30 mm extruded polystyrene insulation with clip-in underfloor heating pipes
100 mm extruded polystyrene insulation
liquid applied DPM
150 mm reinforced concrete slab with edge upstand to support wall lining

FURTHER DATA

COST

(Whole costs not available. Extra costs for energy reduction estimated below, next column.)

The costs for the energy efficiency measures have been prepared by the architect and do not include the builder's work costs associated with interior remodelling of the house.

He refers to a 'pioneer's tax' that early adopters pay. This includes:

- higher costs for some materials as they are still seen as specialist;
- delays on site caused by supply chain problems;
- slower than normal progress on site due to the novelty of some of the details and materials;
- extended period of making good in order to reach higher airtightness performance.

He expects costs for retrofit work to reduce as supply chains improve and contractors become used to new materials and construction methods.

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

MONITORING AND COMFORT LEVELS

Measured energy use indicates that the most significant energy savings are as a result of reduced space heating demand. An 83% reduction was recorded during 2011.

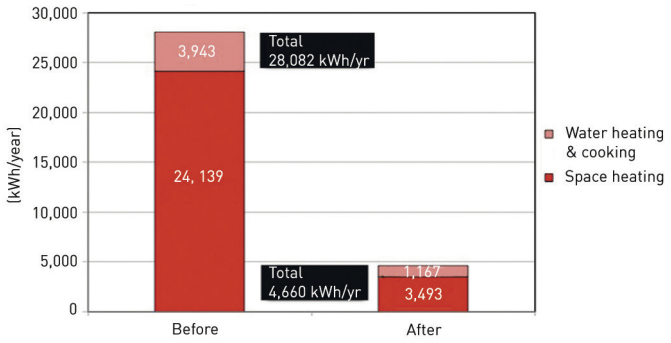
Further analysis indicates that energy use for hot water (and cooking on a gas hob) has been reduced from 3,940 kWh/yr down to 1,170 kWh/yr: a 57% reduction. This result is due to a combination of a lower than modelled occupancy level (2 rather than 3.5 adults estimated by the software) and the new hot water system (compact layout, high-efficiency condensing boiler, insulated tank with insulated pipework). Electricity use has been reduced substantially by the excellent daylight levels provided coupled with a low energy lighting design. Relative humidity has been very stable, and remained within a narrow range of 50% to 65%. Indoor temperature records are similarly stable.

Costs 2010	
Insulation to roof and ground-floor	£ 4,000
Insulation to walls	£ 16,000
Windows + doors	£ 11,000
MVHR	£ 5,000
Airtightness work	£ 12,000
Low energy lighting	£ 1,500
Product and works associated with cold bridging	£ 3,000
PV array	£ 7,500
TOTAL	£ 60,000

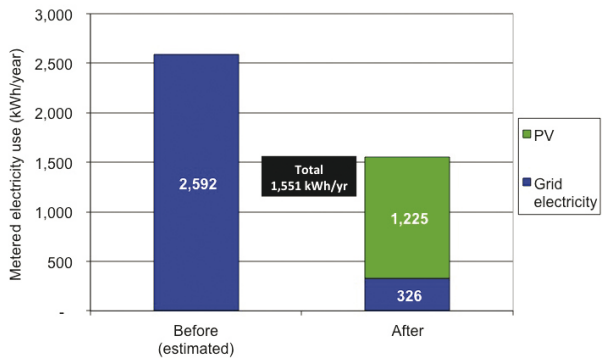
SPECIAL FEATURE

Unlike most of the other case studies presented in this book, this project was commissioned by a private client. Therefore, as well as energy-efficiency measures it also includes extension work and other reorganisation work. In this way it is perhaps a more typical retrofit scenario, where energy-efficiency work is triggered by other building work. Another characteristic that defines the project is the extent to which the client had to go in order to obtain planning permission. Due to the sensitive conservation area where the house is situated, an entire year was spent negotiating with the local authority before works could finally commence on site.

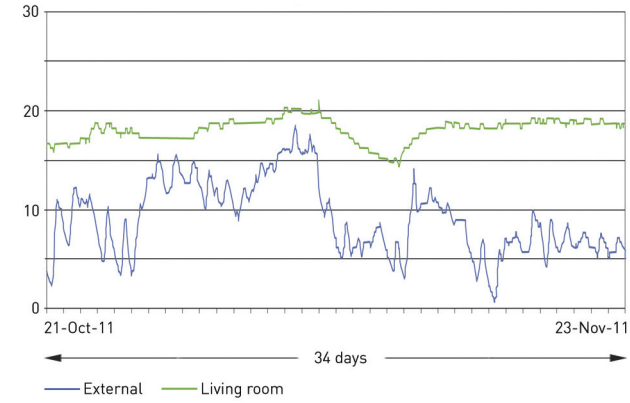
Metered gas use before and after refurbishment



Metered electricity use before and after refurbishment



Temperature (°C)



RETROFIT REVISIT:

Culford Road

SIGNIFICANT CHANGES SINCE THE ORIGINAL RETROFIT

Occupancy: Normally two, but only one for most of time since summer 2022.
Building: No significant changes.

ENVELOPE

Overall fabric performance: The very close correspondence between the PassivHaus PHPP model and measured gas usage over 12 years (25 kWh/m²/yr space heat demand measured compared to 26 kWh/m²/yr predicted) suggests that the fabric and ventilation system are performing well. Their performance is very close to the EnerPHit standard and well below the LETI target.

The smart heat transfer coefficient (HTC) measured assessment by Build Test Solutions Ltd (BTS) is also very similar to the HTC abstracted from PHPP, which further corroborates modelled to measured correspondence.
Airtightness integrity: Modest degradation over 13 years (q50 1.30 to 1.50 m³/m²h), which appears to be attributable to additional leakage associated with windows.
Further investigations: *In situ* U-value measurement of front wall showed 0.18 W/m²K, slightly better than calculated 0.2 W/m²K, possibly due to partially ventilated brick facade contributing to resistance while modelling.

Fungal/mould tests showed low spore count on the day of the visit before and after depressurisation. The report confirmed this and did not indicate any likelihood that mould was present within the IWI material.

A RH sensor was mounted into the IWI air cavity from March 2023. The sensor data shows that RH varies over the period between 70% and 90%, which appears to be following external ambient levels. Dew point is never reached, indicating that interstitial condensation did not take place during the study period.
Rectifications needed: Nothing significant save for common non-retrofit maintenance requirements such as cracked render to front parapet and a slow leak on a WC cistern.

SERVICES

Heating: Underfloor heating on the lower-ground-floor and the towel radiator in the bathroom on the first floor are very effective and these rooms exhibit a stable temperature that follows the thermostat. At upper-ground level, where there are no heat emitters, the temperature is a little more variable and usually a degree or two lower. The wireless heating control with an internet app has not worked well.
Hot water: Simple boiler and tank working effectively without problems.
Ventilation: While homeowners run the MVHR throughout the heating season they switch it off in summer (relying on natural ventilation) to save electricity. The system appears to be functioning well and quietly with no changes since installation 13 years ago.

ENERGY PERFORMANCE (AVERAGES OVER 12-YEAR MEASUREMENT PERIOD)

EUI: 51.9 kWh/m²/yr (meeting LETI target despite gas heating system with only 90% efficiency).
Heating demand: 25 kWh/m²/yr (lower than LETI target of 50) at 18.7°C.
Hot water demand: 10 kWh/m²/yr (interpolated by measurement of summer gas use).
Flue losses assumed to be 10%, so 4 KWh/m²/yr.
Electricity: 13 kWh/m²/yr (used on site ex PV).

PHPP suggests that if the temperature during the heating season were 20°C, an increase in the space heat demand of 4–5 kWh/m²/yr would be expected.

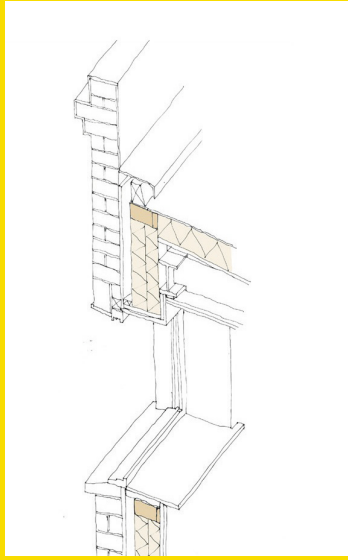
INDOOR ENVIRONMENTAL PERFORMANCE

Temperature: The March 2023 temperature record showed an average internal temperature of around 18.7°C. Previous data collected over winter 2016/17 showed an 18.5°C average, which was a period more representative in terms of occupancy. The living room and study on the upper-ground-floor have no heat emitters and the temperature varies a little more and on cold days, getting as low as 17.5°C, though the occupant does not find this uncomfortable.
Relative humidity: An average of 55%, but generally between 40% and 60% for 93% of time during the measured period. This is seen as very good.
CO_2 concentration: The CO_2 levels during March remain constantly below 1,000 ppm, indicating a very good air quality. The monitoring carried out from December 2016 to March 2017 showed similar continuous low levels of CO_2.

COMMENTARY ON PHYSICAL FINDINGS VS USER FEEDBACK

The homeowner describes the house as always feeling 'fresh', which aligns with CO_2 monitoring, very low fungal spore level count and low mould risk score. The rooms without heat emitters do tend to have greater amplitude of temperature variation than those rooms with radiators or underfloor heating. At the design stage, the architect believed that the MVHR might play a role in evenly distributing the heat around the house. In fact, the rooms without heat emitters tend to sit a degree or two lower in temperature than elsewhere, though it would be quite possible to add extras radiators to the existing system. The

Section though external wall showing IWI



homeowner has not done this as they find the existing arrangement quite agreeable and do not regard it as a problem. The freedom from drafts and absence of cool internal surfaces may predicate a feeling of comfort even with slightly lower air temperatures. On cooler days the client chooses to wear a fleece.

SERVICES STRATEGY

Hot water: The hot water is delivered using a system boiler with a tank. This has performed well. The hot water consumption of 1,200 kWh has been inferred by measuring gas use in the summer when no space heating is required. 1,200 kWh/yr for a two-adult house seems credible. Since the works, technology has evolved to allow excess electrical generation from PV to be directed towards hot water. In this instance, however, as the owners benefit from a 'feed-in' tariff for exported electricity, this has not been adopted.
Space heating: The space heating only has heat emitters in three spaces: the kitchen – underfloor heating (UFH); the lower front bedroom – UFH; and the first-floor bathroom – two towel rail radiators.

The system is powered by a Vaillant ecoTEC 612 condensing gas boiler (with weather compensation) that has a power output of 4.9 kW to 12 kW (now over 13 years old, though not showing signs of decreased efficiency).

The PHP model predicated the heat demand of the house was around 30 kWh/m²/yr (assuming an internal temperature of 20°C). Over 13 years, the average measured space heat demand is closer to 25 kWh/m²/yr. Measurements have shown that the average temperature internally is closer to 18.5°C. Adjusting the PHP model to account for this shows a predicted demand of 26 kWh/m²/yr.
Electricity: Measured data shows an annual domestic electrical use of 1,550 kWh/yr (13 kWh/m²/yr), which is quite low. This is partly due to occupancy by two adults only and their careful selection and use of appliances.
Ventilation: The house has an 'Itho' MVHR unit fitted in the loft extension with short insulated primary ducts. A rigid metal branch system of supply and extract ductwork has been fitted vertically between the historic chimney breasts. The PHP calculation indicated a performance of 88% heat recovery. The electrical consumption does not appear to have varied, and the unit has remained as quiet as when commissioned 13 years ago, indicating the fan motors and bearings have a long service life.
Air quality analysis: (December 2016–March 2017 and March 2023) looking at RH and CO_2 has shown consistently very good levels of air quality.
Renewables: In March 2010, shortly after occupation of the house, a 1.32-kW photovoltaic array was fitted to the flat roof of the loft extension, oriented south-east, inclined from the horizontal at 10 degrees (to limit its visibility from street). Very little overshadowing from chimney stacks occurs. Six panels produce around 1,200 kW annually.

USER FEEDBACK

Questionnaire findings (SOAP and BUS used): The user is very satisfied with the home and the survey findings were rated 'excellent'. The only exceptions were regarding the heating/hot-water controls, which were hard to manage, and the lack of opening windows in the kitchen (leaving the external door open for ventilation, which invites the curiosity of cats and foxes). They noted that, while the comfort level reduces at extremes of weather (hot and cold), it is still generally very good. During severe summer heat waves, the large areas of west-facing glazing on both the upper-ground and particularly in the top-floor study typically make it too hot from 3pm onwards. When it exceeds around 30°C indoors in these rooms, the cooler, lower-ground-floor makes an attractive retreat. When the outdoor temperature is above 35°C, the good cross-ventilation provides little relief. In general, the users consider the overheating in hot weather to be more of an issue than underheating in cold weather, which is easily resolved by an extra layer of clothing and is never so severe as to make desk work unviable.

BPE TECHNIQUES: LESSONS LEARNED

Description of the BPE approach: Building on previous data, including 12 years of energy data and several months of indoor air quality (IAQ) data, during March 2023 a series of additional BPE exercises were carried out. However, limited planning time and a short study period (due to funding deadlines and the need to capture a winter month) reduced the findings' scope and value.
Airtightness testing (blower door and Pulse): Blower door test and Pulse results seemed to align quite well. However, Pulse provides no indication on where leakage points are. Even blower door testing on 'tight' buildings, such as this, requires great patience to find leaks, or else the use of thermography.
Views on methodology: The Smart HTC method seems to provide quite an accurate assessment at a low cost or 'fuss'. It would be great to see this become commonplace at a large scale for building assessment.

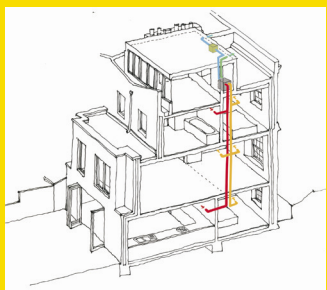
The Heat3D process seemed quite convincing and only required an hour of assessment time, which makes it very deployable and attractive. The confidence margins of around 0.1 W/m²K didn't suit this assessment so well but would be useful for assessing buildings with lower insulation levels (pre- and post-retrofit).

Internal wall installation showing a series of layers built up in situ

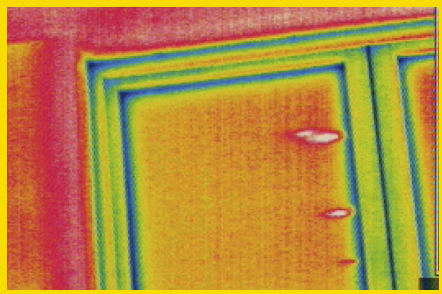




MVHR ventilation distribution



Thermography of part of patio doors at rear lower-ground level



CHAPTER 3

Post-1919

DOI: 10.4324/9781003585701-5

Cwmbach

Post-1919
TSB-10

Internal floor area: **74 m²**

Primary energy
pre-retrofit calculated: **678 kWh/m²/yr**
post-retrofit measured: **218 kWh/m²/yr**

Client: **RCT Homes**

Architect: **BRE (Andrew Sutton)**

Contractor: **Jistcourt (South Wales) Ltd**

Consultants: **Melin Energy, Lee Wakemans Ltd (costs)**

This semi-detached property is a pre-cast reinforced concrete construction that forms part of Cwmbach's Brynawelon Estate, and was probably built during the early 1950s. It is typical of the 30,000 or so Cornish Type 1 houses designed by Beresford and Tonkin and built by Central Cornwall Concrete & Artificial Stone Ltd. The retrofit strategy for this dwelling included external insulation throughout; an airtight layer behind the service void; an MVHR system; an air source heat pump; and triple-glazed window units to all walls. Novel features include a Tata Steel solar collector on the facades to provide pre-warmed fresh air. The external envelope and internal fabric of the adjoining house were retrofitted simultaneously in order to fulfil the planning requirements.

The house type was designated as 'defective' under the Housing Defects Act 1984 on account of widespread cracking in the concrete frame, as well as high levels of corrosion associated with carbonation and chloride ions. A previous refurbishment in the 1990s replaced the original concrete ground-floor cladding with an insulated masonry cavity wall, and the single-glazed windows were replaced with double-glazed uPVC units.

This retrofit saw not only a dramatic improvement in the building's performance, but also a significant change to the visual character of the property. The ground-floor external wall insulation is finished with brick slips throughout, which terminate at first floor. From the first-floor slab level up, metal cladding runs vertically as far as the adjusted eaves and gutter detail, where this matching coloured cladding is then used to provide a steel roof for the property.

From the earliest stages it was known that the refurbishment would not improve the performance of the ground-floor slab: the area beneath the slab was inaccessible, and the short floor to ceiling height above the slab would only allow the installation of the most nominal insulation thickness. The design team therefore proposed extending the external insulation layer vertically down to a depth of 500–600 mm below finished floor level. The intention was to lengthen the heat loss path and thereby reduce heat losses through the ground-floor slab, sometimes referred to as a 'thermal bubble'.

Front facade post-retrofit



Houses after demolition of the existing roof



Facade to ground junction with perimeter insulation



STRATEGY

FABRIC

The existing fabric was upgraded throughout. The original concrete frame posts and ring beam were retained, supported by a new layer of blockwork infill to create a vertical load path for the load-bearing floor slab (note: the existing outer layer of brick from the previous cavity wall was removed).
The ground-floor walls were insulated externally, fixed to the concrete frame and blockwork and clad with brick slips, with a band of render at window height to deal with coordination issues between the brick dimensions and window reveal locations. Concerns regarding airtightness and thermal bridging meant that the mansard roof had to be replaced with a 'traditional' vertical wall with pitched roof construction.
The airtightness strategy included a membrane and sealing tape installed in front of the concrete pre-cast planks and at the back of the service void, targeting and achieving a value of 1 m^3/m^2h.

SERVICES

Room temperatures are maintained by a combination of systems, including an efficient MVHR unit, an air-to-water heat pump and an innovative SolarWall®. In addition, two wet system radiators have been installed operating at a low temperature. Domestic hot water is stored in a 150-litre tank, where a coil connected to the air source heat pump initially brings the temperature up to 40–50°C. This is topped up to 60°C by an immersion heater.

RENEWABLES

A Tata SolarWall cladding system was used; it utilises solar radiation on the existing thermal mass of the structure to provide heat. It was installed on the side of the building at first-floor level and works in conjunction with an air source heat pump and thermal storage for the purpose of warm air delivery. When exposed to sunlight, the perforated steel warms up, creating a convection current in a small void behind. This solar collector in effect pre-heats the air for the heat pump, which then goes to feed the MVHR unit, picking up heat from the exhausted air in the normal way. This innovative unit is located at first-floor level, with access from both the landing and the master bedroom.

VITAL STATISTICS

The fabric upgrade strategy achieved a very efficient building envelope close to PassivHaus standard with U-values for the roof and walls at 0.15 W/m^2K, windows at 0.78 W/m^2K and external doors at 0.8 W/m^2K. Despite the constraints, the ground-floor slab edge insulation brought the floor's U-value down to 0.36 W/m^2K. SAP calculations indicate a 68.3% reduction in carbon emissions in comparison with the building's original performance. However, it must be clarified that this figure does not make any allowance for the contribution of the steel solar collector and is likely to be significantly higher. Monitoring of the collector's performance is in progress.

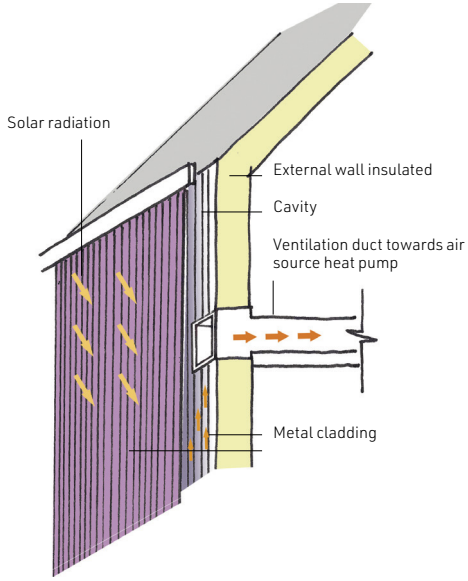
Vital statistics

Characteristics	Before	Target	Measured
Primary energy ($kWh/m^2/yr$)	678	91	218
Space heating ($kWh/m^2/yr$)	–	29	–
Airtightness (m^3/m^2h @ 50 Pa)	–	1	0.94
Type of glazing	double	triple	triple
CO_2 emissions ($kg\ CO_2/m^2/yr$)	125	21	44

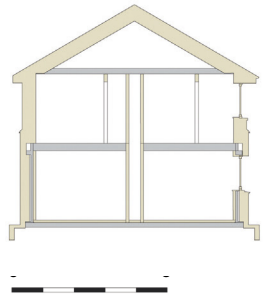
External wall insulation build-up



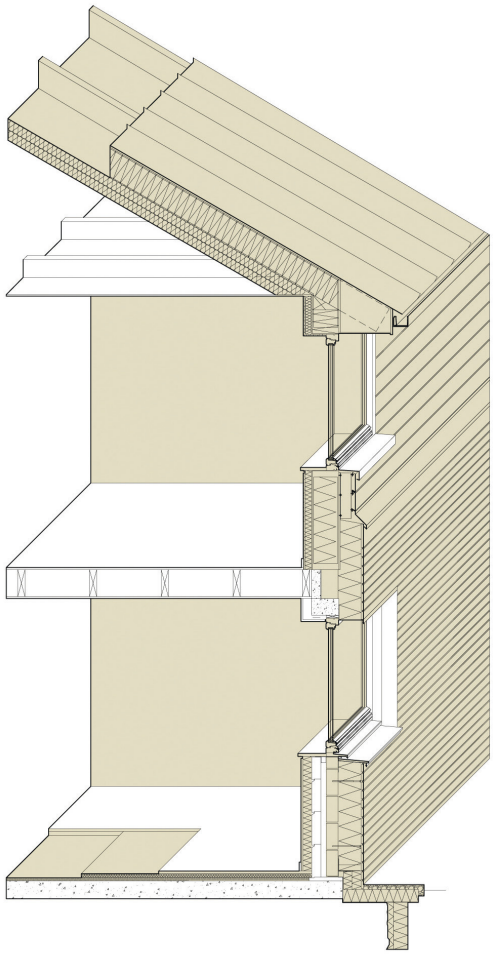
(Tata Steel) SolarWall pre-heating system



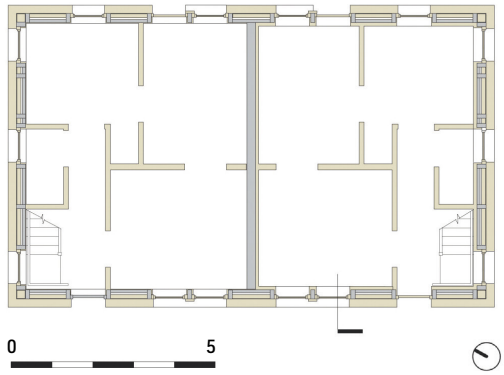
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
standing seam metal roof system
breather membrane
structural insulated timber roof panel
2 × 90 mm mineral wool insulation
vapour membrane

2a FIRST FLOOR WALL
steel cladding with slightly ventilated gap (SolarWall system) used for heat harvesting
20 mm brick slips, dual density insulation slabs (BrickShield®)
220 mm insulated timber panel
vapour barrier
50 mm rigid board insulation
15 mm plasterboard

2b Ground-floor WALL
20 mm brick slips, dual density insulation slabs (BrickShield®) fixed to
new medium density block wall
40 mm cavity
existing concrete infill panels
50 mm rigid board insulation
15 mm plasterboard

3 WINDOWS/DOORS
triple-glazed timber windows

4a GROUND INTERNAL
plywood
30 mm phenolic insulation bonded to plasterboard

4b GROUND EXTERNAL
blue engineering slips below starter channel
tanking membrane to edge of existing slab and returned up face of new blockwork at least 100 mm above horizontal starter channel
XPS insulation board laid to slight fall-away from house
vertical insulation XPS board 500 mm deep below ground level
polyurethane foam insulation infilling rough edge of existing slab to XPS insulation; minimum thickness of foam and XPS 200 mm

FURTHER DATA

COST

Costs were kept within budget overall. However, this followed considerable effort and redesign work after the initial detailed costing considerably exceeded the funding budgets. Some costs were higher than expected; certain manufacturers insisted that their approved installers receive a higher cost than would have been the case with a normal tender if the contractor had been able to use his usual subcontractors. Other unexpected costs were incurred with the discovery of bats in the building, leading to the development and installation of bespoke bat boxes: a new design integrated behind the first-floor cladding. A bat licence was required for these works, which caused delays to the project. The team reported that undertaking the more detailed bat survey earlier in the design development would have enabled faster progress through the statutory requirements and faster delivery on site.

MONITORING AND COMFORT LEVELS

Monitoring data was not available it may be available on: www.ukgbc.org/resources/retrofit-for-the-future-innovate-uk. Please refer to the website for more information on monitoring and measured comfort levels.

Costs 2010	
Fabric (insulation wall; ground; roof; windows; doors)	£68,591
Services (MVHR; ductwork; solar; boiler)	£20,376
Other costs for retrofit	–
Subtotal	£88,967
Non-energy-saving measures	£54,372
TOTAL	£143,339

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

SPECIAL FEATURE

If brick slips are to be used as a finish over external insulation, their integration with window openings needs to be worked out very early on in the design process. Even where existing openings have been constructed to brick dimensions, the addition of external insulation will normally change the opening size and this will have a knock-on effect on how the new finish is set out. If an acceptable detail cannot be identified for this then brick slip finishes should be avoided.

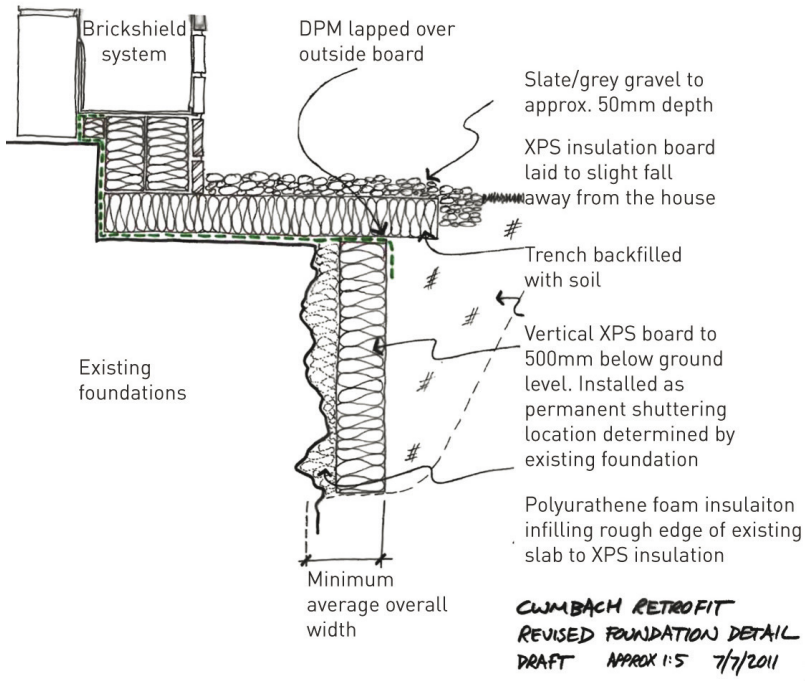
Brick slips applied to external wall insulation



Front elevation with brick slips and render finishes



Foundation detail with perimeter below ground insulation



Byron Square

Post-1919
TSB-25

Internal floor area: **82.6 m²**

Primary energy
pre-retrofit calculated: **321 kWh/m²/yr**
post-retrofit measured: **231 kWh/m²/yr**

Client: **Cambridge City Council**

Architect: **PRP Architects**

Contractor: **Hill Partnerships**

Consultants: **Gawn Associates**

This three-bedroom semi-detached house is located in Cambridge. Constructed in 1947, the property is one of the 34,000 or so British Iron and Steel Federation houses built in the UK following the Second World War. The project sets a useful precedent by demonstrating the capacity of this type of house for accommodating energy-saving measures. The measures implemented are numerous and include some internal/external insulation and triple-glazed windows for the fabric, and a condensing boiler combined with a flue gas heat recovery unit, LED lighting, a waste water heat recovery system, a mechanical extract ventilation system (MEV), and photovoltaic and solar thermal panels for the services. Efficient appliances and an energy display system were also installed for additional user awareness and control of energy systems.

The house is of light gauge steel frame construction with a solid ground-floor and tiled roof. The original walls were clad with render-on-mesh at ground-floor level and with profiled steel sheeting around the first floor; the original steel-framed windows had been replaced with uPVC double glazing in the late 1990s.

Despite being of interest because of the post-war circumstances in which it was built, the property was not considered to have any special architectural significance and external alterations were considered acceptable as part of the retrofit strategy. The fabric upgrade in this house was extremely effective due to the poor performance of the building fabric pre-retrofit.

Taking thermal images before a retrofit can be a valuable exercise to help visualise energy loss through the fabric. Thermal images simply record the temperatures of surfaces. They are often used to identify different rates of heat loss through walls, lighter tones indicating higher heat loss and darker tones the better-insulated elements. However, care needs to be taken in setting up and analysing thermal image surveys to make sure that extraneous factors are taken into account or excluded as far as possible. In this case, the first-floor cladding is shown to be warmer than the ground-floor walls. This was the result of afternoon sun on the metal cladding rather than a difference in insulation levels in the walls.

Front facade post-retrofit



Front facade pre-retrofit



Thermal image of front facade pre-retrofit



STRATEGY

FABRIC

The external walls were upgraded with external wall insulation (phenolic foam) with rendered finish. The ground-floor was fitted with phenolic foam, and the existing roof insulation was retained and topped up with 70 mm phenolic foam on top and a foil-backed plasterboard was positioned on the first-floor ceiling.

The uPVC double glazing was replaced with Sheerframe uPVC triple-glazed units with a low-e coating and a solar factor 'g' of 0.6 and subsequently achieve very low U-values (ranging from Uw 1.78 W/m^{2}K to 0.98 W/m^{2}K). The windows were repositioned further forward to be in line with the external layer of insulation in order to avoid any significant thermal bridges.

Despite the fact that there is no mechanical ventilation system for the whole house but only distributed mechanical extract ventilation (MEV), the windows were not fitted with trickle vents. It is apparently acceptable to omit the trickle vents under Part F of the Building Regulations, provided that the MEV system draws enough air flow into the house and that air permeability is greater than 3 m^3/m^{2}h @ 50 Pa. However, it seems directly contrary to the mantra of 'build tight, ventilate right'.

SERVICES

Heating and hot water are provided by a condensing gas boiler (fitted with a passive flue gas heat recovery unit (photo below). Other elements installed were: a roof-mounted solar thermal panels and a wastewater heat recovery system fitted to the bath wastewater pipes.

The heating system is based on the existing network of radiators retrofitted with room thermostats and TRVs to allow a degree of zone control.

Fresh air ventilation is driven by a distributed MEV system in wet rooms and the electricity requirements are supplemented by a roof-mounted photovoltaic array.

RENEWABLES

A passive flue gas heat recovery unit from Zenex was installed at the top of the boiler. This small box unit aims to recover the amount of heat lost by the gas boiler through the flue outlet, capture it, and use it to help pre-heat hot water for domestic use via a series of coils. This is an entirely passive system and designed to require no maintenance.

The photovoltaic and solar thermal panels used were chosen because of the identical appearance of the two types of panels, therefore offering a coherent external appearance.

The manufacturer (Viridian) developed a strategy for the installation of these panels where all electrics, plumbing, roofing and suchlike are carried out by specialists rather than by a sequence of trades. This allows clear division of responsibility between the roofing and electrical contractors during installation, a helpful set-up for small and sometimes complex retrofits as the market expands.

VITAL STATISTICS

The building envelope has been significantly improved, offering U-values near PassivHaus standard except for the ground-floor, which was more difficult to upgrade. The thermal bridges through the external fabric were partially addressed, the external insulation layer helping to overcome these issues together with a thinner layer of internal insulation effectively encasing the steel structure. It is particularly important to design out thermal bridges in steel frame construction, the thermal conductivity of steel being extremely high at 43 W/mK, compared to 0.14 W/mK for timber.

Vital statistics

Characteristics	Before	Target	Measured
Primary energy (kWh/m^2/yr)	321	165	231
Space heating (kWh/m^2/yr)	–	79	–
Airtightness (m^3/m^{2}h @ 50 Pa)	13.58	5	12.51
Type of glazing	double	triple	triple
CO_2 emissions (kg CO_2/m^2/yr)	62	32	37.1

Roof insulation installation in progress

Roof-mounted photovoltaics

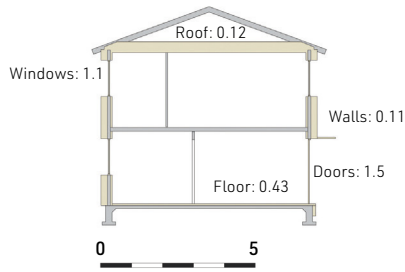




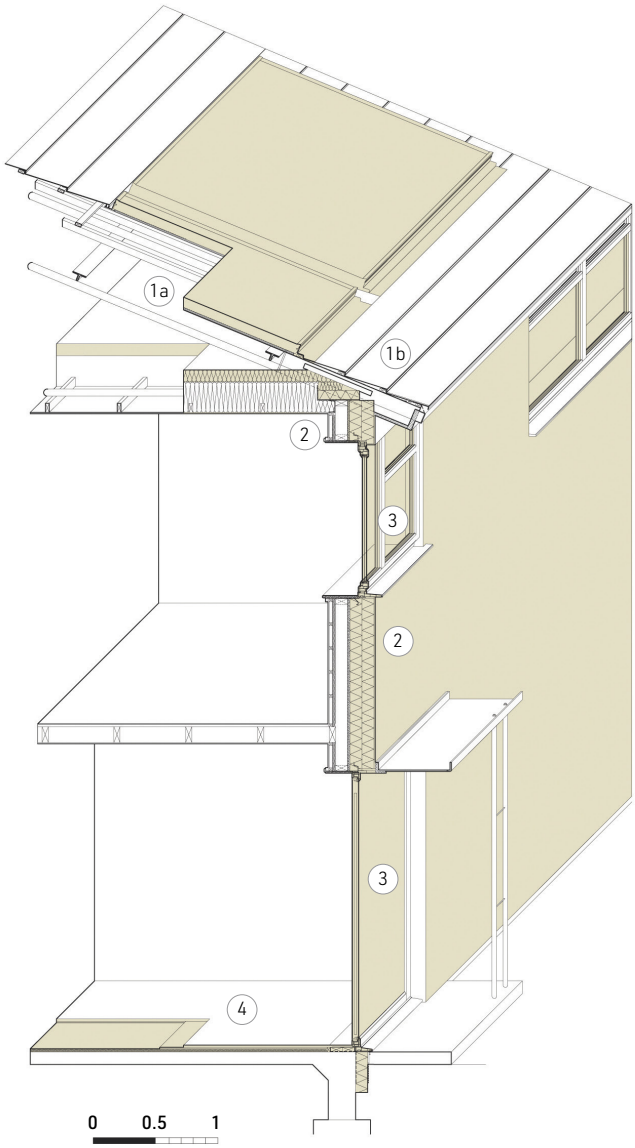
Passive flue gas heat recovery unit mounted on boiler exhaust flue



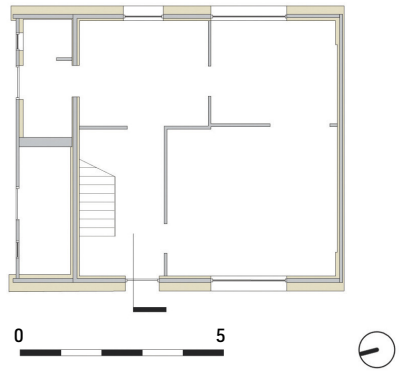
Fabric U-values post-retrofit (W/m^{2}K)



Detailed section



Key ground-floor plan



1a ROOF (from top to bottom)
PV panels
existing metal roofing panels retained
existing tubular steel truss retained
new 100 mm mineral wool insulation
existing 75 × 32 mm joists with 250 mm existing mineral insulation retained
new 10 mm plasterboard with 3 mm plaster skim

1b ROOF – EAVE
existing roof tiles were lifted to enable the installation of a:
new rafter ventilation tray
new 70 mm phenolic foam insulation (effectively joining roof and wall insulation)

2 WALL
new thin coat through colour render
new 200 mm phenolic foam insulation
12 mm sheathing board
vapour control
existing 100 mm BISF steel stanchions with new softwood framing within depth of steel to provide max. 600 c/c fixings for sheathing board
existing 25 × 50 mm timber frame with 25 mm mineral wool insulation
10 mm plasterboard
3 mm plaster skim

3 WINDOWS
new triple-glazed windows

4 GROUND
existing 100 mm concrete slab
new 25 mm softwood battens with 50 mm aerogel insulation in cavity
T&G MR floor-grade chipboard

FURTHER DATA

COST

For the building services, the conventional system accounted for £9,755 of the cost and the low/zero carbon technologies for £29,725. This reflects the aim of the programme: to encourage the implementation of innovative measures for testing purposes and to learn from the most efficient of them.

Costs 2010	
Fabric (insulation wall + ground + roof)	£63,070
Windows + doors	
Services (MVHR and ductwork + solar and boiler)	£29,725
Other costs for retrofit	
Subtotal	£92,795
Non-energy-saving measures	£5,875
TOTAL	£98,670

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

MONITORING AND COMFORT LEVELS

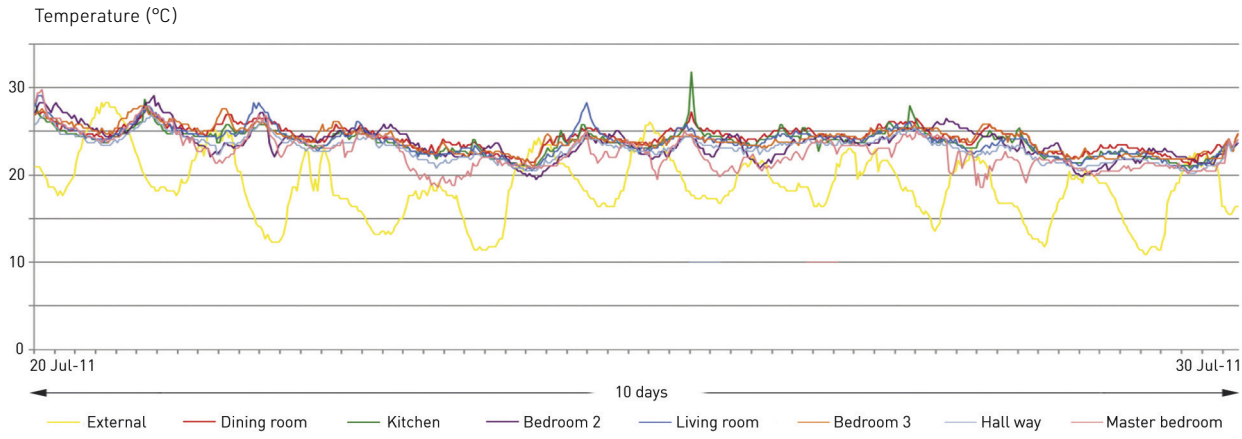
The monitoring over ten of the warmest days of the year in July 2011 illustrates fairly stable and comfortable internal temperatures in comparison with external temperatures, the internal spaces only varying from approximately 20°C to 30°C while the outside fluctuated between approximately 13°C and 36°C. The retrofitting of a thick layer of insulation acts as a thermos in hot weather and seems to do a great job at keeping the heat outside in this project.

While the total time over 25°C (internal comfort is considered 'not comfortable' above this temperature) appears to be fairly low, it would be interesting to know the proportion of time over the whole year that it represents. The PassivHaus standard considers a temperature of over 25°C for 10% of the year acceptable while CIBSE has a more complex calculation in Guide A/TM36, which limits temperatures to 28°C in living rooms and 26°C in bedrooms for more than 1% of the annual occupied period (depending on the type of occupants, elderly or family, etc.).

SPECIAL FEATURE

After completion of the project, the contractor was keen to provide feedback on what could be improved for the delivery of future retrofit projects. Their recommendations included the following:

- Try to appoint a single organisation for the provision of integrated systems such as heat distribution and controls to avoid complicated responsibilities and maintenance contracts.
- Product research and pre-orders should be carried out very early on to prevent any delays in a project of this type where duration on site has to be kept to a minimum. This also applies to the research into potential suppliers.
- The team tried to keep the tenants in situ for as long as possible. This proved to be very stressful for tenants and contractors alike. While it is difficult to temporarily relocate occupants of any house, it is in the best interests of all parties that works are carried out as quickly as possible and that the occupants are exposed to as little disturbance as possible, so relocation is sometimes advisable.



Street elevation post-retrofit



Lynton

Post-1919
TSB-68/69

Internal floor area: **71 m²**

Primary energy
pre-retrofit calculated: **663 kWh/m²/yr**
post-retrofit measured: **188 kWh/m²/yr**

Client: **North Devon Homes**

Architect: **Clive Jones Architects**

Contractor: **RR Richardson Ltd**

Consultants: **Energy Action Devon; Warm Low Energy Building Practice; Curtins Consulting**

This project, located within Exmoor National Park, dealt with a pair of two-bedroom two-storey houses built in the 1930s. Their original walls were made of clinker concrete poured *in situ* between asbestos shuttering. They were fitted with uPVC double-glazed windows and had some loft insulation. There are 1,060 houses in the UK built with this system, called 'Universal Construction'. One of the aims of the project was to find a way to retrofit these houses that could be repeated elsewhere. The principles of this retrofit followed the PassivHaus criteria and included a thick layer of external wall and roof insulation, an MVHR ventilation system and a wood pellet boiler to provide space and water heating for both houses.

Retrofitting these 1930s concrete-wall constructions presented some particular challenges. To address the poor thermal performance of the concrete building fabric, the design team decided to insulate externally in order to maintain the thermal mass of the concrete internally, providing 'inertia' against temperature fluctuations.

After investigating an I-beam system for the walls and also the roof, a standard system of timber studs and additional rafters was chosen as a cost-efficient way of containing the insulation thickness.

The sequence of installation consisted of installing OSB boards, creating openings for windows, constructing the timber stud frame, covering with a hardboard and blowing in Warmcel insulation (recycled newspaper, chosen to minimise the environmental impact of the project). Finally a breathing membrane wrapped the external insulation system, and installed cladding with local cedar.

This new layer was tied back to the existing concrete walls with low heat transfer wall ties (Teplo basalt-fibre wall ties) that were specially engineered to be fixed to both the new timber frame and the existing concrete walls (photo below right).

Overall, the new walls achieved a thermal performance with a U-value below what would usually be required to achieve PassivHaus standard. In fact, a layer of 300 mm would have been sufficient, but due to the prototype nature of the project the team decided to increase the overall thickness to 350 mm because of uncertainty over the quality of the workmanship.

Front facade post-retrofit



Front facade pre-retrofit



Low heat transfer wall tie



STRATEGY

FABRIC

The entire fabric of both houses was significantly upgraded. The external walls and the roof were retrofitted with 350 mm of insulation, and the existing concrete floor was removed and replaced with a new floor incorporating 255 mm of insulation. As commonly occurs when combining both external insulation and internal floor insulation, a cold bridge was created around the foundations. To remediate this issue, a trench was dug around the perimeter of the house as much as possible to install a vertical layer of insulation specifically chosen for use below ground. Due to a large amount of concrete placed under the building it was not possible to create a trench all around the house and so an area of cold bridge remained.

The windows were also upgraded from uPVC to new timber-framed triple-glazed windows to prevent further heat loss and offer a comfortable surface temperature on the internal glass pane.

SERVICES

Due to the relative isolation of the house in the middle of Exmoor National Park, no grid gas connection was available. After first considering solar thermal in combination with an air source heat pump, the team decided to opt for a biomass boiler (2–8 kW 90.5% efficient) after considering that the poor solar radiation reaching the site (due partly to overshadowing and partly to local climate) would not make the solar thermal panels an efficient and viable solution. The biomass boiler and 500-litre hot water cylinder to serve both houses were installed in an adjacent, purpose-built plant room by a local contractor who is also able to provide ongoing maintenance.

The ventilation is provided by an MVHR unit located within the roof void. It was installed by local subcontractors, and commissioned by the Green Building Store.

RENEWABLES

Environmentally, choosing a biomass boiler to provide space heat and hot water comes with some drawbacks. This system uses renewable fuel (timber); however, the wood pellets are currently sourced from Austria so have a significant carbon footprint (but one that the team established was far lower than using equivalent fossil fuel energy). The pellets need to be made to a precise specification, but it is hoped that they can be produced locally in the future. The carbon emissions from the heating system are predicted to be 150 kg/yr, approximately 10% of the refurbished house's annual CO_2 emissions.

VITAL STATISTICS

Considering the very high primary energy demand of the pre-retrofitted house (663 kWh/m²/yr), there was good scope for an important reduction in energy demand. The primary energy demand target set by the team was 77 kWh/m²/yr, taking into account the particular constraints of the house: for example, the floor perimeter's cold bridge. This target is well below the PassivHaus standard criteria for maximum primary energy demand set at 120 kWh/m²/yr. Upon receipt of the monitored data, the 'measured' primary energy demand of the house was found to be above target at 201 kWh/m²/yr, still 70% lower than pre-retrofit.

Vital statistics

Characteristics	Before	Target	Measured
Primary energy (kWh/m²/yr)	663	77	188
Space heating (kWh/m²/yr)	–	12.9	–
Airtightness (m³/m²h @ 50 Pa)	8.5	–	1.1
Type of glazing	double	triple	triple
CO_2 emissions (kg CO_2/m²/yr)	157	9	40

Timber-framed triple-glazed windows



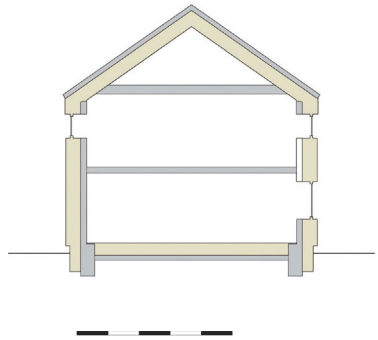
Hot water cylinder



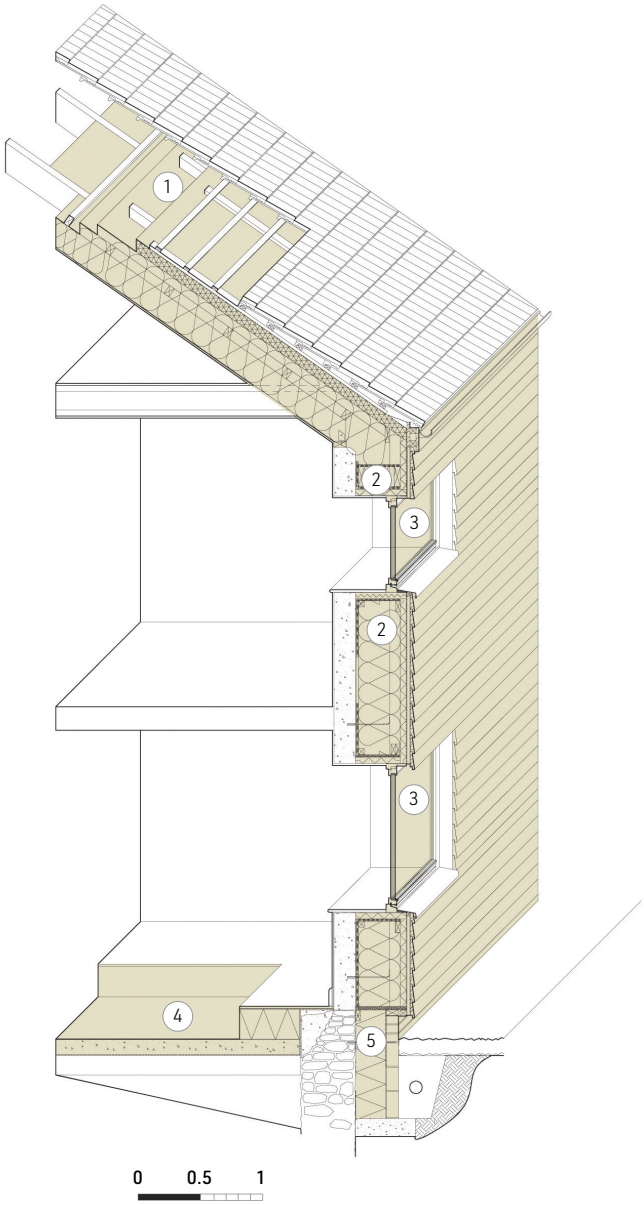
Plant room with biomass boiler



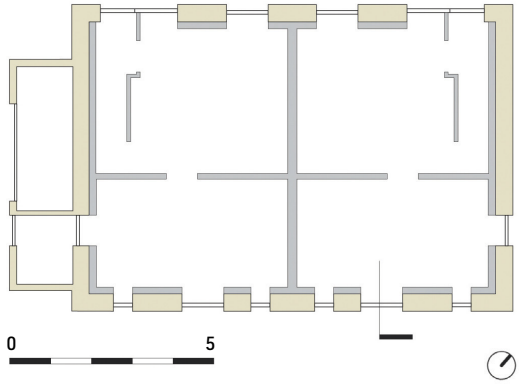
Fabric U-values post-retrofit (W/m²K)



Detailed section



Key ground-floor plan



1 ROOF
original roof tiles
38 × 25 tiling battens on 38 × 25 counter battens
breathable membrane
new 80 mm wood fibre insulation
new double rafter truss
new 350 mm cellulose fibre thermal loft insulation between rafters
vapour barrier
12.5 mm plasterboard and skim

2 WALL
new shiplap boarding on 50 × 25 battens
breathable membrane
new 50 mm wood fibre insulation board
new vertical lightweight timber frame with 350 mm cellulose fibre insulation
18 mm OSB screwed and glued to wall
wall ties resin anchored into concrete wall and secured at outer edge with metal plate
existing concrete wall

3 WINDOWS
new triple-glazed, argon-filled windows

4 GROUND (INTERNAL)
internally, new 22 mm chipboard flooring T&G
new 255 mm extruded polystyrene insulation
new 125 mm concrete slab on sand blunded hard core

5 GROUND (EXTERNAL)
perimeter insulation rigid polystyrene board 250 mm thick/800 mm deep

FURTHER DATA

COST

To explain the costs, the team produced a pie chart illustrating the main expenditures. The energy-saving measures (including a heating and hot water system; an MVHR system; windows and doors; airtightness and insulation) represent 25% of the cost of the project with general build and structure together representing 54%, other items being consultancy fees, asbestos removal and monitoring. This is not to be taken as a 'typical chart' applicable to other projects as the design strategy decided by the team included a full stripping-out of the property (including the roof), which incurred considerable general build costs that would not otherwise be necessary on other projects.

Also, some R&D costs were incurred (such as adapting the Teplo-Tie), which would not be required for any future projects involving this type of house.

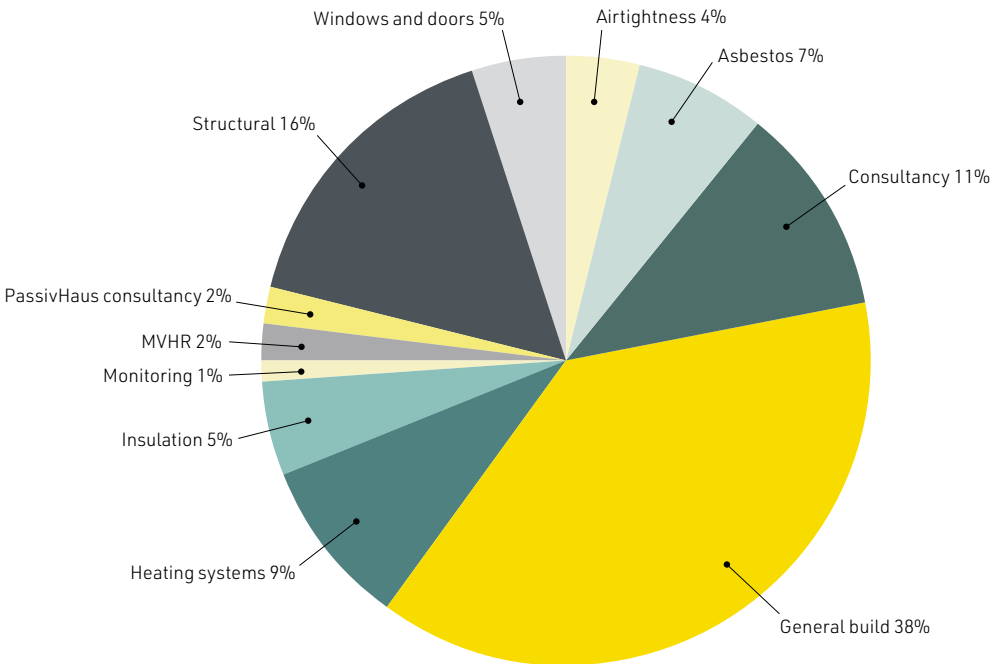
MONITORING AND COMFORT LEVELS

Monitoring data is not currently available but will be eventually uploaded on the www.ukgbc.org/resources/retrofit-for-the-future-innovate-uk website. Please refer to the website for more information on monitoring and measured comfort levels.

SPECIAL FEATURE

In the spirit of the Retrofit competition, which aims to kick-start the market and heighten the skills of the UK construction industry, the design team chose a main contractor that had no previous knowledge or experience of low energy building. While the project was delivered successfully, tensions between different parties arose during the construction due mainly to communication issues. In these R&D projects, it is essential that the whole team work well together. This can be facilitated by the presence of an expert project coordinator, a 'profile' currently being defined by the RIBA and AECB. The coordinator would be someone with good overall knowledge of the specific challenges that retrofit projects face, who can assist and ensure that the various parties work together towards a common and coherent target. This role is gradually developing; it is a major piece of the puzzle in many projects and could help future retrofit projects be delivered more smoothly.

Budget breakdown



Somerton, Newport

Post-1919
TSB-60

Internal floor area: **75.2 m²**

Primary energy
pre-retrofit calculated: **620 kWh/m²/yr**
post-retrofit measured: **160 kWh/m²/yr**

Client: **Charter Housing Association**

Architect: **Design Research Unit of the Welsh School of Architecture (DRUW)**

Contractor: **Charter Building Maintenance**

Consultants: **Structural engineer wL² Ltd**

This two-bedroom end-of-terrace house located in Newport was built in 1989 with cavity wall construction. Its retrofit was managed by the Welsh School of Architecture at Cardiff University and therefore the research had a particular academic focus. The aim was to ensure the process of the project could be used in the mainstream and did not rely on technical 'fixes'. The team deliberately avoided the need to make a planning application and decided to keep the tenant in residence. The measures adopted were agreed by all stakeholders, including the landlord and tenant, and fitted in with existing collaborative framework suppliers and maintenance practices. Energy-saving measures included internal wall and roof insulation, a new extension (sunspace) built with SIPs panels, a ground source heat pump, an MVHR, photovoltaic panels, solar thermal panels and a sun tube. All of these measures are seen as different from the norm within the social housing sector.

The construction industry is just beginning to grasp the supply chain involved in retrofit to minimise waste, improve efficiency and avoid problems, in particular the delays that can disrupt a tight programme. This is generally one of the most challenging parts of a construction project, and on a small-scale R&D project with a fixed budget and programme and in situ tenants to deal with, managing a network of organisations, different processes and activities becomes an even more sensitive issue.

As this was a new type of project, all parties involved had to find new ways of working together. To this end, the project was carefully structured with a framework partner to help in the negotiations, and a collaborative contract was set up with Micaul Solar Limited, provider of the systems, under JCT. All contractors were engaged directly by the client and the project team was completely involved in the selection process for each specialist contractor. Meetings were held with potential suppliers and the team to ensure that all involved understood the holistic, low carbon approach that the retrofit was trying to achieve. The system providers also offered additional training on renewable technologies for the subcontractor's team and their associated staff. This careful organisation helped limit the risks of the project and enhanced team cohesion.

Front facade post-retrofit



New extension cladding with external wall insulation and brick slips



STRATEGY

FABRIC

Existing external walls were upgraded using an internal dry-line foam insulation system returned into the reveals of the new triple-glazed hardwood windows and doors. The roof was insulated with Warmcell insulation and the extension (sunspace) was constructed using SIP Panablok panels for the walls with brick slip cladding to match the house and light gauge steel cassette for the new roof to allow for the inclusion of the planned solar thermal panels. These prefabricated elements followed 'modern methods of construction' (MMC) guidance, which aims to ensure efficient use of resources and limit waste generation: a key goal in this project.

SERVICES

Space heating and hot water are provided by a combination of two renewable energy systems: 2 m^2 of solar thermal panels and a 5 kW ground-to-source heat pump (3.2 COP). Both are linked to an insulated unvented hot water cylinder with solar coil at first-floor level, which provides hot water to the radiators and taps. The ventilation is provided by an MVHR system located in the loft and electricity comes from the grid and 6.3 m^2 of photovoltaic panels. In addition, the electricity demand has been kept to a minimum by fitting low energy light bulbs and A+ energy-rated white goods, and installing a sun tube providing natural light in dark spaces of the house that would normally require artificial light during the day.

RENEWABLES

The procurement of the low carbon technologies described above was one of the biggest learning curves on this project. The team realised that there is a need for greater awareness of the issues associated with low carbon technologies and the range of expertise required for implementation. This is to avoid a potential loss of confidence in systems and suppliers when problems arise, such as incorrect specification of items that require specialist expertise.

It was also felt that it would be easier to establish a procurement process and maintenance regime if a larger retrofit programme were adopted, which would include local materials and skills. Large-scale retrofits in particular would benefit multi-property owners such as registered social landlords or local authorities.

VITAL STATISTICS

When analysing the effectiveness of the energy-saving measures in this house, the Welsh School of Architecture found that, for this house, the new insulated dry-lining offered the best value in terms of cost savings and CO_2 emission reductions but it takes up valuable floor space. Using a ground source heat pump with solar thermal top-up would result in the highest overall CO_2 emissions savings, but this would require a much longer payback period. The triple-glazed, single-storey extension provides little carbon savings but was included to satisfy the residents' need for more space, especially since dry-lining further reduced the usable floor area. The choice of the appropriate measure is made with not only the energy or CO_2 emission reduction in mind; it is based on consideration, including in this case the fundamental need for space.

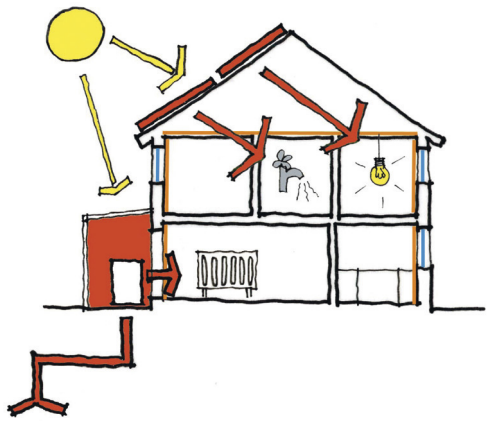
Vital statistics

Characteristics	Before	Target	Measured
Primary energy (kWh/m^2/yr)	620	120	160
Space heating (kWh/m^2/yr)	224	59	–
Airtightness (m^3/m^2h @ 50 Pa)	9.68	–	7.73
Type of glazing	double	triple	triple
CO_2 emissions (kg CO_2/m^2/yr)	115	28	24.2

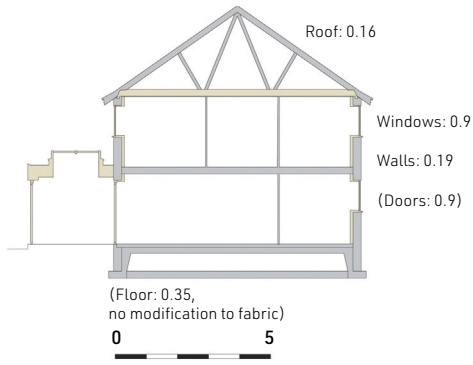
Installation of the ground source heat pumps



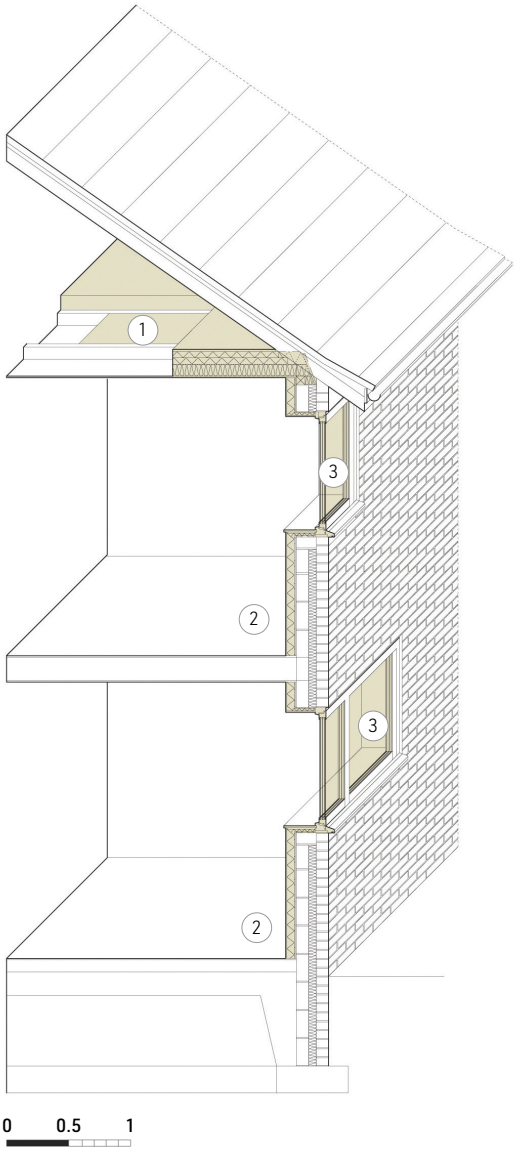
Services strategy with PV, solar thermal panels and ground source heat pump



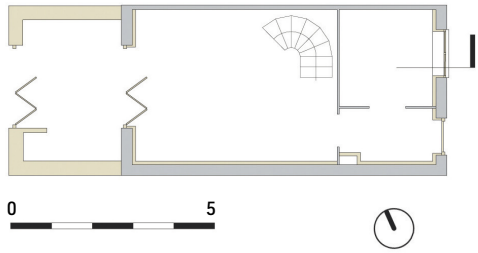
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
existing roof covering
existing rafters
maintain ventilation at eaves using ventilation tray
flexible insulation between rafters at eaves level to ensure continuity with wall insulation
new 18 mm chipboard (OSB) loft board
two new layers of 52.5 mm XPS board at right angles to existing joists
100 mm cellulose fibre thermal insulation

2 WALL
existing brick-block insulated cavity wall
existing plaster finish
72.5 mm insulated dry-lining board
32.5 mm insulated dry-lining board at reveal, head and sill of windows

3 WINDOWS
triple-glazed timber windows

FURTHER DATA

COST

With a total cost of £53,541 for the energy-saving measures, this project is among the least expensive of the programmes. Despite this, upon completion of the project the team found the cost of this retrofit prohibitive and not financially viable in the current market. As mentioned above, an economy of scale could improve this situation in the future. Considering that 8.5% of dwellings in England and Wales were constructed between 1981 and 1990 (representing 1,997,500 dwellings, of which 352,500 belong to LAs or RSLs), we can imagine that this type of project would be widely replicable.

Costs 2010	
Fabric (insulation wall + ground + roof)	£17,663
Windows + doors	£10,323
Services (MVHR + solar + PVs + GSHP)	£25,555
Other costs for retrofit	-
Subtotal	£53,541
Non-energy-saving measures	£69,401
TOTAL	£122,942

MONITORING AND COMFORT LEVELS

The CO_2 concentration average varies between 700 and 1,200 ppm – slightly on the high side, but nothing that could be detrimental to the health of the occupants. We can see that higher levels appear during the heating season.

The relative humidity average is between 50% and 60% in all rooms, indicating a good moisture level in the air overall.

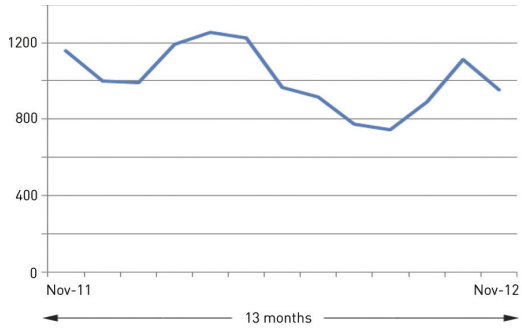
The temperature graph below shows very comfortable average temperatures (between 21°C and 26°C) in the house's main living spaces and bedrooms. The sunspace temperatures range from 15°C to 23°C (on average), which do not provide enough comfort in the winter months but act as a good buffer between the house's living room space and the garden.

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

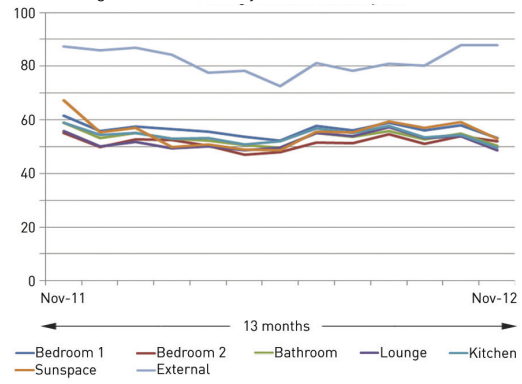
SPECIAL FEATURE

The Welsh School of Architecture compared the cost of this retrofit and the cost of demolishing the house and rebuilding it. They found that the cost of retrofit is approximately £400/m² lower than the average cost of rebuilding, including demolition. However, having studied a range of rebuild techniques, the lower range estimate for rebuilding was found to be only £52/m² more expensive than the refurbishment. This cost could come down even further if better reclaiming strategies were implemented during the demolition process and timber frame were used instead of brick and block (to achieve the same U-values for the fabric). The estimated costs were:
Refurbishment with extension: £1,389/m²
New build brick and block: £1,786/m²
New build timber frame: £1,767/m²
However, costs can vary significantly from project to project and a detailed assessment is recommended.

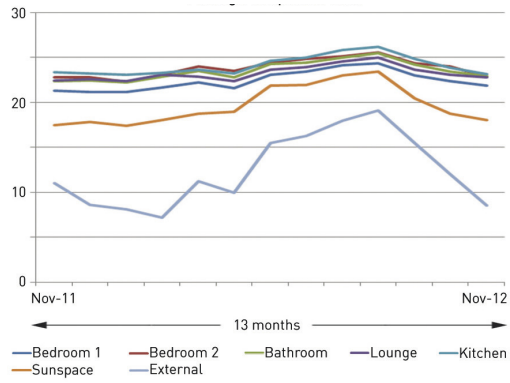
CO_2 concentration (ppm) – internal



Average relative humidity (%)



Average temperature (°C)



Installation of roof-mounted renewable systems



Passfield Drive

Post-1919
TSB-108

Internal floor area: **96 m²**

Primary energy
pre-retrofit calculated: **566 kWh/m²/yr**
target calculated in 2013: **119 kWh/m²/yr**
post-retrofit measured in 2013: **219 kWh/m²/yr**

Energy Use Intensity post-retrofit measured in 2023:
169 kWh/m²/yr

Client: **Southern Housing Group**

Architect: **Bere Architects**

Contractor: **AD Enviro**

Consultants: **Alan Clarke (M&E services engineer)**
Galbraith Hunt Pennington (structural engineer)

This property is a 1950s three-storey, three-bedroom mid-terrace house occupied by a family of eight. Before the retrofit, it had uninsulated solid brick walls with single-glazed, metal-framed windows. It was cold, draughty and damp. As it was decided that the tenants would remain in occupation during the works, retrofit solutions were chosen with this constraint in mind. The energy-saving measures include external insulation; PassivHaus triple-glazed windows; reduction of draughts and vacuum insulation on the ground-floor slab; a heat recovery ventilation system (MVHR) to provide background ventilation; solar thermal panels; and elimination of cold bridges from neighbouring facades. In addition, a bathroom addition was completely rebuilt.

The architects used the PassivHaus Planning Package (PHPP) as a design tool. It enabled the team to model solutions that could reduce the space heat demand from 303 kWh/m²/yr at 20°C down to 25 kWh/m²/yr at 20°C – a 92% reduction. In reality the winter comfort conditions have been improved from 17°C (before retrofit) to a very warm 24°C (after retrofit). The occupants are enjoying their new affordable comfort, and the family's asthma symptoms have disappeared.

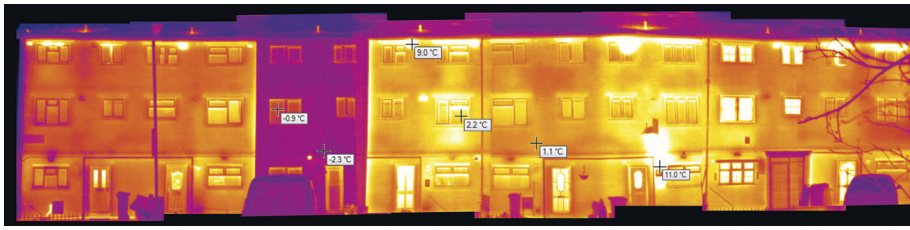
In this project, the PassivHaus approach and its broad range of factors worked together to overcome the defects of the original building. The wall insulation formed part of this approach and retrofitted on the external face of the facade walls (and over the foundations), it enabled a significant thermal upgrade of the walls without the loss of precious internal floor space; it was also a factor in enabling the occupants to remain in the property for the duration of the works.

The architects believe that to achieve significant energy efficiency improvements economically and at scale, external insulation will need to be widely regarded as an essential part of the mix. The three main advantages of this approach are: (1) it is better in terms of building physics (e.g. it avoids cold bridging of the floors and around windows), (2) it is cheaper, and (3) it can be done one terrace at a time without needing to temporarily rehouse people and their possessions. With the thermal image below, this house has become representative of what the future of retrofits with external insulation could offer.

Front facade post-retrofit



Thermal image of the front facade



STRATEGY

FABRIC

The fabric upgrade strategy consisted of wrapping the house with external insulation, changing the windows and doors, and adding floor and roof insulation.

While the application of external insulation is straightforward, the front and rear walls finish were tight against the roof tiles, so overcoming cold bridging at the top of this wall was achieved by inserting a fillet of internal insulation at this point (see detail on following page). If the whole terrace had been retrofitted, tilting fillets could have overcome this problem. In the end, the tilting fillet was omitted because a top-floor wardrobe would no longer have fitted. Post-occupancy, the occupants understood how even a small cold bridge can affect their thermal comfort and wanted the fillet put in.

To upgrade the ground-floor with minimal disruption, a layer of high-performance vacuum insulation (just 20 mm thick) was laid on top of the slab and protected by T&G chipboard flooring. The windows were replaced with new triple-glazed timber units, certified to PassivHaus standard.

SERVICES

Hot water is provided by a reconfigured conventional boiler linked to a solar tank and solar thermal panels. The solar hot water tank stores water heated by the solar panels and is kept topped up by the boiler when there isn't enough solar energy. To provide copious fresh air in winter without the need to open the windows, a heat recovery ventilation unit saves 90% of the heat in the stale air extracted from bathrooms and kitchens. This was mounted in the attic, with fresh air and exhaust air fittings mounted on opposite roof pitches to avoid any risk of recycling stale air.

RENEWABLES

Retrofitting heat recovery ventilation can be a challenge. In this project the architects minimised the disruption by concealing the air ducts on both sides of the chimney breast.

VITAL STATISTICS

A small amount of air leakage was found to occur through the party walls of the house, which were deliberately outside the scope of the project in order to minimise disruption to the occupants. If the whole block had been retrofitted, leakage through the party walls would not have affected the airtightness of the house. Nevertheless, excellent airtightness was achieved. Although the numbers were low (1.4 m^3/m^2h @ 50 Pa), they were still far too high for PassivHaus EnerPHit certification of the house, but this is still a significant achievement.

The PHPP assessment of the energy consumption of the house suggests that it may still operate with a specific heat demand equivalent to PassivHaus EnerPHit levels if the thermostat is set to 20°C.

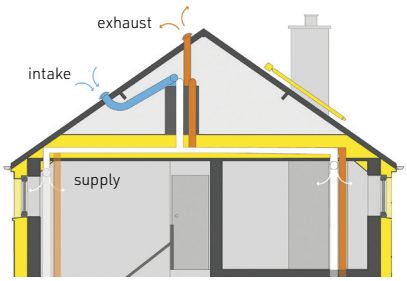
Vital statistics

Characteristics	Before	Target	Measured 2010	Measured 2023
Primary energy ($kWh/m^2/yr$)	566	119.2	219	–
Space heating ($kWh/m^2/yr$)	303	25	–	–
Airtightness (m^3/m^2h @ 50 Pa)	5.6	1	1.4	1.7
Type of glazing	double	triple	triple	triple
CO_2 emissions ($kg\ CO_2/m^2/yr$)	106.5	25.2	36.5	–
Annual gas use (kWh)	20,045	–	11,687	12,466
Annual electricity use (kWh)	3,546	–	4,142	3,763

Eaves detail showing the continuous insulation

Ventilation strategy with MVHR unit in loft space

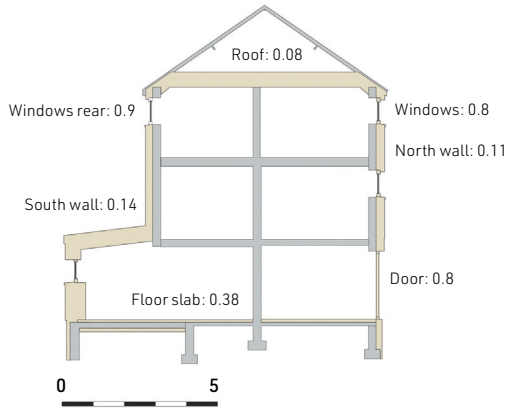




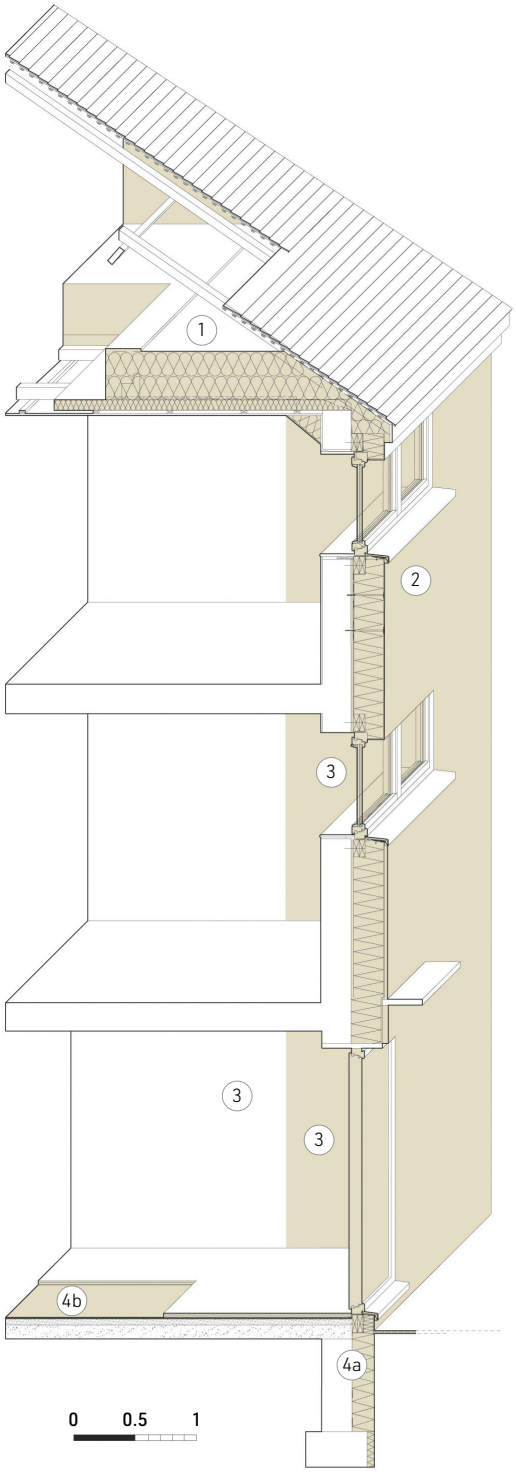
Ventilation ducts concealed in wardrobes



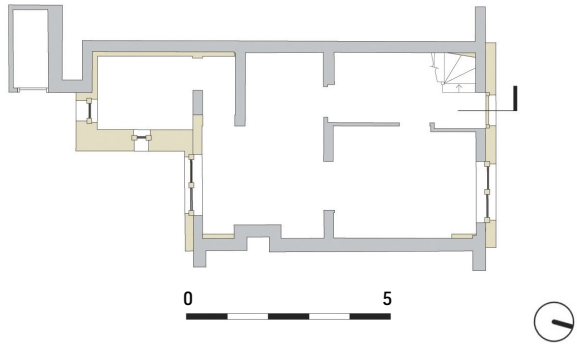
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
existing tiles
existing timber battens
existing timber truss
200 mm new mineral insulation
200 mm existing mineral insulation
existing ceiling joists with 90 mm of existing insulation
airtightness membrane laid over insulation and joists and glued and taped to existing walls
existing plasterboard

2 WALL
215 mm new insulated rendered system, consists of 200 mm EPS insulation boards glued and mechanically fixed, with 8 mm render finish
existing solid brick wall

3 WINDOWS/DOORS
new triple-glazed timber PassivHaus windows
new aluminium window sill
new insulated timber PassivHaus door

4a GROUND
XPS insulation used below ground level
waterproof adhesive coating applied over face of insulation and lapped over reinforced bedding mortar and decorative finish to min. 150 mm above ground level

4b GROUND
reinstated existing floor finish
15 mm T&G chipboard
10 mm vacuum insulation panel protected by 4 mm foam sheeting
existing screed and concrete slab

FURTHER DATA

COST

Now that they have a first experience, the client feels that repeating the project on a larger scale would probably save money. If funding was not available, they would consider reducing the number of technologies. They would prioritise external insulation and they might fit slightly lower-specification windows. The architects investigated whether installing a large-scale ventilation unit at each end of the terrace with the ductwork running in loft spaces would save money but as it didn't, the architect concluded that installing the ventilation unit in a porch/bin-store at the front entrance would be a better option.

Costs 2010	
Fabric (insulation wall + ground + roof)	£31,202.38
Windows + doors	£13,941.40
Services (MVHR and ductwork + solar and boiler)	£17,598.16
Other costs for retrofit	-
Subtotal	£62741.94
Non-energy-saving measures (extension etc.)	£38,875.83
TOTAL	£101,617.77

Costs exclude: VAT; contractor's prelims; fees; monitoring.

MONITORING AND COMFORT LEVELS

The architect reported as follows: the temperatures in the monitored rooms are steady and are hardly affected by the external conditions in summer or winter (graph below). At first the occupants turned the thermostat down at night to save energy, but they subsequently found this was unnecessary.

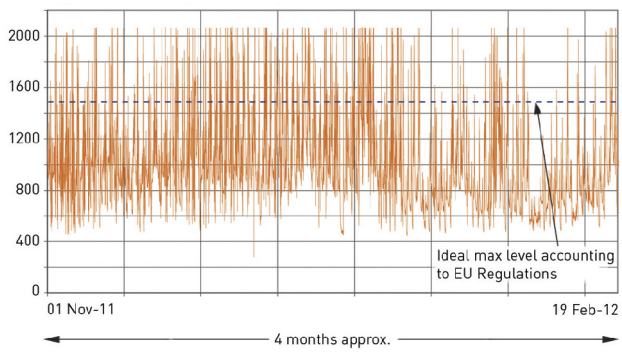
Relative humidity levels are optimum most of the time. The humidity in the lounge is often affected by extensive daily family cooking in the adjacent kitchen, but the humidity quickly stabilises after cooking has finished – one of the benefits of a well-balanced ventilation system.

Air quality is another comfort factor, and most of the time CO_2 levels are much better than the maximal level required by EU regulations. Occasionally in peak occupancy the CO_2 level momentarily exceeds 1500 ppm concentration (possibly partly due to the burning of gas for cooking) but there is a simple 'boost button' to increase the ventilation for 30 minutes.

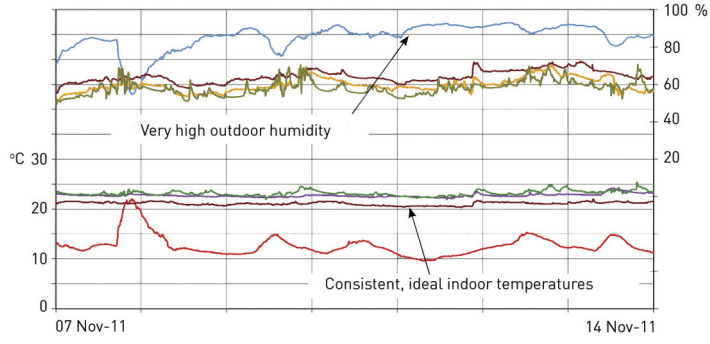
SPECIAL FEATURE

Another very important factor in a successful retrofit is the provision of easily understandable information about the building for the occupants. This is a prerequisite to best ensure that the 'designed' strategy has a chance to become an 'actual' strategy by which the house functions. The architects in this instance have produced a simple information board to be pinned to a wall and thus be always available to the occupants. This panel describes the house and the core reasoning behind each aspect of the design, as well as describing how to use the key controls. The importance of such a clear piece of information for future reference cannot be stressed enough. It can be daunting to receive verbal instructions from the designer when the project is completed, so it is important that the occupants can refer to a reader-friendly document after the design team and contractors have all vacated the site.

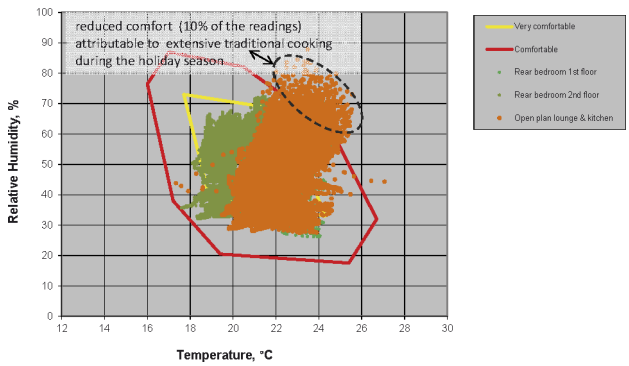
CO_2 concentration (ppm) – living room



Relative humidity (%) and temperature (°C)



Comfort chart for period between 1 November 2011 and 19 February 2012



RETROFIT REVISIT:

Passfield Drive

SIGNIFICANT CHANGES SINCE THE ORIGINAL RETROFIT

Occupancy: No significant changes.
Building: No significant changes.

ENVELOPE

Overall fabric performance: The retrofit significantly increased the house's indoor comfort while reducing energy consumption.
Airtightness integrity: Testing found slight improvements in air test result after 10 years, which indicates there has been no deterioration of the airtightness strategy.
Further investigations: None identified.
Rectifications needed: The rear garden door performs as designed when shut, however the recalibration of one hinge is required; a minor maintenance job. The housing association owner sent a specialist to review the door. They recommended replacing the door with a non-PassivHaus alternative, which would have undermined the performance of the house. The architect and the tenant worked together to repair the door instead.

SERVICES

Heating: There is minimal radiator use. Instead, a very high level of gas cooking by the household provides most wintertime space heating.
Hot water: Residents are satisfied with their hot-water system. However, the solar thermal system has not been functioning since 2012 and does not contribute to the hot water.
Ventilation: MVHR has performed well, however filters have not been provided to the tenant on a regular basis for replacement. Occasionally the architect donates filters.

ENERGY PERFORMANCE

EUI: 65% of pre-retrofit EUI. This has stayed the same in the 10 years since the retrofit.
Gas: 6.7% higher in 2022–3 than it was in 2012–13. The increase equals the heating previously provided by the solar thermal hot-water heating system.
Electricity: 9.2% lower in 2022–3 than it was in 2012–13. This may be because in the winter of 2012 the family also used two electric oil-filled radiators on the second floor.
Space heating demand: Lower demand than expected because of high level of gas cooking contributing to heating the house.

INDOOR ENVIRONMENTAL PERFORMANCE

Average temperature and humidity levels are in a comfortable, healthy range; slightly higher on the ground-floor due to cooking but remaining healthy.
Temperature: In the monitored period of March internal temperatures were:
Ground-floor kitchen: mean 23.7°C, minimum 21.2°C, maximum 34.4°C
Entire ground-floor: mean 21.7°C, minimum 18.6°C, maximum 34.4°C
First floor: mean 20.1°C, minimum 18.7°C, maximum 22.4°C
Second floor: mean 18.6°C, minimum 16.2°C, maximum 22.3°C.

Residents reported using the radiators at most once a day, for only 20 minutes. Most of the space heating is from ground-floor cooking. The coldest second-floor room was below 18°C for 32% of the monitored period. If neighbours were insulated, using the scalable external wall insulation approach, heat loss through party walls would be effectively eliminated and the temperature difference between top floor and ground-floor would be much less.
Relative humidity: During the monitored period in March, relative humidity levels were:
Ground-floor: mean 52.1%, minimum 38.2%, maximum 76.3%
First floor: mean 54.0%, minimum 41.5%, maximum 72.3%
Second-floor (excl. bathroom): mean 57.3%, minimum 44.0%, maximum 71.8%
Second-floor bathroom: mean 63.6%, minimum 48.6%, maximum 88.8%.
NB the humidity sensor placed in the ground-floor bathroom was nonfunctioning.

The 24-hour moving average relative humidity (RH) never exceeded 75% anywhere in the house and only exceeded 65% at times on the second floor, for 266 hours in the bathroom, 57 hours in the rear bedroom and five hours in the front bedroom.
CO_2 concentration: CO_2 levels ranged generally between 700 and 1,100 ppm and averaged roughly around 900 ppm. This is slightly on the high side, but still

in the comfortable zone.

COMMENTARY ON PHYSICAL FINDINGS VS USER FEEDBACK

In the SOAP survey, the residents indicated a preference for a 'warm', 22°C, internal temperature. General comfort is 'very comfortable' and overall comfort in winter 'somewhat comfy', but the temperature in winter on the second floor is 'slightly too cold', which reflects the lower recorded temperature on the second floor. Despite this, the residents are 'very satisfied' with the heating system (radiators), which they try to avoid using. The humidity in winter was 'just right', which reflects the recorded mean relative humidity falling within a normal healthy range. They were also 'very satisfied' with ventilation.

SERVICE STRATEGY

Hot water: Based on data from when the solar thermal system functioned, also supported by PHPP predictions, the solar thermal system could provide 60% of the DHW demand.

Space heating: Gas cooking produces far more heat than the house needs in the summer, and nearly meets the winter heat load without any supplementary heat. Annual gas use is significantly higher than would be the case if occupied with less intensive cooking habits.

Electricity: Nothing unusual to report.

Ventilation: Maintenance of the filters for the MVHR unit is an issue. Southern Housing has not provided replacement filters for the unit, but the occupants regularly vacuum the filters and wash the kitchen extract filter monthly. The architects donate new replacement filters from time to time.

Renewables: See section above on domestic hot water.

USER FEEDBACK

The SOAP survey was positive with overall score 'good' (75%). Residents also found improved health, with asthma symptoms from the pre-retrofit period entirely gone.

Questionnaire findings: The external wall insulation (EWI) strategy minimised impact on the tenants who stayed *in situ* during the retrofit and were 'very satisfied' with the installation process. They also find the external appearance 'very good'. Despite the unrealised energy saving potential of a wider EWI rollout to eliminate party wall heat losses, the tenants are 'satisfied' with the outcomes of the retrofit. They find stability of conditions 'consistent' in both winter and summer. They find summer overall comfort 'comfy', air movement and humidity 'just right' but the temperature is 'slightly too hot'. The tenants report 'no' condensation but responded 'yes' to mould, later confirmed verbally to be a mistake. There has been no building handbook use because the tenants have a 'user board' on the cupboard door instead. Tenants found the quality and usefulness of the introduction 'very good' and are 'satisfied' with general controls.

BPE TECHNIQUES: LESSONS LEARNED

This deep retrofit enabled the occupants to remain *in situ* while their home was improved. The results demonstrate the benefits of applying PassivHaus methodology to a deep retrofit. The occupants increased indoor temperature and eliminated asthma symptoms while reducing energy consumption. Retrofitting adjacent houses is a cost-effective way to achieve the full potential energy savings. This is due to reducing heat loss through the connecting walls between a warm insulated house and its cold, uninsulated neighbours.

Description of the BPE approach: Core BPE scope, no detailed tests. Temperature and relative humidity sensors placed in every room in the house. CO_2 sensor placed in the first-floor living room. Smart meter data downloaded for the recorded period.

Airtightness testing: The air permeability was lower (i.e. better) under the Pulse test than the blower door test.

Views on methodology: Concurrent temperature monitoring in the home and direct neighbours would give a more accurate evaluation of heat loss. To give the most accurate evaluation of heat loss through party walls it would be necessary to monitor temperatures in both neighbours' homes.

Stanmore, London

Post-1919
TSB-72

Internal floor area: **130 m²**

Primary energy
pre-retrofit calculated: **350 kWh/m²/yr**
post-retrofit measured: **160 kWh/m²/yr**

Client: **London Borough of Harrow, Paul Mullins**

Designer: **Gifford, Part of Ramboll, UK**

Contractor: **Kier Building Maintenance; Westgate (Subcontractor)**

Engineers: **Ramboll, UK**

This 1960s three-bedroom semi-detached house is located in the borough of Harrow, north-west London. It is typical of social housing in the area, originally constructed with a cavity brick wall, solid ground-floor, timber upper floors, internal masonry walls, and a traditional tiled and pitched roof. The property was extended at the back, however, with a 'whole-house' retrofit approach in mind. The retrofit measures included Aerogel Spacetherm™ insulation, an efficient boiler with a hot water cylinder, solar thermal panels, a 'positive input' ventilation system, bespoke controls for thermal zoning, lighting control and new electrical appliances, and also a rainwater-harvesting tank that meets half of the non-potable water demands of the property. IES Virtual Environment (version 6.0) was used to estimate the energy consumption and carbon savings associated with the retrofit works.

In order to reduce the energy demand for space heating and improve internal air quality, the team opted for a combination of systems: a 'positive input' ventilation system (PIV) (Sunwarm system by Nuaire) was chosen, which draws in external air via the loft space, taking advantage of heat gain in the loft as normally utilised by a conventional positive input ventilation unit. This slightly tempered air is then filtered and passed through a solar collector, which heats it further.

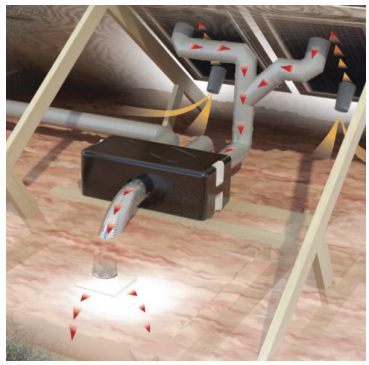
The warmed air is then filtered again within the ventilation heat recovery unit before it is finally delivered to the dwelling. The air is also extracted from the house's wet rooms by this unit and then discharged outdoors.

Note: the concept of a positive input ventilation (PIV) system was originally developed in the 1970s to deal with condensation by providing continuous (and quiet) ventilation throughout a dwelling, without cold draughts and without affecting the operation of open-flued combustion appliances. However, the PIV unit installed in this house is a much evolved version of this original concept and now provides pre-warmed fresh air in the house as opposed to external ambient temperature fresh air. Therefore, in comparison with the original system, it aims to significantly save space-heating energy as well as provide good-quality fresh air.

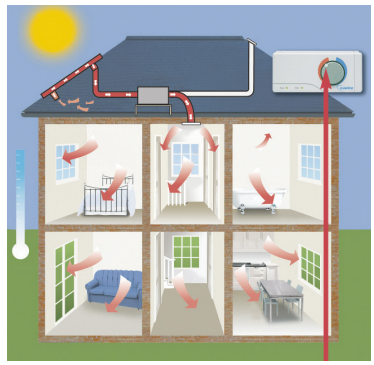
Front facade post-retrofit



Positive input ventilation loft installation



Positive input ventilation strategy on a cold day



STRATEGY

FABRIC

The whole-house insulation strategy consisted of upgrading the external cavity walls by injecting a layer of Knauf Technitherm insulation into the existing cavity and adding a 25 mm layer of Aerogel Spacetherm faced with plywood and internally finished with plasterboard. The ground-floor level was raised and 25 mm of Kingspan Kooltherm K3 insulation boards were fitted on top of the existing concrete ground-floor. Finally, 100 mm of Warmcell Cellulose insulation was installed in the roof in between the joists and topped up with 200 mm of Thermafleece wool insulation. All windows were replaced with new triple-glazed aluminium-clad timber units.

SERVICES

One of the key design features in this project is the combination of natural ventilation with openable windows and PIV system. The solar collector integrated into the ventilation system also heats a new 300-litre twin coil hot water store on the first floor. This feeds the existing radiators (which were retained but lagged with insulation) and domestic hot water services. A high-efficiency boiler was also installed to satisfy the additional heat requirements in periods where the solar thermal panels do not provide sufficient hot water. To give occupants the option of controlling the heating on a room-by-room, upstairs/downstairs or living areas/bedrooms basis, new wireless eTRV technology was installed. This innovative system involves retrofitting small fittings to each radiator valve that can programme time and temperature with a small remote control. The overall aim of this system is to limit the waste of space heat energy and to give users control of their heating, minimising waste and improving comfort.

The strategy also included a 'last man out switch' so that upon leaving the property the residents can turn off all light fittings and selected appliances with one switch. Twelve wireless 'Bye Bye Standby' devices (also called 'Online Energy Controllers'), which fit behind plugs, were also installed, allowing tenants to choose which appliances they control (e.g. lamps, computers, televisions). These devices are connected to a wireless central box and controlled via an internet interface.

RENEWABLES

The team developed the services strategy only once the planners approved the installation of solar thermal panels. Once approved, the team installed 6.9 m^2 of solar thermal panels on the south-facing roof at a 30-degree incline. These panels aim to satisfy 60% of the annual hot water demand, therefore aiming to considerably reduce the use of the gas boiler and both saving on energy costs and reducing CO_2 emissions.

VITAL STATISTICS

The team originally intended to remove the existing chimney in order to reduce heat loss, however this implied costly structural strengthening works, which were outside the budget objectives from the council. A new idea was found with an insulated thermal break plate proposed at loft level, where the chimney meets the roof construction (greatest heat loss zone). The existing brickwork at top-floor ceiling level was removed and carefully replaced with an insulating block on top of a slate covering the whole flue opening. This blocked the air path through the flue and reduced the cold bridge through the brickwork.

Vital statistics

Characteristics	Before	Target	Measured
Primary energy ($kWh/m^2/yr$)	350	115	160
Space heating ($kWh/m^2/yr$)	–	40	31
Airtightness (m^3/m^2h @ 50 Pa)	7.84	5.5	5
Type of glazing	double	double	triple
CO_2 emissions ($kg\ CO_2/m^2/yr$)	–	17	25.5

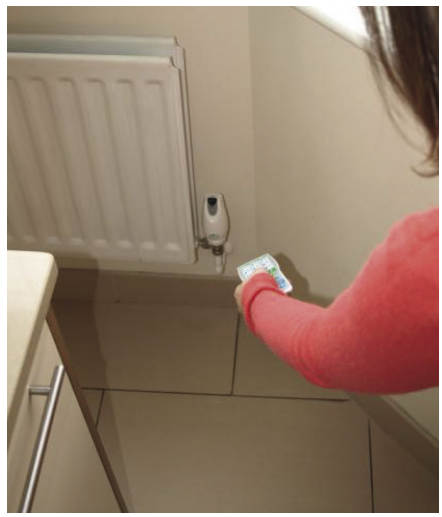
Thermal break plates

Solar thermal panels

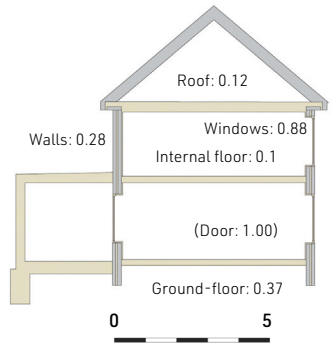




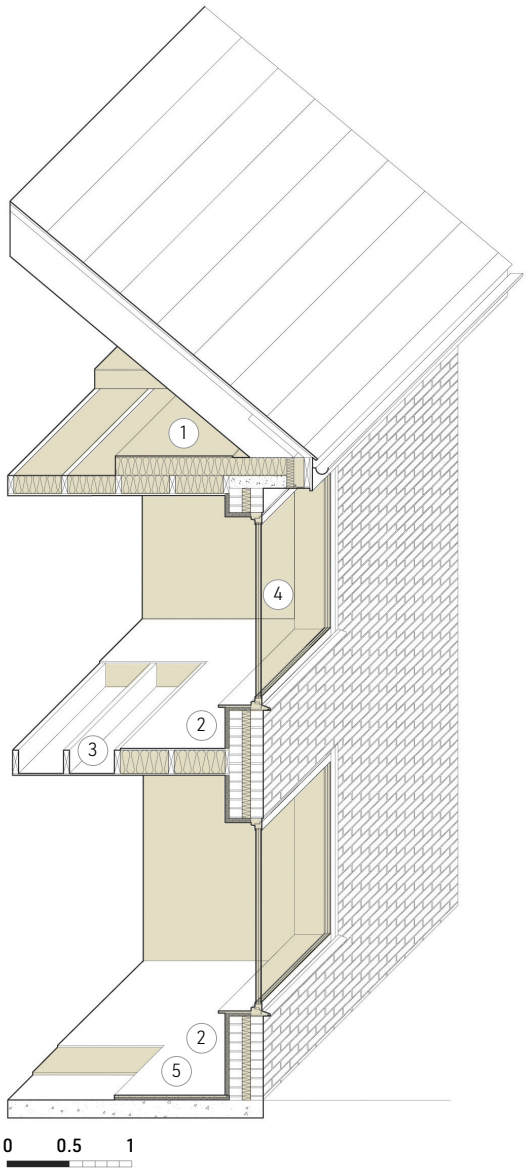
eTRV system



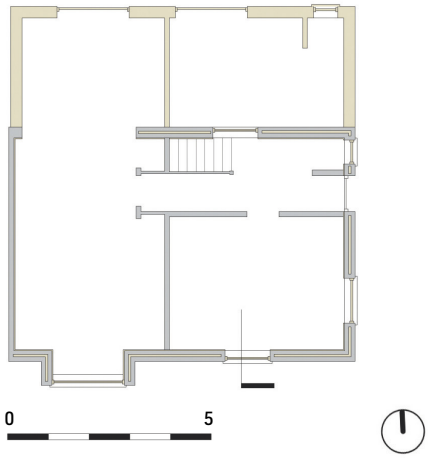
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
chipboard
300 mm cellulose loose fill insulation between and above existing joists
insulation plug, rafter baffle and soffit vent for roof ventilation

2 WALL
existing facing brickwork
cavity filled with new foam insulation
existing internal brickwork
25 mm aerogel insulation
thermal plasterboard

3 INTERMEDIATE FLOOR
200 mm cellulose loose fill insulation between existing joists

4 WINDOWS
triple-glazed windows
solid insulated wooden doors

5 GROUND
new carpet
new thermal plasterboard
new 25 mm Kingspan Kooltherm K3
existing concrete floor

FURTHER DATA

COSTS

The most expensive items for this project were the triple-glazed windows, the Aerogel Spacetherm™ insulation and the rainwater-harvesting system. Finding alternative products and systems could be one way of reducing costs as the market develops. The team reported that these items were not easily procured through the client's existing supply chain. As a result, they were not able to obtain as many quotations as they would have liked. For example, some of the window suppliers they approached who produce suitable triple-glazed window products did not normally deal with schemes on such a small scale.

Costs 2010	
Fabric (insulation wall + ground + roof)	£23,930
Windows + doors	£16,566
Services (MVHR and ductwork + solar and boiler)	£29,756
Other costs for retrofit	-
Subtotal	£70,252
Non-energy-saving measures	£25,762
TOTAL	£96,014.33

Costs exclude: VAT; prelims; fees; monitoring.

MONITORING AND COMFORT LEVELS

The relative humidity was measured at between 60% and 70% – slightly higher in the rear study room than the front bedroom, which shows better results: nearer to an average relative humidity of 60%, which are overall good results.

The temperature graph shows that overheating is not an issue in this house, and that the mean temperature for the front bedroom is 20.9°C, which is comfortable. However, temperatures in the heating season are shown to be a little low at around 18–19°C.

Water consumption was also monitored and it was found that the rainwater-harvesting system had provided the occupants with a very significant proportion of their total water consumption. Overall, the occupants use 1,000 litres in one week, with 775 litres coming from rainwater – that is, 77.8% of the total water consumption. Further monitoring should be carried out to ascertain whether these impressive results are representative of the whole year.

SPECIAL FEATURE

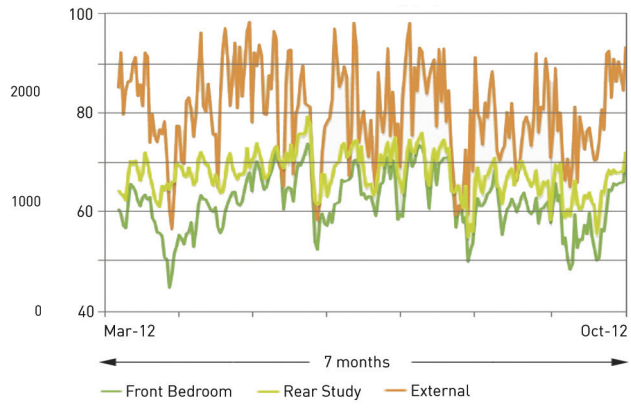
The installation of a rainwater-harvesting system was not directly related to energy use but was part of a holistic sustainable design approach.

The system aims to satisfy half of all non-potable water demands in the property. It includes a 2,000-litre rainwater collector buried 4 m below ground in the garden, which pumps the water for use in the WCs, washing machines and for outdoor use.

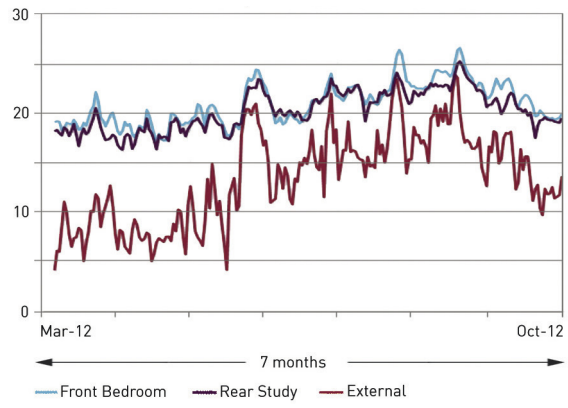
The UK construction industry is fairly cautious of installing such systems as there are perceived issues with maintenance, complicated pipework and embodied energy. The solution is often thought best suited to larger-scale projects. The monitoring of such projects will however eventually inform whether such systems are suitable for domestic users.

The original plan to install a combined grey water and rainwater recycling system was found to be too expensive but this was replaced by the simpler rainwater-harvesting alternative, although this still had a non-negligible cost of £9,575.

Relative humidity (%)



Temperature (°C)



Relative humidity (%)
Rainwater-harvesting tank



Penzance

Post-1919
TSB-64

Internal floor area: **68.48 m²**

Primary energy
pre-retrofit calculated: **544 kWh/m²/yr**
post-retrofit measured: **113 kWh/m²/yr**

Client: **Penwith Housing Association (Devon & Cornwall Housing Group)**

Lead designer: **Penwith HA**

Contractor: **Mears Ltd**

Consultants: **Earth Energy Engineering, Woodmead Energy Services, GeoScience Ltd**

The project property is located in West Cornwall and was built in the 1950s as part of a local authority development. Mains gas is not available, and the dwelling was therefore previously reliant on solid fuel for heating. The original construction is concrete block with a 50 mm insulated cavity, solid in situ concrete ground-floor and a traditional timber pitched roof with concrete tiles. The main low energy strategies implemented consist of two components: super insulating the fabric of the house externally and adding a pre-fabricated conservatory named the HeatPod containing a prototype ground/air/solar source heat pump combined with an MVHR and the hot water cylinder. Other energy saving measures include triple-glazed windows, photovoltaic panels and a wood pellet stove.

The particular area of focus for the team on this project was the design of what they named the 'HeatPod'. The concept behind the name was to create an add-on item, which could potentially be retrofitted to any existing house while it is occupied. It was intended to contain all of the services equipment required to run the house post-retrofit, therefore avoiding potential floor area loss. The idea was also to provide an extra room in the house that combined enough space to store bikes, dry clothes under cover and for most of the low energy equipment. Additionally, its materials and form were designed to use passive solar gain to warm up the incoming air before being drawn into the house. Furthermore, the HeatPod floor is constructed as a passive heat sink to enhance this effect, giving off warmth when the building cools. This HeatPod forms an integral part of the comfort strategy for the house.

The new volume has been designed as a prefabricated 'bolt-on' addition to a house. Upon completion, the team was very pleased and reported that they would be likely to replicate this on other projects where possible but that they would also like to see some further technological development and check that the monitoring data proves good internal comfort. In practice, joining the conservatory to the house in conjunction with a 100 mm layer of external wall insulation required some very careful detailing to achieve a watertight and visually satisfactory connection. This is an area of overlap between construction and manufacturing, introducing new ideas into construction work and calling for smart product development.

Rear facade post-retrofit



Services cupboard



Rear extension 'HeatPod' internal view



STRATEGY

FABRIC

The fabric measures implemented consisted of installing 100 mm of phenolic external wall insulation, extended 500 mm below ground level with expanded polystyrene insulation (EPS). The windows were replaced with triple-glazed softwood in addition to high performance external doors. The fact that the external insulation was installed at the same time as the new triple glazing and external doors were fitted allowed a substantial reduction in cold bridges, which are usually difficult to avoid. Finally, 400 mm of mineral wool insulation was installed in the loft space. According to the team, the strategy to carry out as much work as possible on the outside of the property worked well in practice and although external insulation is not suitable for all homes, there is a strong argument that it should be the wall insulation of choice wherever it can be fitted.

SERVICES

The services design strategy was determined by the lack of mains gas, with long-term fuel availability and occupant convenience favouring an all-electric solution. Running costs and the very low CO_2 target set the details. Having first fixed the best practicable passive measures and selecting low energy appliances and lighting, the design team worked backwards from the CO_2 target to determine the remaining energy available to meet the heating functions. These were calculated to total 7100 kWh/yr, but with a maximum of 11 $kgCO_2/m^2$ being 'permitted' for the task, only 1700 kWhe of electricity would be available to provide it! It was clear that a heat pump system with an overall annual efficiency (SPF) of 4.2 would be required, which led the team to develop a GASSHP system.

RENEWABLES

EoN HeatPlant ground source heat pumps installed in PHA properties had proved the possibility of this level of efficiency if an output temperature of 45°C to the radiators could be matched with an average input temperature of 8˚C from the ground. The house is sealed so mechanical ventilation is necessary. A fan mounted in the HeatPod extracts moist warm air from the bathroom and kitchen, which is ducted to the outside. An air/water heat recovery coil is inserted into this duct and is connected to the heat pump's ground loop. This is cooler than the discharge air, so useful energy is recovered and stored in the ground. Make up air, tempered by both solar gains and heating system losses, is drawn from the HeatPod into ducts, which connect to ceiling diffusers in the two bedrooms and the hallway. The electricity for the fans and MVHR is matched by a 1 kWp PV array. A wood pellet stove is fitted in the lounge to provide both emergency back-up heat and a real flame fire.

VITAL STATISTICS

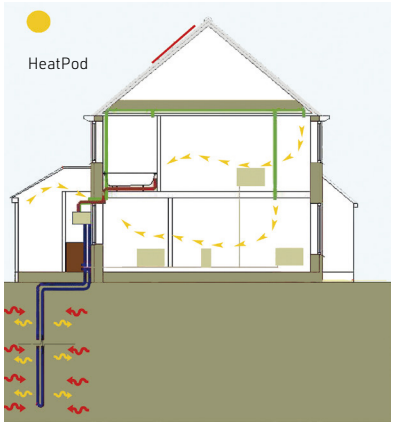
Although the airtightness is relatively high, the energy performance of the fabric has been vastly improved with good post-retrofit U-values. This will ensure a minimum heat loss through the core of the house's fabric. Thanks to the comprehensive energy strategy, the monitored CO_2 emissions of the building in use are showing very good and low results, measured to be approx. 88.6% lower than the pre-retrofit house and slightly better than the target set by the Technology Strategy Board.

The fuel bills have shown to be reduced dramatically, in line with the reduction of energy demand, from approximately £2,000 down to just £382 per year: a notable 80% reduction.

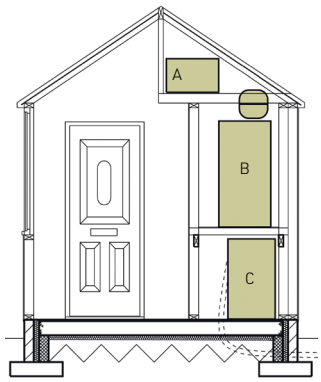
Vital statistics

Characteristics	Before	Target	Measured
Primary energy ($kWh/m^2/yr$)	544	110	113
Space heating ($kWh/m^2/yr$)	276	14.05	8.98
Airtightness (m^3/m^2h @ 50 Pa)	5.57	3	5.25
Type of glazing	double	triple	triple
CO_2 emissions ($kg\ CO_2/m^2/yr$)	147.6	16.6	16.9

Services strategy with ground source heat pumps, MVHR, radiators

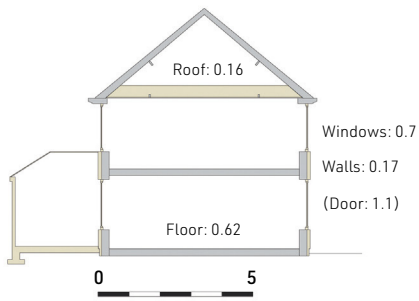


Services cupboard in HeatPod

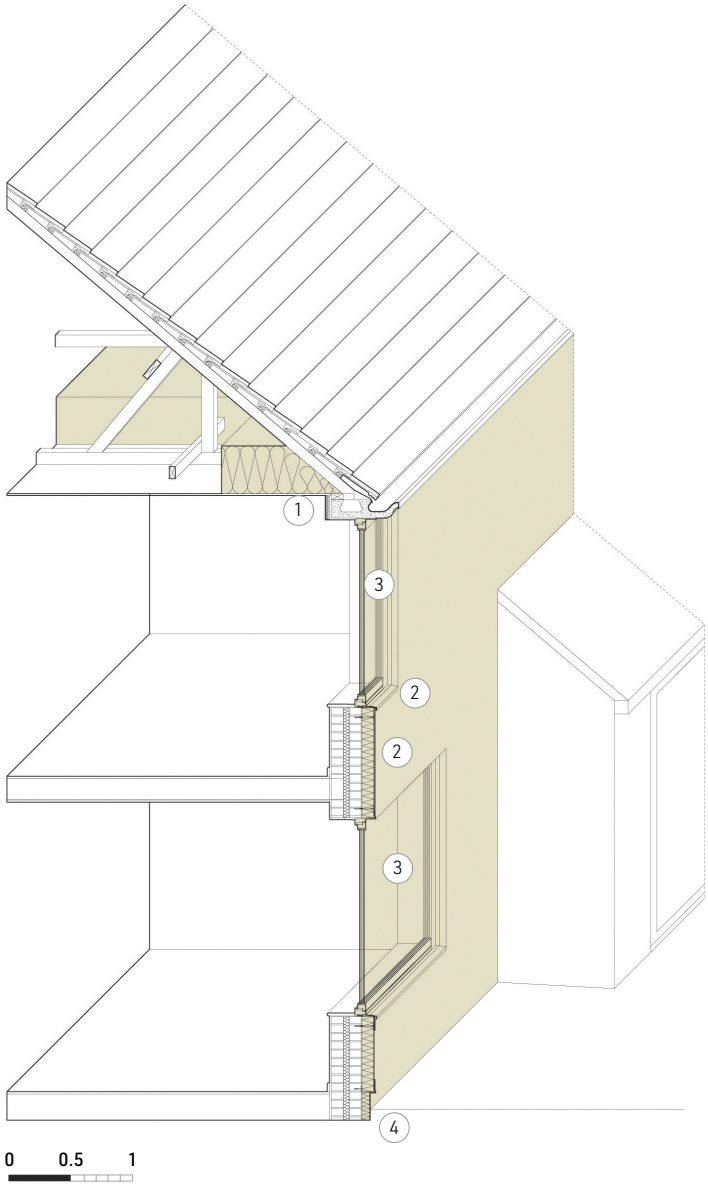


A Ventilation/heat recovery unit
B Hot water cylinder
C Ground source heat pump

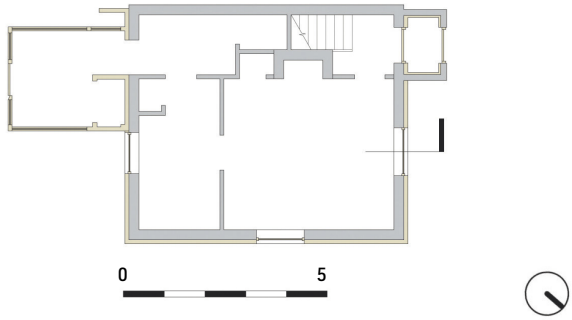
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
400 mm of mineral wool in loft space
30 mm phenolic foam board insulation with 5 mm ply painted white next to existing Finlock gutter to prevent thermal bridging

2 WALL
Top coat render applied to the grain thickness
Reinforcing mortar applied to a thickness of 8 mm
High impact alkali resistant glass fibre reinforcing mesh applied to the whole surface with a minimum 100 mm overlap on the edges
100 mm thick phenolic insulation board
existing wall with insulated cavity retained

3 WINDOWS
new triple-glazed timber window

4 GROUND
70 mm thick EPS insulation board 500 mm deep below DPC level

FURTHER DATA

COST

In a retrofit, it is sometimes difficult to justify the replacement of certain items. For example, in this house, the existing windows were already double-glazed and in relatively good condition. In the planning stages of the project, there was some debate among the team about the cost-effectiveness of replacing existing double glazing with triple glazing, but it was eventually included in the finished scheme in order to meet the CO_2 emissions reduction target. However, it is worth noting that replacing the windows enabled cold bridges to be removed from the building envelope, therefore avoiding both heat loss paths and potential condensation issues.

Costs 2010	
Fabric (insulation wall + ground + roof)	£15,219
Windows + doors	£4,940
Services (GSHP + MVHR and ductwork + solar PV)	£ 22,991
Other costs for retrofit (HeatPod; white goods; pellet stove)	£15,417
Subtotal	£ 58,567
Non-energy-saving measures	£2,954

MONITORING AND COMFORT LEVELS

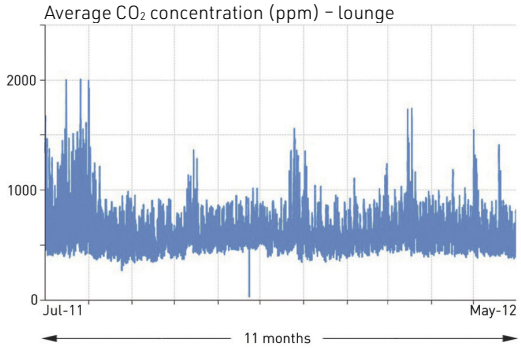
This project has been monitored extensively. The internal comfort data indicates a good living environment, such as the stabilisation of CO_2 concentration in the lounge after August 2011, which corresponds to the installation of the MVHR unit. In the following months, the CO_2 concentration averaged 600 ppm, demonstrating improved air quality.
The relative humidity graph illustrates an aspect of the West Cornwall climate. Those not familiar with the region may be surprised to see how high the external humidity can be, but it is consistent with local meteorological data. The internal relative humidity is much lower and within acceptable levels (below 70%). The graph bottom right represents two years of relative humidity monitoring, one pre- and one post-retrofit. The right-hand side of the graph illustrates that the MVHR system has helped to achieve a more consistent internal environment in the post-retrofit year. The internal temperatures are stable and range between 18°C and 19°C, which is the tenants' preferred room temperature.

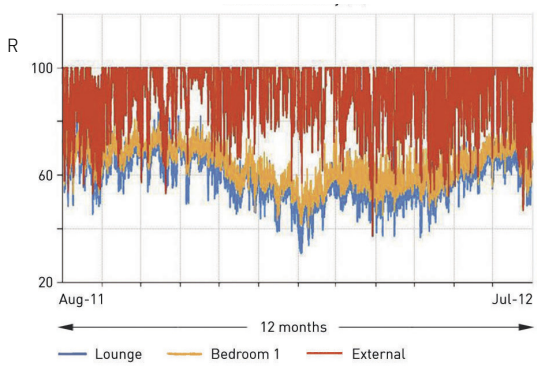
Costs exclude: prelims; fees; monitoring.

SPECIAL FEATURE

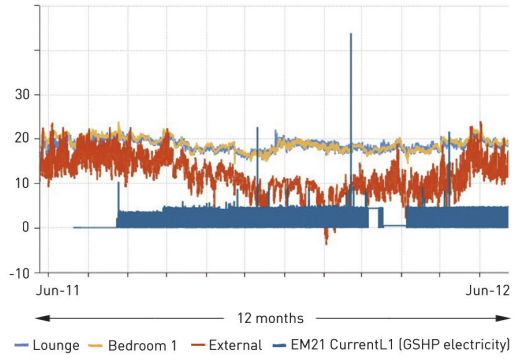
The building services consultant gave his own interesting perspective on low energy retrofit: 'There is a need to understand the whys and hows of low temperature heating system design in highly insulated dwellings. This is essential if household fuel costs are not to spiral out of control as fossil fuels are depleted. Technical knowledge about the design and installation of such systems is very rare in the UK. Also, the practical aspects of installation are outside the experience of many domestic plumbers or "central heating specialists" who normally carry out such work. The development of the "HeatPod" package, which could incorporate all the necessary knowledge and skills in one "box", factory built off site and capable of being installed by semi-skilled labour, could be a real breakthrough in both reducing fuel poverty and decarbonising the existing housing stock in the UK at an affordable cost. This project has proved it is possible to do this, now the challenge is to make it affordable.'

CO_2 concentration (ppm) – living room

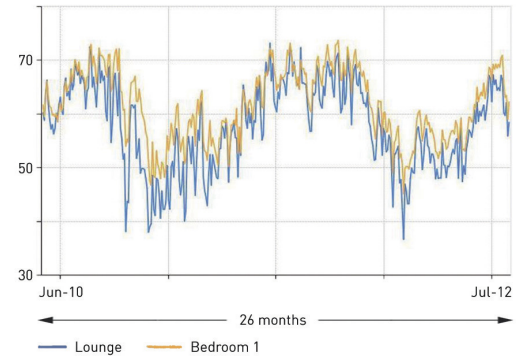




Temperature (°C)



Internal relative humidity (%)



Haddington Way

Post-1919
TSB-31

Internal floor area: **99.5 m²**

Primary energy
pre-retrofit calculated: **430 kWh/m²/yr**
post-retrofit measured: **174 kWh/m²/yr**

Client: **Places for People**

Architect: **MEPK Architects**

Contractor: **Willmott Dixon**

Consultants: **Rickaby Thompson Associates, Viridian Solar**

This three-storey mid-terrace house in Aylesbury is a highly typical construction type of the mid-1990s. The construction consisted of a suspended concrete ground-floor, insulated masonry cavity walls, and a pitched roof on timber structure with some insulation and double-glazed windows. The services were all electric with electric storage heating; hot water was provided by a dual immersion cylinder and the ventilation was natural. This project is of particular interest for the client as they have another 18,563 houses of this type in their portfolio. The proposed retrofit strategy put a strong focus on making maximum use of renewable solar energy. It included the use of solar thermal panels and innovative photovoltaic panels. In addition, a whole house ventilation with heat recovery is provided via an EAHP (exhaust air heat pump); this contributes to both hot water and space heating.

After applying the principles of fabric first, a system of efficient services was installed, including renewable solar technologies. The systems included are both passive and active.

The main passive measure installed (not requiring any energy to function) was the two sun pipes. These tubular pipes, fitted with a highly reflective lining, run from the roof to both internal bathroom ceilings providing daylight, thus reducing the need for artificial lighting during the day and contributing towards the reduction in electricity use.

The active systems include solar thermal panels that provide hot water and photovoltaic panels that provide electricity.

There is also an exhaust air heat pump (Nilan VP 18), which aims to extract hot humid air from kitchens and bathrooms (moisture and smells) and extract useful heat from the humid air to provide domestic hot water and to heat the incoming air. During the winter the production of hot water has first priority, while any excess energy is used to heat the incoming air. The unit itself consists of a 180-litre hot water cylinder and two fans for inlet and exhaust respectively. It is also fitted with a supplementary heating coil for connection to the solar panels. According to the team, this EAHP system has performed very well, both providing sufficient heating and hot water and delivering good internal air quality.

Front facade post-retrofit



Rear facade post-retrofit



Services equipment in attic



STRATEGY

FABRIC

To complement the existing insulated cavity walls, an internal insulated dry-lining made of Spacetherm PP (which consists of 9.5 mm of plasterboard, 6 mm of plywood and a 40 mm aerogel sheet bonded to plasterboard was added). The team pointed out that the size and weight of the Spacetherm boards meant that it required two people to handle them, which increased the time needed to install this product and the cost. The ground-floor was insulated with 75 mm of rigid phenolic insulation (Kingspan Kooltherm K3) laid on top of the structural beam and block floor. Because of the raised floor level, the internal doors were cut short and then rehung.

The roof was upgraded with 150 mm of Celotex insulation laid within the sloping soffits. Windows were replaced with new argon-filled ultra-low-e double glazing units (U-value 1.10–1.24 W/m^{2}K) and the external doors were replaced with new insulated doors that achieve U-values of 1.6 W/m^{2}K.

SERVICES

Space-heating demand is met principally by the EAHP combined with the MVHR unit. One small electrical panel heater, which is able to provide top-up heat if required, was also installed in the hallway of the property.

The hot water required is produced by the air heat pump and stored in its integral hot water cylinder; it is also pre-heated via the solar thermal panels and a separate 250-litre hot water storage cylinder. Through the development of this innovative service design, the team found that it was unfortunately not possible to directly connect the heat pump hot water supply with water from the solar thermal panels.

RENEWABLES

The renewable energy systems installed include 4 m^2 of flat plate solar thermal panels combined with a 250-litre capacity hot water storage cylinder and 1.35 kW peak of prototype photovoltaic panels by Viridian.

The photovoltaic panels have an inverter, which converts the DC electric current produced by the panels into AC for use in the house, or for export to the grid. The normal approach would be to use a so-called string inverter; however, in this project the team chose instead to carry out the first commercial installation of Enecsys micro-inverters in order to reduce costs, as only a single inverter is required rather than a string of inverters. Viridian, who installed this system, will be assessing the performance of this new technology during the monitoring period. The figure bottom left illustrates Enecsys's principle that when the performance of one module is compromised in a traditional approach, it drags down the output of the whole system, whereas in the installed system each module functions entirely independently, aiming to maximise the energy harvest.

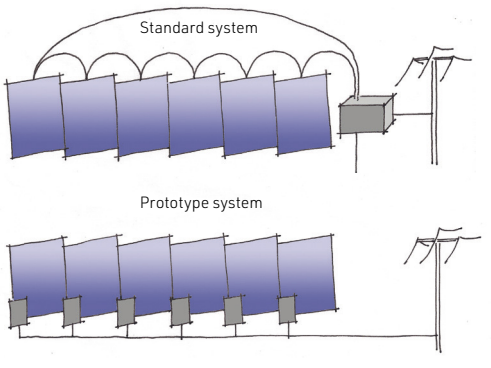
VITAL STATISTICS

The property's retrofit strategy aimed to significantly improve the performance of the house, reducing CO_2 emissions by almost 60% to a level that the team considered reasonable and affordable. The U-values have been significantly improved and much effort was made to enhance the airtightness of the house from 13 down to 5 m^3/m^{2}h @ 50 Pa. Pro Clima Tescon tape was wrapped around joists and vertically at the reveals to connect to an Intello Plus vapour check fitted between the plywood face of the internal insulation and the plasterboard facing. Pro Clima Roflex airtightness grommets were also used where possible where pipes penetrated the airtightness layer.

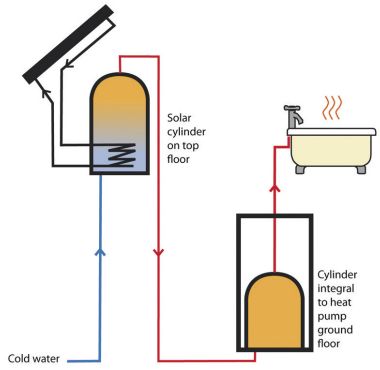
Vital statistics

Characteristics	Before	Target	Measured
Primary energy (kWh/m^2/yr)	430	117	174
Space heating (kWh/m^2/yr)	–	41	–
Airtightness (m^3/m^{2}h @ 50 Pa)	13	5	5
Type of glazing	double	double	double
CO_2 emissions (kg CO_2/m^2/yr)	65	17	26.1

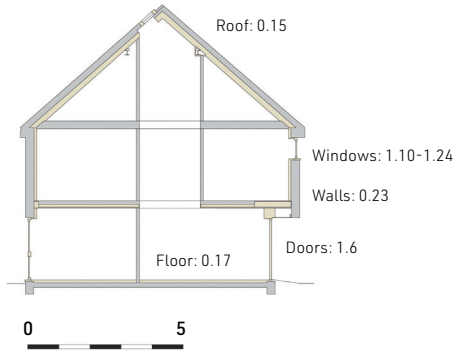
Photovoltaic arrangements



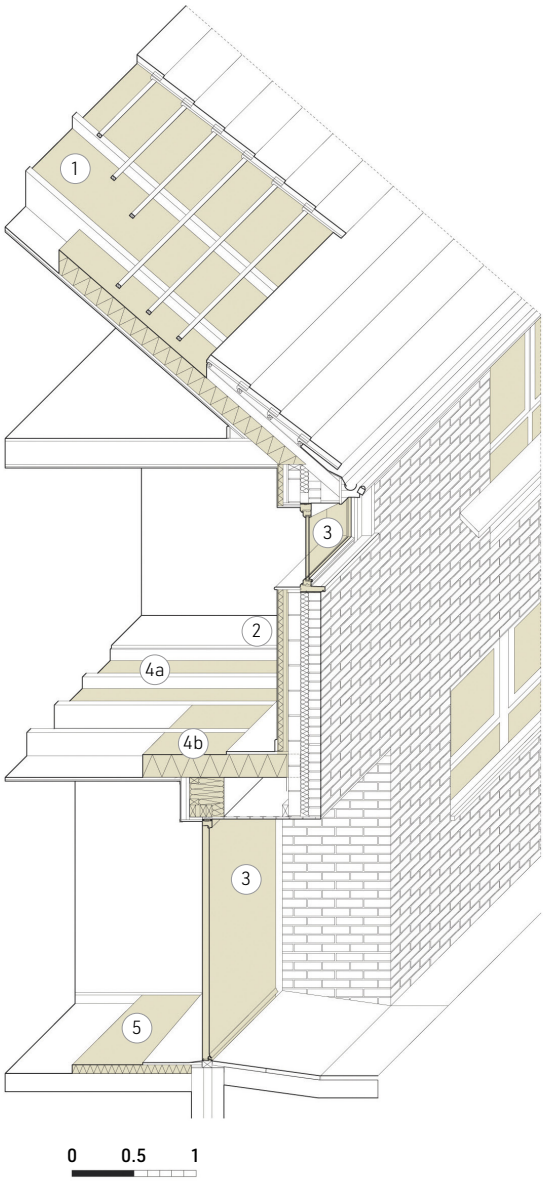
Domestic hot water strategy



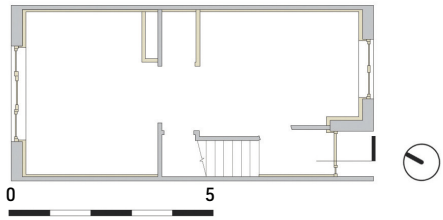
Fabric U-values post-retrofit (W/m^{2}K)



Detailed section



Key ground-floor plan



1 ROOF
existing tiles
50 × 25 mm treated softwood tiling battens
vapour permeable underlay, seal laps at valleys and penetrations with tape
min. 25 mm ventilation gap between breathable felt and insulation
150 mm PIR insulation board between rafters
insulated dry-lining plasterboard

2 WALL
existing facing brickwork
existing insulated cavity
existing internal blockwork
existing plaster finish
9.5 mm plasterboard, 6 mm plywood and 40 mm Spacetherm aerogel (material derived from silica gel)
sheet mechanically fixed to GypLyner system

3 WINDOWS/DOORS
new timber-frame double-glazed windows
new timber door (front: insulated door blank with softwood stiles; rear: hardwood mortised and tenoned door)

4a INTERMEDIATE FLOOR
100 mm mineral wool between existing joists
150 × 200 mm PIR insulation between joist and external wall to minimise thermal bridging

4b INTERMEDIATE FLOOR ABOVE ENTRANCE
190 mm rigid thermoset insulation floor board friction fitted between existing joists, provide nail restraint to base of insulation
existing framing removed and replaced with new airtightness membrane and 75 × 50 mm treated softwood framing with mineral wool insulation

5 GROUND
75 mm rigid thermoset insulation board with 18 mm T&G chipboard
DPM, all joints 300 mm lapped, twice folded and taped to form 100 mm min. welded joint; lap DPM up wall by min. 150 mm
existing beam and block floor

FURTHER DATA

COST

The team reported that the cost of the project placed restrictions on doing it again on the same basis, but many lessons have been learned that can inform future projects. The team reflected on the choices that had been made and stated that they would probably not use Spacetherm (aerogel) insulation boards for internal wall insulation generally because of the expense but would use small amounts of the material in places where thickness is at a premium (e.g. for window reveals).

Costs 2010	
Fabric (insulation wall + ground + roof)	£81,712
Windows + doors (included in fabric)	–
Services	£35,365
Other costs for retrofit	–
Subtotal	£117,077
Non-energy-saving measures	–
TOTAL	£117,077

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

MONITORING AND COMFORT LEVELS

This project has been extensively monitored and analysed by Rickaby Thompson Associates Ltd.

The levels of CO_2 in the living room and the relative humidity in the living room and both first-floor bedrooms show that the Nilan VP18 unit is providing sufficient ventilation for the property and good internal air quality.

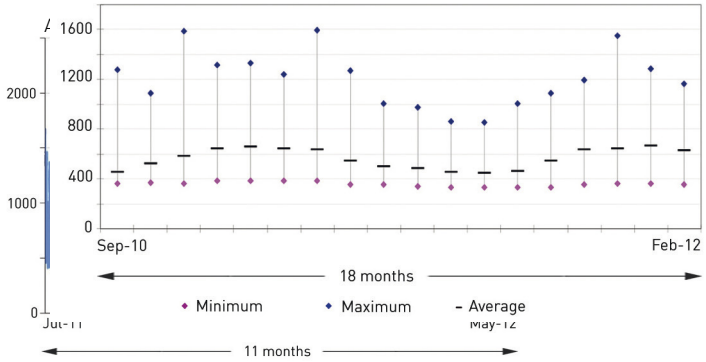
The internal temperatures in winter months are very good, with 20°C on average in the first year and 23°C in the second monitored year.

On the subject of monitoring the services, it is worth mentioning that the team measured that the solar hot water system is supplying the majority of the domestic hot water used in the property from mid-spring until early autumn. In 2011, the solar hot water system was delivering hot water from mid-March until mid-October. The analysis of the Nilan unit's electrical consumption during June and December 2011 shows that the domestic hot water system appears to be working as designed.

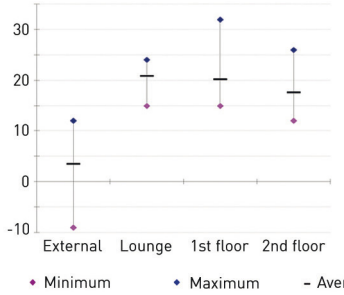
SPECIAL FEATURE

On completion of the project, the team reported:

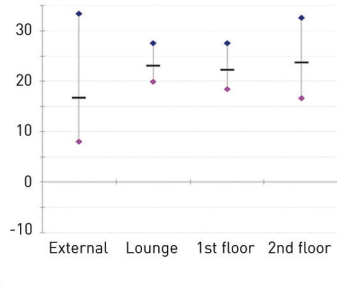
'It has become apparent that the Retrofit for the Future standard of 80% reduction in CO_2 emissions at current emissions factors is inappropriate and unaffordable. We think 60% reduction in CO_2 emissions at current emissions factors is more appropriate, and retrofit to this standard seems to cost approximately half as much. The balance of the overall 80% emissions reduction can be made up by decarbonisation of the electricity grid, allowable (i.e. off-site) solutions and an element of replacement of the worst performing dwellings with new "zero carbon" homes. For us, this is the most important lesson we have learned from Retrofit for the Future.'



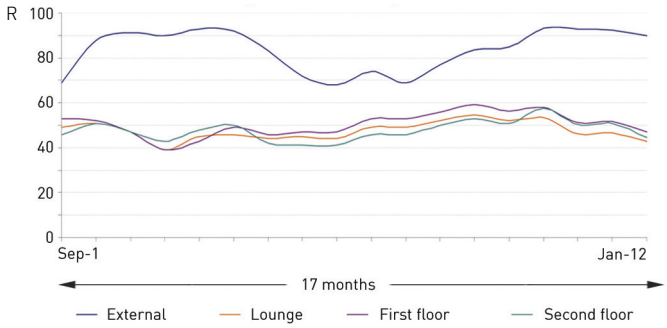
Average temperatures (°C), winter 2010–11



Average temperatures (°C), winter 2011–12



Average relative humidity (%)



Coach Road

Post-1919
TSB-77 and 78

Internal floor area: **80 m² per house**

Primary energy
pre-retrofit calculated: **531 kWh/m²/yr**
post-retrofit calculated: **107 kWh/m²/yr**

Client: **Gentoo Sunderland**

Architect: **Devereux Architects (project architects: Mark Siddall, now of LEAP: Low Energy Architectural Practice, and Adam James, now of Acton Ostry Architects)**

Contractor: **Gentoo Construction**

Consultants: **Alan Clarke (services and PassivHaus)**

This project features a pair of semi-detached houses of traditional cavity construction built in the 1960s and located in Washington, Tyne and Wear. The houses are typical of the client's housing stock (the client owns approximately 20,000 houses of this type, or very close derivatives). The original aims and objectives were to achieve a space-heating demand of 50 kWh/m²/yr and a primary energy demand of 107 kWh/m²/yr. This led to sub-objectives including replicability; keeping occupants in situ during the works; ensuring that the retrofit should not unduly compromise the space standards, or indeed the quality of life, provided by the existing building; ensuring that the technologies employed were (a) simple, (b) proven, (c) maintenance-free as far as possible, (d) cost-effective to maintain, and (e) understandable and occupant-friendly. Also, the technologies employed had to have potential additional benefits such as (a) improving indoor air quality and humidity, (b) improving the stability of energy costs so that occupants are less exposed to rising fuel bills, (c) helping to improve health and well-being, (d) helping to improve acoustic comfort as well as thermal comfort, and (e) helping to reduce fuel poverty.

During the design and construction process consideration was given to minimising and preventing a range of thermal bypass[15] mechanisms. Great attention was consequently given to airtightness and the installation of the insulation so as to avoid party wall bypass and wind-washing.

When these aspects of retrofits affect the thermal performance of insulation, they can short-circuit the insulation and cool down an air barrier system; these aspects are not currently considered within Building Regulations. It is, however, important to think of them during a retrofit as they can have a significant impact on the performance of the overall building fabric. In this project, the architect produced detailed site visit log sheets to highlight the issues observed on site, particularly those concerning the installation of the layer of external insulation. Photographic reports were also produced and now form a useful set of documents for educational purposes. This case illustrates the importance of the teams considering this issue just as seriously as the performance of the design.

Front facade pre-retrofit



Front facade post-retrofit



External wall insulation and installation challenges: gaps behind EPS insulation



STRATEGY

FABRIC

The walls were externally insulated with 270 mm of rigid insulation, which was then taken down 450 mm below ground level so as to reduce thermal bridging and increase the internal surface temperature (thereby avoiding mould growth during the winter). The external skirt of insulation means that the heat loss from the uninsulated solid ground-floor (which was not disturbed) could be reduced.

An air barrier was formed across the existing building envelope; a parge coat was used on the external walls and at roof level a membrane with taped joints. At the roof, new I-beam timber rafters were placed on top of the existing rafters with 350 mm of mineral wool between them. To reduce thermal bridging, the new airtight double-glazed windows were fixed within the plane of the external insulation layer. Finally, the internal spaces were only altered to fit the hot water cylinder, the MVRH system and its ductwork.

SERVICES

The ventilation strategy consisted of an MVHR system for the winter months and natural ventilation for the summer. For water heating, 4.1 m^2 of Viridian flat solar thermal panels were fitted to the roof, connected to a super-insulated twin coil hot water storage tank, which is also fed by a new gas condensing boiler. The space heating is provided by the boiler via the original radiators DHW Pipework, which was insulated.

Efficient household appliances and lighting were provided to reduce the primary energy demand and to reduce the cooling load that arises during the summer months.

RENEWABLES

The building's orientation was ideal for using solar thermal panels to reduce primary energy consumption. Water-efficiency measures such as low-flow showers and taps were included, not only to save water but also to reduce the amount of hot water that needs to be provided. Reference was made to the AECB Water Standards in an effort to ensure that the reduced flow rates remain realistic and practical.

VITAL STATISTICS

On the fabric upgrade, the architect reported that one of the particular challenges when improving the standard of airtightness was at roof level where the complexity of the existing structure, services penetrations and interfaces made this difficult. To reduce complexity, the air barrier was formed by taking a reinforced membrane over the top of the existing roof structure. This was then bonded to the external parging that forms the air barrier externally. It proved very successful, with a result below 1 m^3/m^2h @ 50 Pa.

Vital statistics

Characteristics	Before	Target	Measured
Primary energy ($kWh/m^2/yr$)	531	107	–
Space heating ($kWh/m^2/yr$)	–	39	–
Airtightness (m^3/m^2h @ 50 Pa)	11.9	–	0.94
Type of glazing	double	double	double
CO_2 emissions ($kg\ CO_2/m^2/yr$)	98	22	–

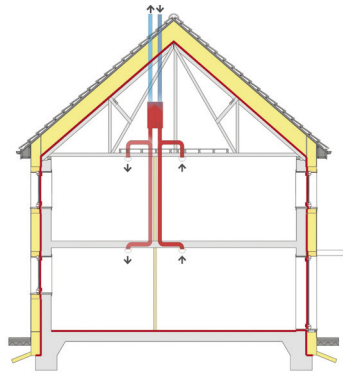
Installation of external wall insulation



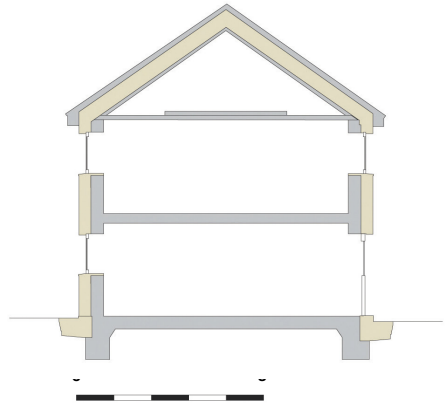


Rear facade post-retrofit

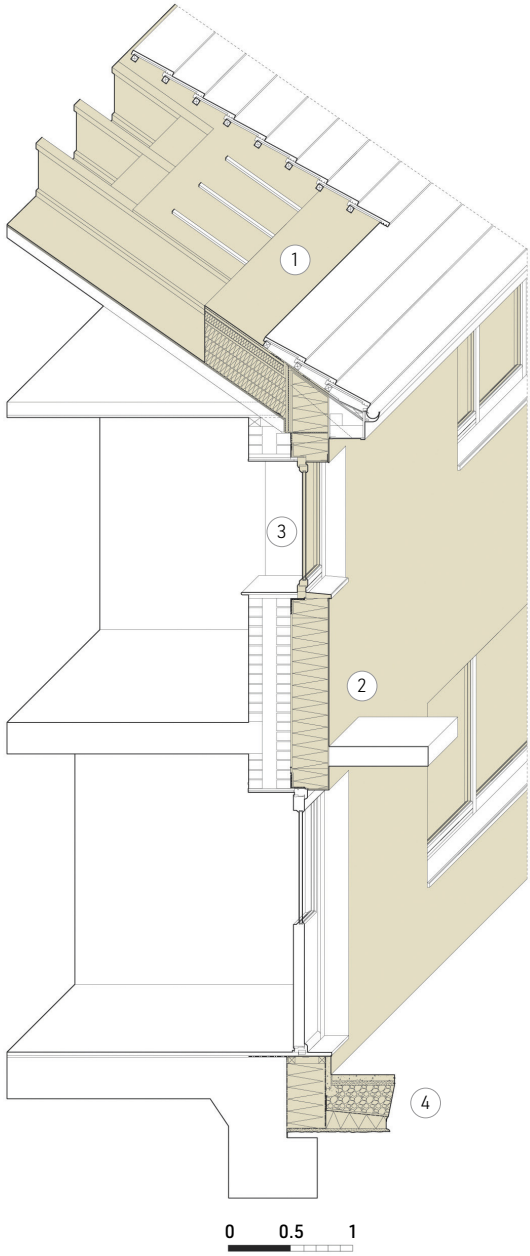
Ventilation (MVHR) and whole-house insulation strategies



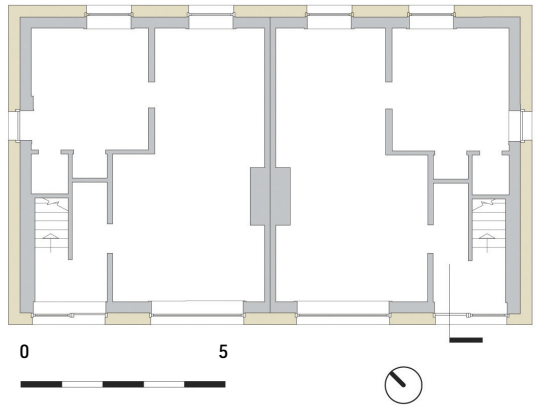
Fabric U-values post-retrofit (W/m^2K)



Detailed section



Key ground-floor plan



1 ROOF
roof tiles
47 × 47 battens on 25 ×19 counter battens
vapour permeable, windtight membrane with taped joints on OSB
new 350 mm I-beam rafter
350 mm mineral insulation between rafters
airtight membrane with taped joints
plywood board
existing rafters

2 WALL
render to exterior
270 mm rigid insulation (EPS)
airtight parge coat, formed using adhesive for EWI, bonded to existing building envelope
existing wall

3 WINDOWS/DOORS
double-glazed airtight windows

4 GROUND
perimeter to external wall: 90 mm concrete paving with laying course
external wall insulation continues 450 mm deep below ground level
backfill 100–150 mm thick, 500 mm wide below ground insulation

FURTHER DATA

COST

The team reported that some of the proposed works were omitted at design stage as their contribution to the reduction of CO_2 emissions was disproportionate to their cost. A good example of this was the insulation in the solid ground-floors. To install the required level of insulation throughout would have required a new staircase, alterations to upper floors, new internal and external doors, damp-proofing and other associated minor works. This element of the works was therefore not carried forward past the option appraisal stage; however, mitigation measures were taken, such as the installation of the perimeter insulation (external wall insulation carried below ground by 450 mm) to reduce cold bridging and heat loss.

MONITORING AND COMFORT LEVELS

Monitoring data is not currently available but will be eventually uploaded on the www.ukgbc.org/resources/retrofit-for-the-future-innovate-uk website. Please refer to the website for more information on monitoring and measured comfort levels.

Costs 2010	
Fabric (insulation wall + ground + roof)	£50,860
Windows + doors	£13,470
Services (MVHR and ductwork + solar and boiler)	£23,522
Other costs for retrofit	-
Subtotal	£87,522
Non-energy-saving measures (extension etc.)	£91,841
TOTAL	£179,693.00

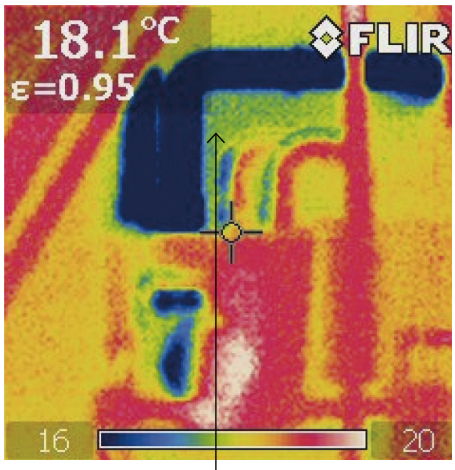
Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

SPECIAL FEATURE

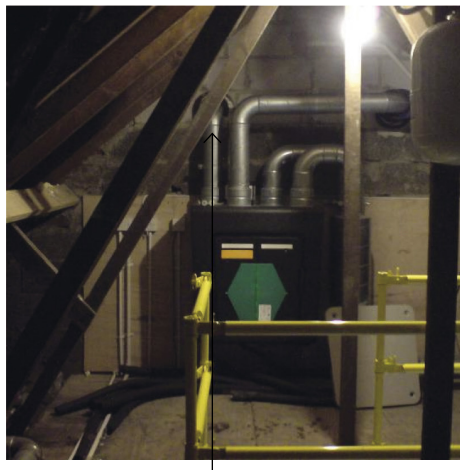
The project architects Mark Siddall and Adam James and engineer Alan Clarke designed the scheme following quality assurance procedures established by the PassivHaus standards. They oversaw the project on site, provided a clerk of works service and produced site visit reports that highlighted the successes, challenges and lessons learned. Andrew Farr of the Green Building Store was responsible for commissioning of the MVHR system and snagging prior to handover, as well as providing inspection and feedback to the relevant parties after the defects liability period. This is a process that is rarely seen but can fit small projects well. It allows a clear line of responsibility and quality assurance: an advantage for the client.

One of the site visit reports highlighted some missing insulation on primary ducts. The effect of not insulating these ductworks (heat loss, and condensation) are illustrated in the 'real image' and the 'thermal image' below. Clear illustrations of this nature helped all team members involved to embrace common issues easily.

Ventilation (MVHR) unit illustrating condensation issues when not insulated



primary ducts


primary ducts


condensation

Hensford Gardens

Post-1919

Internal floor area: **107 m²**

Energy Use Intensity
pre-retrofit calculated:**176 kWh/m²/yr**
Post retrofit step 1 measured 2016: **99 kWh/m²/yr**
Post retrofit step 2 measured 2023: **64 kWh/m²/yr**

Client: **Marion Baeli and Robert Prewett**

Architect: **Prewett Bizley Architects**

Contractor: **Borisa Ristic**

Consultants: **Green Building Store, Rodrigues Associates**

The staged retrofit of this mid-terrace 1960s family home achieved the PassivHaus retrofit standard EnerPHit level of performance (not yet certified). The retrofit was carried out alongside a wider re-planning of the house to suit the needs of the family. The step-by-step retrofit illustrates how building improvements can be realised over a number of stages and a number of years, which greatly helps spread the capital expenditure of the retrofit works as and when the family is able to invest.

At the outset, the client conducted a comprehensive analysis using computer modelling scenarios to assess the project's potential and determined that achieving EnerPHit certification (PassivHaus for retrofits) for the property was feasible. Due to budget constraints, it was decided to execute the work in stages.

The first stage, which was the most disruptive, involved adding a loft extension to create an additional bedroom/study, installing two roof lights and removing internal partitions on the ground-floor to create an open-plan space. In conjunction with these changes, insulation was added to the existing roof structure and ground-floor slab. Party walls were insulated, both internally (to mitigate thermal bridges) and within their cavities. Additionally, metal ducting was installed throughout the house to accommodate a future mechanical ventilation with heat recovery unit (MVHR) and avoid disruptive works later on.

Three years later, the second stage focused on replacing the front and rear facades. The original brick and block cavity walls, which had been filled with polystyrene beads, were removed and replaced with a super-insulated timber frame wall that supports new triple-glazed alu-clad timber windows.

The third stage addressed the MEP strategy, replacing the 15-year-old gas boiler and installing an MVHR unit to provide a constant fresh air supply and moisture extraction, an essential measure now that the house had been made more airtight.

A fourth stage saw all wet radiators removed and a single electric radiator installed in the dining area. Monitoring showed comfort was achieve throughout the winter.

A planned fifth stage will involve replacing the gas condensing boiler with an electric hot-water heat pump combi unit to provide domestic hot water.

Front facade



Internal wall insulation on party wall carefully taped to existing plaster



Cavity wall insulated with polystyrene beads being removed as part of stage one



STRATEGY

FABRIC

The house has a simple east-west 'shoebox' form with an efficient form factor, but the staggered adjoining houses complicated the insulation strategy. The building primarily featured brick cavity walls with timber floor joists spanning party walls. Various thermal elements of the building fabric were enhanced in different project stages.

Ground: The original screed was removed, and 80 mm of expanded polystyrene (EPS) insulation was added over the solid slab floor, with a vertical layer of insulation (XPS) on the slab edge and down into the ground to mitigate thermal bridging.

Roof: A flat roof was upgraded with 200 mm of PIR insulation and a new waterproofing membrane.

Party walls: Cavities were filled with blown rockwool insulation. Internal insulation (XPS) – well taped to plaster to avoid interstitial moisture build-up – was added where walls were solid and externally exposed.

Elevations: In stage two, the non-load-bearing front and rear elevations were rebuilt with highly insulated timber-framed walls and alu-clad timber triple-glazed windows.

Airtightness: Un-plastered brick areas were parged and joints were taped to ensure a continuous airtight barrier, including a new vapour control layer (VCL) below roof insulation.

SERVICES

During the third stage of works the MEP strategy was upgraded, including a new boiler and whole-house ventilation system with MVHR and galvanised ductwork runs, which is located in the roof extension.

Hot water: Currently produced by a gas combi boiler, however a switch to an all-electric hot-water heat pump is planned for the future stage.

Space heating: This was provided through a 'wet' system until December 2023, with five small radiators. However, since the fabric works have been completed, all radiators have been removed and a single electric one, located in the dining room, manages to keep the whole house warm throughout the year.

Ventilation: A PassivHaus certified MVHR unit is used with 89% efficiency and low specific fan power. It provides constant fresh air and extract moisture from all wet rooms.

RENEWABLES

There are currently no renewables installed, but PV and solar thermal units are planned at the next stage of work. The combination of renewables, hot-water heat pump and MVHR systems will complete the sustainable services strategy for the house.

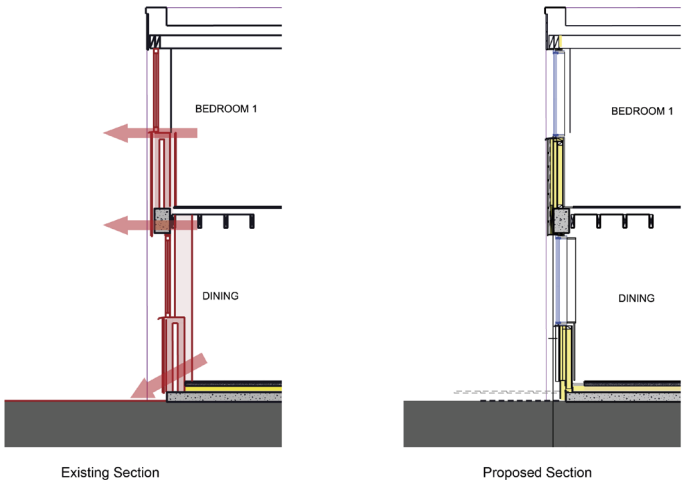
VITAL STATISTICS

The modifications made to the building over the four work stages have led to an approximate 60% reduction in energy use intensity (EUI). The graph below details the step-by-step EUI reductions achieved with each phase of work. This project attained impressive U-values, including flank walls at 0.17 W/m²K; end walls at 0.14 W/m²K; roof at 0.1 W/m²K; windows at 0.09 W/m²K; and ground-floor at 0.18 W/m²K.

Vital statistics

Characteristics	Before	Target	Measured 2016	Measured 2023
Primary energy (kWh/m²/yr)	–	60	50	–
Energy use intensity (kWh/m²/yr)	178	–	110	64
Space heating (kWh/m²/yr)	150	–	23	–
Airtightness (m³/m²h @ 50 Pa)	–	–	0.63	0.96
Type of glazing	double	–	double	triple
CO_2 emissions (kg CO_2/m²/yr)	70	–	–	–
Annual gas use (kWh)	-	–	3,787	4,214
Annual electricity use (kWh)	–	–	2,844	3,264

Section showing stage one thermal bridges and stage two remediation



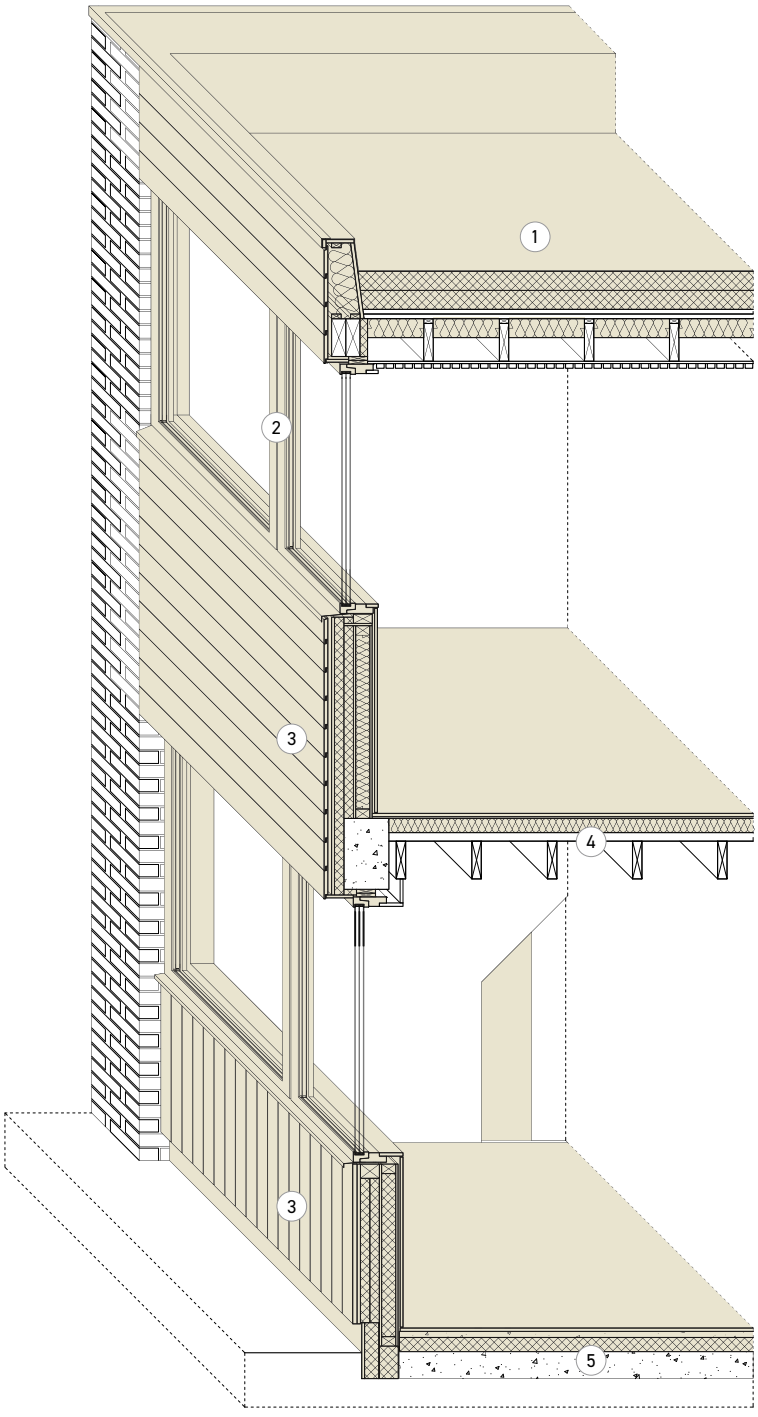
Existing Section

Proposed Section

Stage two with new insulated timber-frame front facade and windows being installed

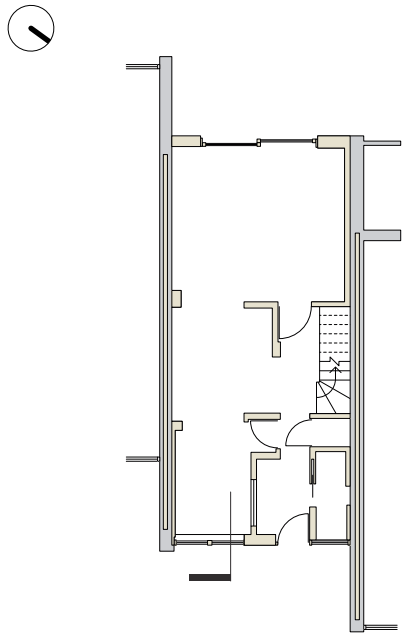


Detailed section (1:50)



0 0.5 1m

Key ground floor plan (1:200)



0 1 5m

1	FLAT ROOF
OUTSIDE	EPDM Membrane
	200mm PIR insulation
	existing 25m concrete screed
	existing 25mm Stramit board
	25mm firrings
INSIDE	200 x 50mm joists with mineral wool infill
2	WINDOWS
	Triple-glazed aluminium-clad timber framed windows
3	WALL
OUTSIDE	25mm timber cladding (vertical or horizontal)
	18mm timber battens
	15mm cement board
	2 x 50mm Vacuum Insulation Panel
	12mm plywood
	75mm stud framing with EPS insulation fill
	12mm plywood
	25mm PIR insulation
	15mm cement board
INSIDE	Plasterboard on batten
4	INTERMEDIATE FLOOR
FLOOR	18mm Plywood
	50mm battens on rubber pads with mineral wool infill
	20mm original timber floor, with fire-rated paint on underside
	Timber joists
5	GROUND FLOOR
FLOOR	10mm floor tiles
	30mm Screed
	75mm Rigid Insulation
	on top of DPM
	Existing concrete slab

FURTHER DATA

COST

The total budget for stages one to three of the build was £150,000. The energy efficiency measures were about £55,000.

MONITORING AND COMFORT LEVELS

The house performs very well, with occupants finding it very comfortable, with the exception of the risk of overheating in the summer. There were no observable moisture issues following the retrofit works. RH levels have been consistently stable save for some rooms with slightly elevated RH which may be associated with a small roof leak (now resolved).

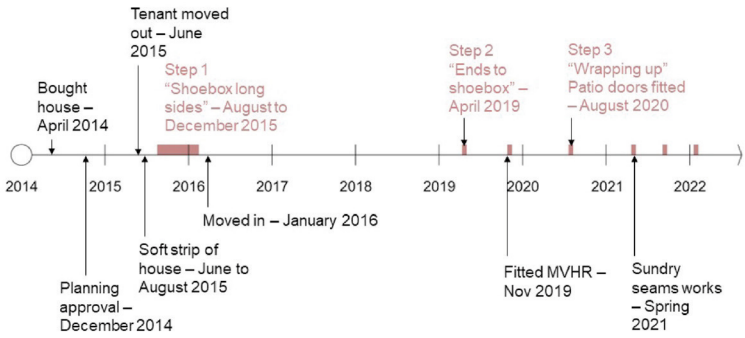
SPECIAL FEATURE

During stage two of the works, when the front and rear facades were completely relaced, as much of the removed material was recycled. Bricks and blocks were crushed and reused to form the base of a new terrace and landscaping at the rear of the house. The original 5 m-long oak facade cladding panels were taken down, re-planed, painted and re-installed on the new timber frame facades. The windowpanes of the original PVC glazing were taken down and reused to form allotment glass houses. A strategy of 'no waste to landfill' was tested, highlighting the size of the challenge that the industry faces in order to become truly circular.

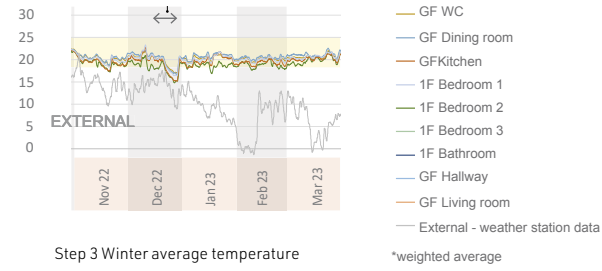
Costs 2010	
Fabric (Insulation: ground-floor £2,000; roof £3,000; walls £10,000 (two phases); airtightness estimated at £3,000)	£23,000
Windows + doors + rooflights	£20,000
Services (MVHR + ducts + boiler + radiators)	£12,000
Subtotal	£55,000
Non-energy saving measures	£95,000
TOTAL	£150,000

Costs exclude:
VAT; contractor's prelims; design fees; monitoring costs (installation, equipment or collection of data).

Retrofit timeline



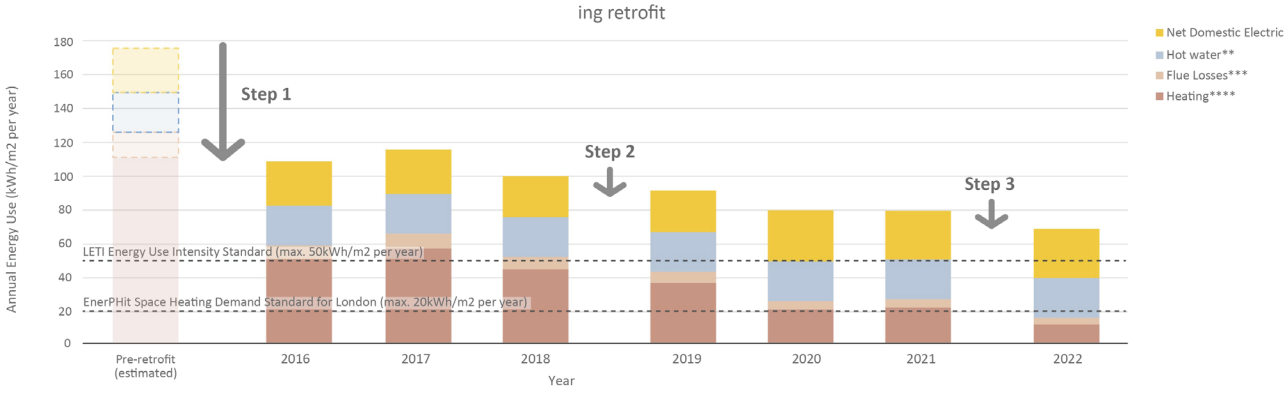
Summer temperature sensor data



Step 3 Winter average temperature 2022-2023 19.7 °C

*weighted average

EUI at each stage



** Annual Hot Water use is inferred as 7kWh/m2 per year, based on recording gas use over summers 2019-2023 when the heating is off.
*** Overall gas use has not changed significantly, therefore it is assumed that boiler efficiency has remained at 90%.
**** Space heating demand is inferred having made the assumptions on energy use for hot water provision and flue losses.

RETROFIT REVISIT:

Hensford Gardens

SIGNIFICANT CHANGES SINCE THE ORIGINAL RETROFIT

As a 'step-by-step' project, building works have continued since the initial occupation in 2016.

Occupancy: The family group has remained the same, but the children have grown up from a baby and toddler to young children. Pandemic lockdowns for 2020 and 2021 likely increased both domestic electrical loads and hot water use, a pattern that is still partly true.

Building: Refer to the above 'Retrofit timeline'.

ENVELOPE

Overall fabric performance: After an eight-year process the external envelope work is complete and the space heat demand for 2022/3 meets the PassivHaus Enerphit target. While a number of cold bridges had been left during the process, no condensation was ever observed, and these have now been made good. During the March 2023 retrofit revisit testing, the airtightness test showed that a high-level window in the bathroom had been left open for some weeks, possibly explaining why gas use that month exceeded expectation and why the heat transfer coefficient (HTC) measurements from that month were also much higher. Using data from December 2022, the measured and calculated HTC values show a much closer relationship.

Airtightness integrity: There appears to be a modest difference between the 2016 airtightness test and 2023 airtightness test (q50 0.70 to 0.96 m^3/m^2h). This may have been due to fabric degradation or the test rig not fitting especially well in the front door opening (it dislodged twice).

Post-retrofit revisit note: Another test was carried out in December 2023, which resulted in a q50 0.59 m^3/m^2h, which confirmed the possible issue with the previous blower door test.

Further investigations: The owner has a moisture content sensor located in one of the cavity walls. The moisture content of a block of timber attached to it varied over the year from 10% to 16%, indicating that the cavity insulation remains 'dry'.

Rectifications: The building fabric is all in good condition and no defects were observed. There was a flat-roof leak in 2020/21, which has been rectified.

SERVICES

Heating: The simple 'wet' heating system, consisting of five small radiators, has provided adequate heating for the whole house since the first retrofit step.

Hot water: A combi boiler is used. The hot water consumption appears to be relatively high (around 2,550 kWh/yr) based on summer measurements, suggesting daily consumption of 7 kWh. This may be due to poor boiler efficiency associated with short duration washes using the hand basin and kitchen tap, possibly exacerbated by longish (6 m) pipe run to the kitchen tap.

Ventilation: The MVHR unit was installed by the owner of the building, an architect, who used a 'balometer' to roughly balance it and has tested the CO_2 count within the rooms. Measurements of electrical use suggest an annual consumption of 460 KWh/yr in line with the PassivHaus PHPP estimate of 480 kWh/yr. The primary ducts are made of EPS insulation but are missing a layer of armaflex neoprene closed-cell insulation around them, which has left galvanised jointing pieces exposed giving rise to occasional 'sweating'. Filters are changed three to four times per year.

ENERGY PERFORMANCE (AVERAGES OVER 12-YEAR MEASUREMENT PERIOD)

March 2023 data: The gas usage in March 2023 was around 17 KWh/day.

Discounting for flue loss and hot water left around 9 kWh/day, whereas a PHPP model suggested around 6–7 kWh/day. Therefore, March 2023 appears to be an outlier (see note earlier about a window that was open during the testing period).

Annual data for stage one project: The PHPP model predicted heat demand of the original retrofit was around 60 $kWh/m^2/yr$ (assuming an internal temperature of 20°C), and the measured use was around 50 $kWh/m^2/yr$ (internal temperature 21°C).

Annual data for the completed project in 2022/3: The total annual gas use for 2022/3 was 39 $kWh/m^2/yr$ (using GIFA) with a split of 24 $kWh/m^2/yr$ for hot water and assumed waste of 4 $kWhr/m^2/yr$ associated with flue and interpolated space heat demand of 11 $kWh/m^2/yr$. The EUI measured for 2022/3 was 68 $kWh/m^2/yr$ (with a high(ish) domestic electric use of 30 $kWh/m^2/yr$).

INDOOR ENVIRONMENTAL PERFORMANCE

Temperature and relative humidity have been good since stage one of the retrofit and have tended to become more stable as the retrofit stages progressed.

Temperature: During winter 2022/3 the average temperature was 19.7°C and the previous two years were almost identical. The March 2023 temperature record showed an average internal temperature of around 19.5°C, which closely matched the winter average (perhaps little cooler due to the open window). Rooms are set by TRV. Living spaces tend to be around 21°C and bedrooms closer to 19°C as a matter of occupant choice. During the summer periods, it is clear that the relatively large glazing area can make the house

prone to overheating, though when the occupants are at home and able to manage natural ventilation and shading the annual overheating is only 7%. Temperatures look very stable with a modest daily fluctuation of less than 1°C.
Relative humidity: This was generally between 40% and 60% for the March 2023 period. This is seen as very good.
CO_2 concentration: The CO_2 levels during March 2023 remained constantly below 1,000 ppm, and have been consistent since the MVHR installation, indicating a very good air quality (except when the airtightness test was carried out and the unit switched off). The monitoring carried out from 2018 to date showed similar continuous low levels of CO_2. Before that point, the occupant had managed to keep CO_2 levels low by relying on infiltration and opening/closing windows.

COMMENTARY ON PHYSICAL FINDINGS VS USER FEEDBACK

The internal temperature, RH and CO_2 levels have been stable and at close to optimum levels, which matches the positive user feedback. Looking at the longer-term measurements provided by the occupant, the home appears to have become more comfortable over time and it is interesting to note the slight reduction in internal air temperature that took place when stage two was carried out – suggesting that fewer drafts and higher internal surface temperatures allow a slightly lower internal temperature. The current heating demand appears to be under prediction, though this may be partly counted for by the higher-than-normal internal gains associated with the domestic electrical use, as well as the internal average temperature being just below the modelled 20°C assumed in the PHP. After the new airtight windows were fitted, the occupant noted that commissioning the MVHR became essential as managing CO_2 by opening/closing windows became very difficult.

SERVICES STRATEGY

Hot water: The hot water is produced instantaneously by combi boiler.
Space heating: The space heating only has heat emitters in five spaces. The system is powered by a Worcester condensing boiler without weather compensation operated by simple thermostat/programmer.
Electricity: Measured data shows an annual domestic electrical use of 3,150 kWhr/yr (29 kWh/m^2/yr), which is quite high. This appears to be inflated by a 'rogue' refrigerator, which consumes close to 3 kWhr/day (almost three times its declared value). If this is replaced the annual use is expected to fall to less than 2,300 kWhr/yr.
Ventilation: There is a Paul 200 MVHR unit in the loft extension with short insulated primary ducts and a rigid metal branch ductwork system for supply and extract. PHPP indicated a performance of 89% heat recovery.
Renewables: Currently there are none; PV and solar thermal planned for future.

USER FEEDBACK

Questionnaire findings (SOAP BUS used): The homeowner is generally very satisfied with the house, save for some reservations regarding the tendency to overheat and the overabundance of daylight within some of the spaces. Both are a result of the original glazing pattern and large glazed area to the new loft extension. While the glazing area at the rear was reduced a little, a bolder approach would have reduced the overheating. The owner/designer is intending to fit clip on external shades to a number of windows in 2024 having trialled some mock-ups in 2023 with positive results.

BPE TECHNIQUES: LESSONS LEARNED

The short time to plan the testing, combined with limited study period to carry out the tests (due to funding requirement to complete the exercise before the end of March 2023 and the necessity to capture a winter/cold month) reduced the potential scope and value of some of the findings.
Description of the BPE approach: Smart HTC measurement/calculations; mould risk assessment; airtightness measurements (blower door test and Pulse); eight years of energy consumption and internal environment data.
Airtightness testing (blower door and Pulse): The blower door test was hampered by the owner not having closed all windows and the door rig slipping out of the opening more than once. The difference between previous tests was around 0.3 m^3/m^2h @ 50 Pa, which is small and could be attributed to measuring error. The blower door test and Pulse results seemed to align quite well, indicating that Pulse may be useful for measuring permeability, if not leak detection. It is worth noting that, in this case, open windows were only disclosed by running the blower door fan. As Pulse does not highlight such issues it may be prone to recording misleading measurements.
Views on methodology: While the March 2023 HTC measurement seems to be unrepresentative due to a window being left open for most of the period (resulting in higher-than-normal gas use), a similar Smart HTC calculation has been performed using available data for December 2022. This output was much closer to that from PHPP but still markedly different (110 versus 67). This may be due to assumptions made by the HTC calculator regarding hot water use, compared with a known high(ish) consumption. The more energy efficient any house is, the bigger any impact between real and assumed hot water consumption will have in the HTC assessment. So, for highly efficient houses, this tool may be less reliable.

Beaulieu Avenue

Pre-1919

Internal floor area: **138 m²**

Energy Use Intensity measured in 2023:
25.4 kWh/m²/yr

Client: **Undisclosed**

Architect: **Howland Evans Architects**

Contractor: **Earl and Calam Design and Build Ltd**

Consultants: **Elite Renewables Ltd**

The property is a north-south oriented three-storey mid-terrace, built in the late 1960s. It is occupied by a multi-generational family who wished to upgrade the building fabric to improve the internal environment, and to enable the installation of an air source heat pump to replace the existing gas boiler. Works included the installation of aerogel as external wall insulation, a centralised MVHR system and new, triple glazing throughout. External solar shading was installed to first- and second-floor windows at the rear to address excessive solar gain. Works were carried out in phases to allow the family to remain *in situ* throughout.

The main living space and kitchen are on the first floor with bedrooms on the second floor; the ground-floor houses a bedroom for the owner's mother (converted previously from the garage), a shower room, utility room and a study. At early stages of the project, the possibility of reconfiguring the internal layout to allow for a kitchen and dining space on the ground-floor was explored, but this was later discounted due to the costs associated of upgrading the fabric, as well as the required disruption.

The decision to maintain the existing layout also made it viable to retain the uninsulated ground-floor slab. It would have been preferable to excavate in order to install floor insulation, but this proved to be prohibitively expensive. The ground-floor rooms are generally 1–2°C colder than those on the upper levels as a result, but the ground-floor acts as a buffer to those above, which are more intensively used. PIR insulation has been added to the ground-floor walls between studs, so the owner's mother's bedroom and shower room, both at the front, are much more comfortable than they had been previously. The small portion of cavity to the rear wall has not yet been filled with cavity-wall insulation, but the owner may opt to do this in the future.

The project is a successful retrofit that demonstrates the effectiveness of an air source heat pump in meeting the space heating requirements of a common house type in London and the South East, with a nuanced approach to fabric upgrade where only walls and roof have been significantly improved. The insulation works were unobtrusive externally, allowing the architectural character of the original house to be retained. Unsympathetic and poor-quality later additions, such as UPVC windows, are replaced with high-performing, well-designed, contemporary windows that better reflect the original design aspirations.

Rear facade during construction



Rear facade showing solar shading retracted (left) and deployed (right)





STRATEGY

FABRIC

Given the age of the property, it had been assumed that all of the external walls would be of cavity construction. This would have allowed for the economical and straightforward installation of blown insulation into the cavity. This was true of a small portion of the brick-faced ground-floor wall at the rear. However, during investigative opening-up, it was discovered that the first and second floors were 140 mm, aerated concrete blocks plastered internally and clad externally with tiles on battens or T&G cladding (timber, later replaced with UPVC). As a result, an external wall insulation approach was chosen.

The use of insulation boards as internal wall insulation was initially explored, with the intention of achieving a U-value of 0.2 W/(m^{2}K) or lower. However, the preferred solution was to use a 20 mm layer of high-performance, non-combustible aerogel insulation as external wall insulation, fixed to the outside face of the blockwork behind the cladding. This had the significant benefit that the owner was able to remain *in situ* throughout, as there was very little disruption internally. The external appearance remained totally unchanged, as the masonry party walls projected 100 mm beyond the line of the cladding, which offered space to add the thin layers of aerogel. A U-value of 0.45 W/(m^{2}K) was achieved a much-enhanced value from the existing 2.0 W/(m^{2}K) calculated.

The existing UPVC double-glazed windows were of poor quality and the owner was motivated to replace them to improve the internal thermal comfort and to increase noise reduction, particularly to the rear, which faces a busy road. Triple-glazed composite windows from Velfac were chosen; these open inwards to allow ventilation when the external shading is deployed. Choosing a window type with a shading strategy is critical to enable both functions – ventilation and shading – to operate simultaneously.

SERVICES

The majority of the internal pipework and radiators have been retained (to minimise disruption and cost). It was not necessary to install larger radiators as is commonly understood to be necessary with heat pumps, as the improvements to the building fabric offset the lower flow temperature of 45°C. Fabric improvement was instrumental in this case.

A heat loss survey was carried out and the unit sized by a specialist contractor, Elite Renewables. The installation was offset by a domestic RHI rebate, then replaced by the government's boiler upgrade scheme.

An airtightness test has not yet been conducted, but the works appear to have improved the overall airtightness of the house, helped in part by the removal of trickle vents and the new windows with better seals. A whole-house ventilation strategy was therefore required. PIV with MEV extraction was explored for the kitchen and bathrooms, however the owner was motivated to install MVHR throughout for completeness. This was possible without significant disruption, as the building has a compact plan arrangement, and the existing service risers were able to also accommodate the MVHR ductwork. The unit was installed in the loft space, with fresh-air intakes installed at the front, away from the busy road to the rear. The owner wished to monitor internal pollutant levels prior to installing environmental filters, and the data indicates a level of PM 2.5, well below the WHO maximum level of 10 µgm-3.

RENEWABLES

A 4.32 kW PV array was installed on the rear roof slope. No battery storage was installed as space internally was limited. The owner is interested in installing a bidirectional EV charger once these are commonly available. A solar diverter has been installed to divert excess energy from the PVs to the hot-water storage cylinder.

The installation of the air source heat pump has enabled the property's mains gas connection to be removed. As a whole, the upgrades have reduced the property's annual energy demand by an impressive 73%.

VITAL STATISTICS

The project was commissioned by a private client, whose primary motivation was to reduce the energy demands and CO_2 emissions associated with their property. Although the replacement triple-glazed doors and windows represent around one quarter of the overall costs, their carefully considered design and superior thermal performance mean that both the visual appearance and the comfort of the house are greatly improved.

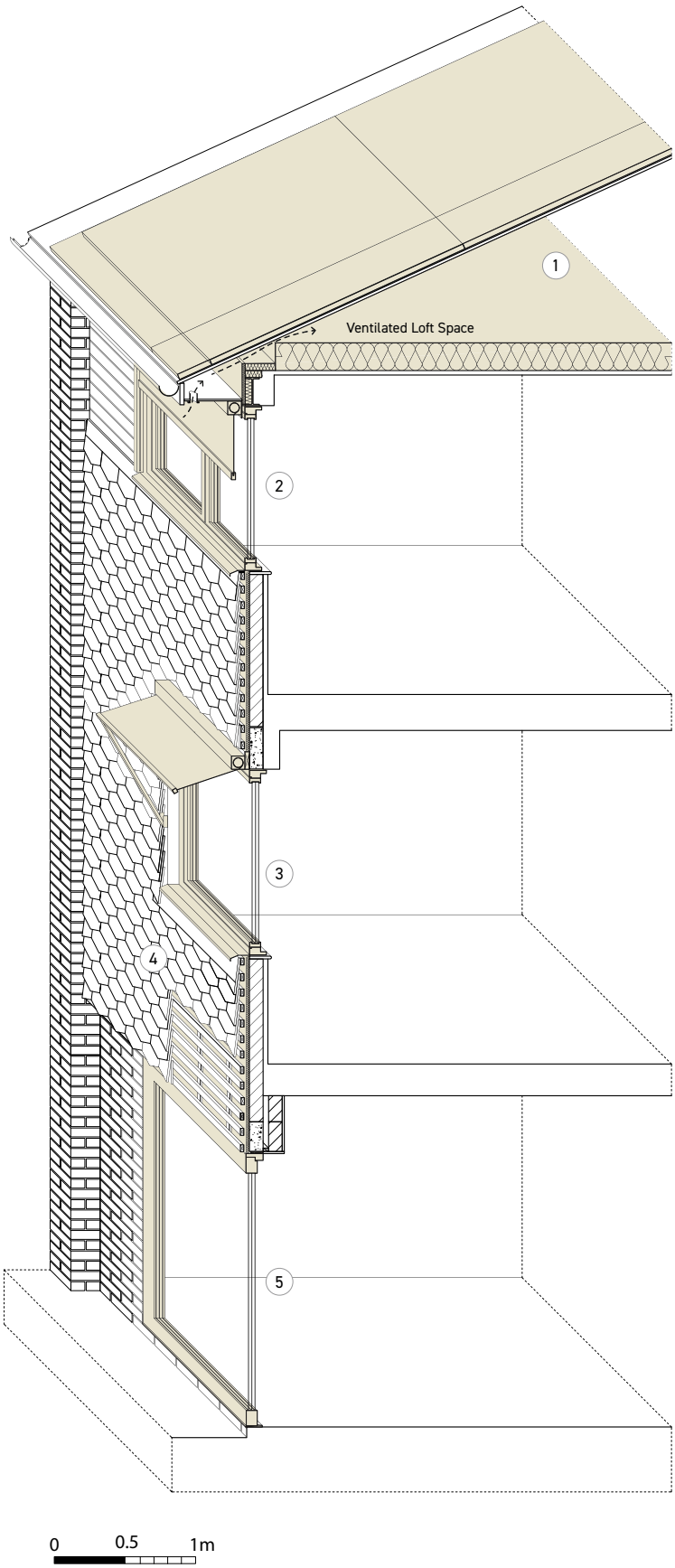
Similarly, aerogel is much more expensive than other insulation boards, but its use allowed the external appearance of the house to be reinstated while achieving a significant thermal upgrade of the fabric. Removing and rehanging the tiles over the insulation was labour intensive and costly, but it would be much simpler for a house with timber-cladding, which is common to other similar houses of the period.

The contractor had significant experience working on low-energy retrofit projects, and brought valuable expertise pertaining to airtightness and the MVHR system.

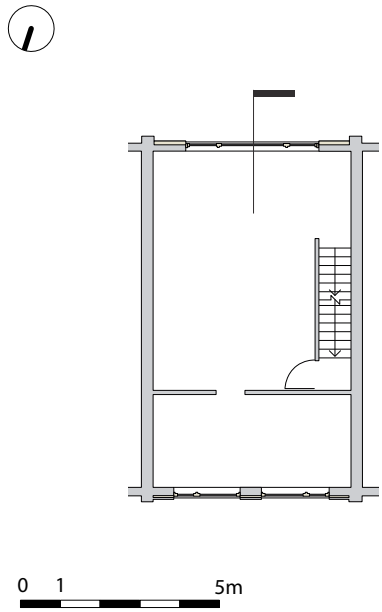
Vital statistics

Characteristics	Before	Target	Measured 2022	Measured 2023
Primary energy (kWh/m^2/yr)	–	–	–	–
Energy use intensity (kWh/m2/yr)	107.7	–	79	25.4
Space heating (kWh/m^2/yr)	–	–	–	–
Airtightness (m^3/m^{2}h @ 50 Pa)	–	–	–	–
Type of glazing	double/ single	–	triple	triple
CO_2 emissions (kg CO_2/m^2/yr)	–	–	–	–
Annual gas use (kWh)	–	–	–	–
Annual electricity use (kWh)	–	–	–	0

Detailed section (1:50)



Key ground floor plan (1:200)



1 ROOF

OUTSIDE Photo-voltaic panels
Existing roof tiles retained where possible
Existing rafters retained
200mm mineral wool loft roll insulation between and over joists at ceiling level
Plywood soffit

INSIDE Existing ceilings retained

2 SECOND FLOOR WINDOW
Mineral wool insulation packed tightly into web of existing steel lintel above window
Triple-glazed aluminum-clad timber frame window unit installed in existing opening
External roller blind shading device (head box fixed to new soffit)

3 FIRST FLOOR WINDOW
Drop-arm awning / shading device (head box attached to softwood pattress with lead dressing, attached to existing concrete lintel)
Triple-glazed aluminum-clad timber frame window unit installed in existing opening

4 FIRST & SECOND FLOOR WALLS

OUTSIDE Existing arrow-head terracotta tiles retained
Tyvek breather membrane
Horizontal timber battens
Vertical timber battens
20mm Aerogel insulation
Existing single-leaf concrete blockwork

INSIDE Existing render & skim

5 DOOR
Triple-glazed aluminum-clad timber frame French door unit installed in existing opening

FURTHER DATA

COST

Enhancing the building fabric, including walls, roof, windows and doors, cost approximately £49,500. The new services, including ASHP and PVs, cost just under £20,000, and the retractable shading cost £6,700.

MONITORING AND COMFORT LEVELS

The design team were concerned that MVHR may not be suitable, given the unproven airtightness of the property. Recent research from the PassivHaus Trust indicates that MVHR can still be effective in homes with an airtightness of up to 9 m^3/m^2h @ 50 Pa. The monitoring data and energy consumption figures suggest that the MVHR system is operating effectively and efficiently. Due to budget constraints, an M&E engineer had not been engaged to produce a design/whole-house strategy, so a designer was employed by the contractor to specify a 'contractor-designed' system. The internal environment is much improved in terms of thermal comfort, noise reduction, humidity levels and air quality.

SPECIAL FEATURE

Solar shading has been incorporated into the refurbishment of the south-facing rear facade. External shading is much more effective than internal shading as it prevents the sun from heating up the surface of the glass, therefore minimising the radiant heat transfer through the window. External solar shading is common throughout Continental Europe, and it seems likely that rising summer temperatures will also lead to wider adoption in the UK, both in new-build and retrofit projects.

Bespoke solutions were considered, but ultimately it was agreed to procure proprietary products from established manufacturers. On the second floor, horizontal drop-down white blinds from Renson match the adjacent T&G cladding. On the first floor, a projecting Markilux awning was chosen; when deployed, the yellow fabric creates a striking architectural element that complements the warmth of the red shingle cladding. Both systems have discrete white PPC housings, so are inconspicuous when not in use.

Costs 2010	
Fabric (insulation wall + ground + roof)	£26,604
Windows + doors	£22,994
Services (MVHR and ductwork + solar and air source heat pump) including RHI rebate)	£19,864
Solar shading	£6,720
Non-energy-saving measures (asbestos removal + essential roofing work)	£10,430
Scaffolding (24 weeks hire)	£6,536
TOTAL	£92,918

Costs exclude:
VAT; contractor's prelims + design fees.

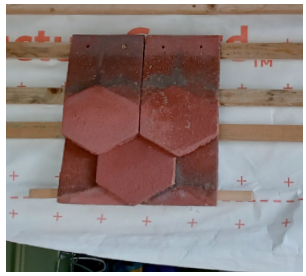
Installation of aerogel insulation



Installation of MVHR ductwork

Commencement of the rehanging of tiles to the rear elevation





Leadwork soakers dress the edges of the rehung tiles, prior to the installation of the solar shading to the rear elevation



PV array

Air source heat pump





Wilmcote House

Post-1919
TSB-77 and 78

Internal floor area: **12,646 m² (whole building)**

Energy Use Intensity Intensity
pre-retrofit calculated: **91 kWh/m²/yr**
post-retrofit measured in 2023: **56 kWh/m²/yr**

Client: **Portsmouth City Council**

Architect: **ECD Architects**

Contractor: **Keepmoat/Engie with GSA Architects and Curtins Engineers**

Consultants: **Wilde Carter Clack, Keegans**

Wilmcote House is an 11-storey residential building in Portsmouth. Built in 1968, its original structure comprised of large, poorly insulated pre-cast concrete panels with inefficient windows and extensive thermal bridges, leading to high heat losses, internal condensation, mould growth and low internal comfort levels. With no place to relocate the residents within the existing 107 flats and maisonettes, Portsmouth City Council commissioned ECD Architects to regenerate the building, with the residents remaining in situ. The project aimed to achieve a reduction in space heating demand by significantly reducing fabric heat losses following the principles of the PassivHaus/EnerPHit. It was, at the time of completion, the largest residential building in the world designed to the EnerPHit standard, delivered with residents in occupation.

The Wilmcote House project had various quantitative and qualitative POE studies completed during a period of over 10 years, before, during and after the retrofit works. These studies found evidence of fuel poverty before the retrofit and evidence of much-improved environmental conditions after the works, as well as little need for active heating to reach WHO-recommended minimum indoor temperatures during the winter months, hence eliminating fuel poverty and improving residents' comfort, health and wellbeing.

Wilmcote House was originally built using a prefabricated large panel system (LPS), which required very careful consideration of both the structural condition and any proposed adaptations. The existing prefabricated wall panels included a very small amount of insulation, but this was ineffective and, alongside inefficient double-glazed windows and old electric storage heaters, the flats experienced high levels of heat loss.

The fact that the residents could be classified as experiencing fuel poverty was evidenced by the monitoring undertaken by the team from the University of Southampton; this showed how economic constraints resulted in many residents underheating their homes (below WHO recommendations), which also exacerbated the risk of damp and mould growth.

The existing building suffered from a downward spiral of decay and required a radical overhaul. The retrofit design sought to deliver a fresh, bold vision of high-quality housing that met the stringent retrofit design standards and created a future-proof, low-maintenance building that residents can be proud to call home.

Road-side facade shown before the retrofit process



Facade during the construction stage and the installation of the external wall insulation





STRATEGY

FABRIC

The thermal and airtightness strategy involved the simplification of the thermal envelope in plan and in section, as well as the improvement of the building's form factor. This strategy avoided extensive thermal bridges around the walkway slabs, and allowed the external corridors to be enclosed and the living rooms to be extended to meet the new external wall (gaining 7 m^2 per home).

The main stair cores were left uninsulated and outside the thermal envelope, which also significantly improved the building's form factor. The three blocks were externally insulated with nearly 300 mm of non-combustible mineral wool insulation. This wrapped the entirety of walls and roofs, protecting the existing structure from further weathering and extending its lifespan. Triple-glazed windows were installed on the main three blocks and double-glazed windows were installed on the two main cores outside the thermal envelope.

SERVICES

The building was not allowed to have a gas supply due to its LPS structural system and the risk of explosion and disproportionate collapse. The fabric first approach resulted in minimal heating required after the retrofit. The landlord removed old and inefficient electric storage heaters (previously one per room) and replaced them with small, direct electric heaters (typically one per maisonette, in the living room). All flats had high-efficiency individual MVHR units installed. The maisonettes originally did not have showers, only baths. The retrofit included the installation of electric showers and new, efficient hot-water cylinders. Purge extract fans, activated via the cooker hoods, were included for additional ventilation in the kitchens.

RENEWABLES

The building operates entirely on electricity, with no connection to a gas supply. This approach future-proofs the building, enabling it to further reduce carbon emissions as the national grid becomes greener. Additionally, the council is considering installing rooftop photovoltaic panels to further lower the building's operational carbon footprint.

VITAL STATISTICS

The building fabric's thermal performance was significantly enhanced, leading to a substantial reduction in space heating demand. As a result, fuel poverty among residents has been alleviated, the impact of current and future energy price increases have been mitigated, and health and wellbeing have improved due to the elimination of damp and mould.

Improved airtightness across the blocks was achieved through the application of a parge coat on the exterior of prefabricated concrete panels or airtightness membranes, depending on the location, alongside meticulous taping of all windows and doors. An airtightness champion was appointed to oversee inspections and ensure training for site operatives. The achieved U-values were 0.14 W/m^2K for walls and 0.09 W/m^2K for roofs.

While airtightness between individual flats was improved, the targets were established at block level, rather than for each unit. Post-retrofit, whole-building airtightness testing proved unfeasible due to the logistical challenge of coordinating all residents within a block. As a result, the contractor conducted airtightness tests on individual units, which do not directly reflect the overall block-level performance targets.

Vital statistics

Characteristics	Before	Target	Measured 2023
Primary energy ($kWh/m^2/yr$)	–	–	–
Energy use intensity ($kWh/m^2/yr$)	91	57	56
Space heating ($kWh/m^2/yr$)	57	23	22
Airtightness (m^3/m^2h @ 50 Pa) (single flat)	2.85	0.98	1.77
Type of glazing	double	triple	triple
CO_2 emissions ($kg\ CO_2/m^2/yr$) operational	19	12	12
Annual gas use (kWh)	–	–	–
Annual electricity use (kWh)	–	–	–

Completed elevations

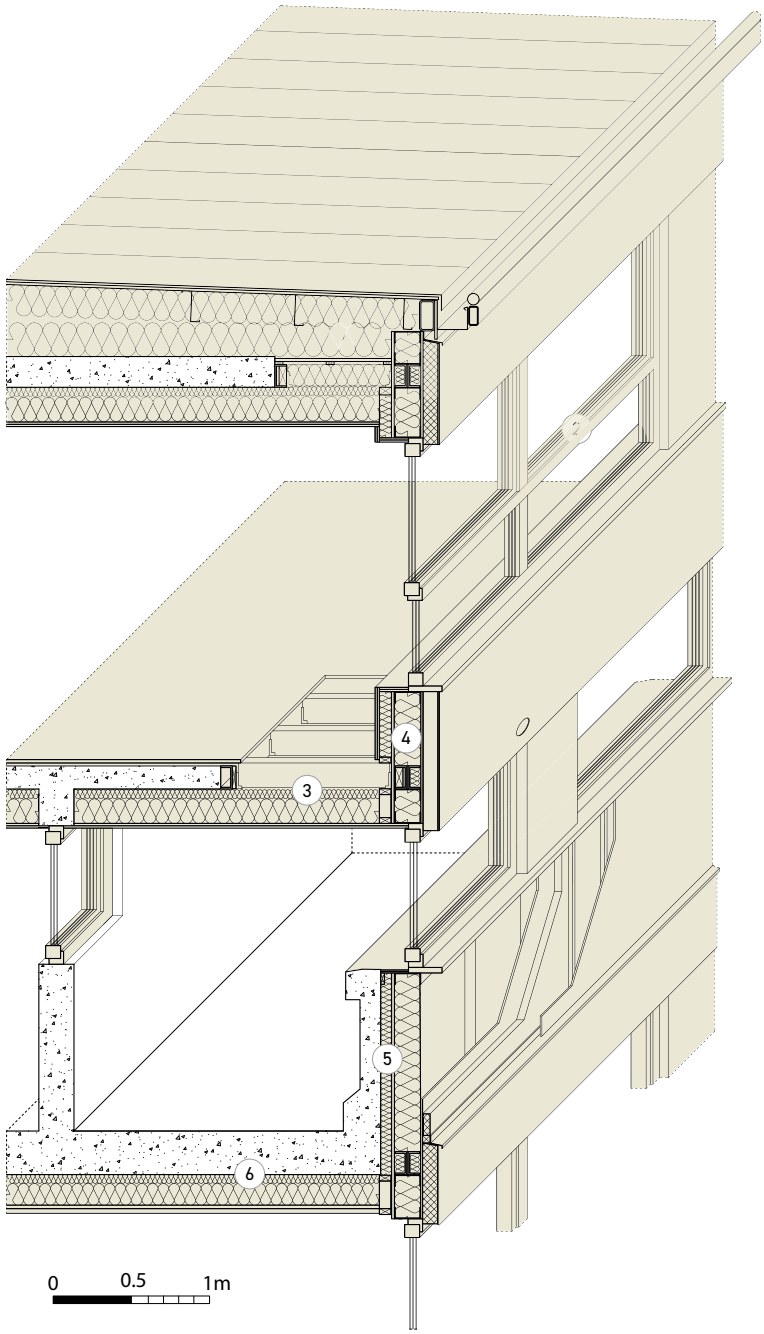


External walkways before and after the retrofit

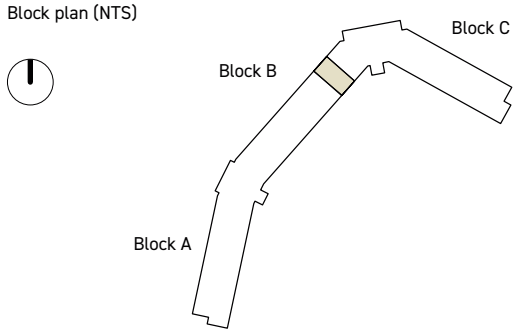




Detailed section (1:50)



Block plan (NTS)



1 ROOF (EXTENDED ROOF)
OUTSIDE roof covering
waterproof membrane
plywood deck
loft insulation between steel frame system*
plywood deck (extended section only below)
timber battens
loft insulation between joist hangers attached to steel frame system*
mineral wool insulation (2 layers varying thicknesses) between proprietary suspended ceiling system (for acoustic attenuation)
INSIDE plasterboard

2 WINDOWS
triple-glazed UPVC units sealed with airtightness tapes

3 INTERMEDIATE FLOOR (EXTENDED FLOOR)
FLOOR particleboard flooring
timber joists on joist hangers attached to steel frame system*
mineral wool insulation (2 layers varying thicknesses) between proprietary suspended ceiling system (for acoustic attenuation and MVHR ducting)
CEILING plasterboard

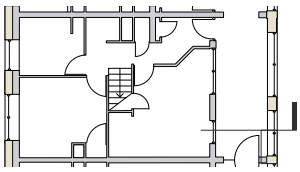
4 WALL (EXTENDED FACADE)
OUTSIDE mineral wool external wall insulation system with render finish
cement particle board
steel frame system filled with mineral wool insulation
plywood sheathing
air-tightness membrane
Timber studs filled with mineral wool insulation
INSIDE plasterboard

5 WALL
OUTSIDE proprietary cladding system with non-combustible insulation
cement particle board
steel frame system filled with mineral wool insulation*
plywood sheathing
mineral wool insulation between concrete and steel structure to address site tolerances
INSIDE existing concrete wall

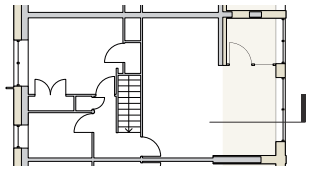
6 INTERMEDIATE FLOOR
FLOOR existing concrete slab
mineral wool insulation (2 layers varying thicknesses) between proprietary suspended ceiling system (for acoustic attenuation)
CEILING plasterboard

* (Steel frame system attached to existing concrete structure using thermal break plates)

Maisonette key plans (1:300)



Lower Floor



Upper Floor

FURTHER DATA

MONITORING AND COMFORT LEVELS

Wilmcote House has benefitted from extensive research and post-occupancy evaluation (POE) studies, providing valuable data on real-world performance. The London School of Economics (LSE) interviewed residents before, during and after the retrofit works, focusing on the health, social and financial impacts of the retrofit. Meanwhile, the University of Southampton monitored internal temperatures, CO_2 and humidity in selected maisonettes to assess the impact on winter fuel poverty and summer overheating.

Before the retrofit, over half of the monitored residents were not heating their homes to the WHO-recommended minimum temperatures (some as low as 13–15°C). Additionally, 28% never used their electric heaters due to fuel poverty. As a result, the expected energy and carbon savings, typically modelled on homes maintained at a constant 21°C, were unlikely to be fully realised.

If fuel poverty is not considered in energy modelling, projected energy and carbon savings are significantly overstated compared to actual meter readings. Excluding fuel poverty, this project would show a 75% reduction in total energy use. In reality, many homes were underheated before the retrofit, leading to varied savings. Although some flats now maintain 20–22°C in winter without active heating, savings ranged from 28% to 68%, with an average of 51.5%. Metered data showed an average 40% reduction, aligning with projections adjusted for pre-retrofit conditions.

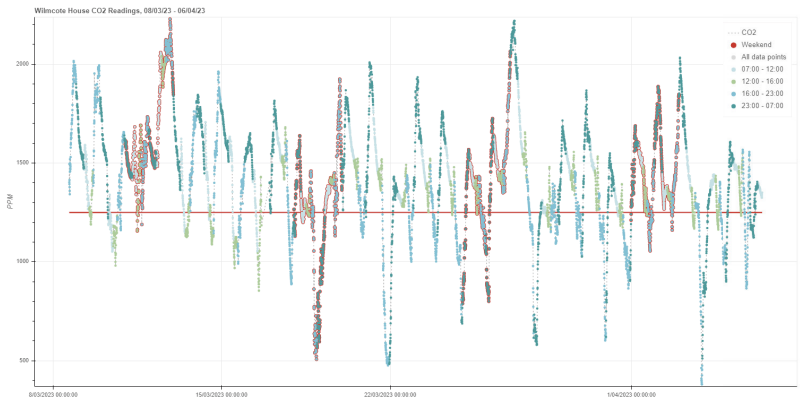
Further research over the first three winters after completion showed that the building could maintain minimum WHO temperatures with minimal or no heating. Sixty percent of monitored residents used heating less than once per week; whilst 36% not at all. A 2023 POE confirmed that the fabric-first approach improved thermal comfort significantly, even without active heating. Summer monitoring also showed improved performance: during a June 2018 heatwave when outside temperatures reached 32°C, indoor conditions stayed between 22°C and 27°C.

Following the retrofit, although some residents remained unable to operate their heating systems due to financial constraints, the improved building fabric now allows comfortable indoor temperatures to be maintained passively. As illustrated in this monitoring graph, pre-retrofit living room temperatures were significantly below comfort levels for a resident unable to afford space heating. Post-retrofit, under the same financial constraints, the indoor temperature stabilises at approximately 21°C during winter months. This reflects a substantial enhancement in the building's thermal performance, with clear benefits for occupant health, wellbeing, and resilience against fuel poverty.

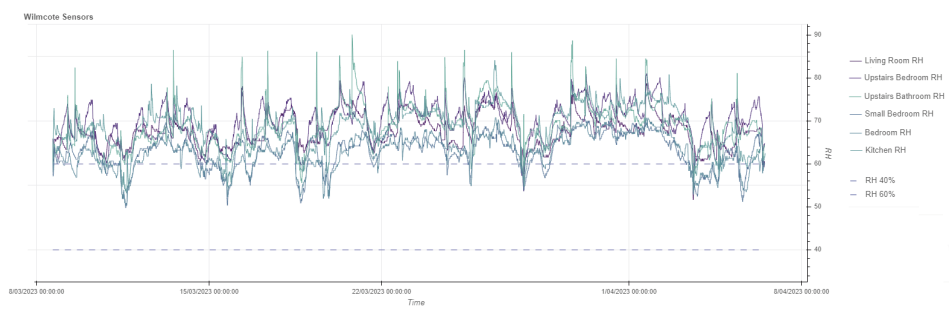
SPECIAL FEATURE

Residents were actively involved in the design process. ECD Architects and the council hosted consultation events and created a show flat to gather feedback and build engagement. At the time of construction, Wilmcote House was the largest residential EnerPHit project in Europe and became the UK case study for the EU-funded EuroPHit programme. The project team received funding to train clients, contractors and consultants in Passivhaus and EnerPHit principles, leading to the development of a step-by-step approach to phased certification. The completed scheme now stands as a benchmark in high-rise retrofit and has inspired similar projects across the world.

Wilmcote House; carbon dioxide (ppm)



Wilmcote House; relative humidity (%)



Blaise Castle

Post-1919

Internal floor area: **202 m2 (post-retrofit), 154 m2 (pre-retrofit)**

Primary energy
pre-retrofit calculated: **205 kW h/year**

post-retrofit measured in 2014: 64 kW h/year
post-retrofit measured in 2022: 72 kW h/year

Energy Use Intensity measured: **56**

Client: **Undisclosed**

Architect: **Ian Mawdit**

Contractor: **Greenheart Sustainable Construction**

Consultants: **Four Walls, Bent Copper Plumbing, Kilo Electrical**

This 1960s detached family home in Bristol was extended and retrofitted to achieve very low energy demand in line with the PassivHaus EnerPHit standard. The house alterations were required to meet the specific needs of the owners, which included two offices for the couple, who work from home. The layout changes included the conversion of a storage space on the lower-ground-floor into a kitchen/diner and the addition of a side extension. The facade was also altered to add character and interest. The thermal and comfort enhancements focused on addressing thermal bridges, enhancing the thermal envelope and installing a new MVHR unit for ventilation. Data loggers were installed before and after the build to give ongoing feedback of the performance of the building.

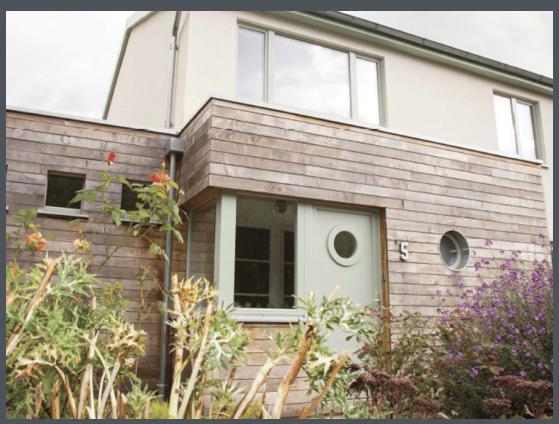
A key challenge of the project was overcoming thermal bridges caused by the concrete elements throughout the house, a common feature of a building of this age. A number of these, such as the guttering and external steps, also had a structural role, so could not simply be removed. Dealing with these required a balance between finding a practical solution that was also thermally effective, without pulling the whole house down.

A particularly challenging area was the concrete guttering that spanned all the way across the facade to act as a wall plate, taking the load of the trusses, rafters and roof. This was addressed by cutting the gutters flush with existing walls and burning up the external wall insulation as far as possible. Extending the existing rafters to create a new eaves line, with 60 mm of insulation across the top of the gutters, enabled a reduction in thermal bridges to an acceptable level.

The balcony was an extension of the concrete ground-floor slab, which created a significant thermal bridge. This was dealt with by shearing off the slab, so it was flush with the existing building, and replacing it with a timber balcony. This didn't eliminate the thermal bridge completely, but reduced to it an acceptable level. The concrete steps cast against the south side of the house were addressed by installing insulation on the rear side to minimise thermal bridges.

Once the thermal bridges were addressed, the thermal envelope was improved. The approach was external wall insulation with timber-framed triple-glazed windows. As well as enhancing the thermal envelope, the external wall insulation, finished with white render, keeps the internal temperature constant through winter and summer, and the white render radiates away solar energy in hot summers.

Rear elevation with EWI and balcony



Original Finlock gutter being removed



STRATEGY

FABRIC

A hybrid approach was used to create an effective thermal envelope. Cavity walls were filled with expanded polystyrene insulation (EPS), with phenolic external wall insulation (EWI) above ground, and extruded polystyrene insulation (XPS) below ground to the foundations. Where external wall insulation was not possible, internal wall insulation was used.

The solid ground-floor was partly replaced with an insulated slab in the new dining area on the lower-ground-floor, to increase the headroom and provide an opportunity to insulate the floor. However, this was an expense that couldn't be justified in the neighbouring utility room, where the existing ground-floor slab was retained and aerogel-backed board applied. This ultra-high-performance 20-mm layer enabled generous floor to ceiling heights to be retained in this area.

The existing roof was filled with cellulose insulation, and flat/warm roofs were treated with PIR insulation. New triple-glazed windows were installed throughout.

Thermal bridges: The EWI extends and abuts with the ground-floor/foundation insulation. The original Finlock concrete gutters were removed, which enabled roof eaves and insulation to extend and abut with the EWI. The original concrete balcony was removed and replaced with a timber ground-supported balcony. The existing porch was insulated to bring it within the thermal envelope.

Airtightness: The air permeability was reduced during the retrofit through targeted measures including a sand/cement render slurry coat applied before the EWI; air sealing tapes around openings and junctions; grommets to any services penetrations; and air-sealing foam around original intermediate floor joins that penetrated the cavity.

SERVICES

The original gas boiler, which was relatively new at the time of the retrofit, has been retained. It is oversized for the house's heating needs and there are plans to replace it in the future. A new multizone heating system replaced the original system, along with the installation of a new 210-litre vacuum-insulated hot-water cylinder.

A 300 m^3/m^2h MVHR system was installed as part of the retrofit, connected to rigid steel ducting throughout through house. This costs just £37 a year to run, plus £50 for filters and provides permanent fresh air and expels moist air.

RENEWABLES

There are no renewables at present. Original plans to install solar thermal has been abandoned due to technical advances in solar PV. There is a plan to install a PV array in the future.

VITAL STATISTICS

The carefully considered approach to improving airtightness and the building envelope resulted in impressive improvements to key building performance metrics as tested before and after the retrofit works. Airtightness has improved significantly, from 18.4 m^3/m^2h @ 50 Pa to 1.85 m^3/m^2h.

The building envelope has impressive improvements in U-values all helping to reduce drastically the house's energy demand:

- walls increasing from 1.4 W/m^2K to 0.14–0.12 W/m^2K;
- floors increasing from 0.57 W/m^2K to 0.13–0.25 W/m^2K;
- flat roofs increasing from 4.65 W/m^2K to 0.14 W/m^2K;
- pitched roofs increasing from 0.7 W/m^2K to 0.10 W/m^2K;
- windows and doors increase from 2.4–3.2 W/m^2K to 0.8 W/m^2K.

Vital statistics

Characteristics	Before (2011)	Target	Measured 2014	Measured 2022
Primary energy ($kWh/m^2/yr$)	gas: 19,349 elec.: 4,120	–	gas: 4,437 elec.: 3,181	gas: 5,910 elec.: 3,244
Energy use intensity (kWh/m2/yr)	91	57	–	56
Space heating ($kWh/m^2/yr$)	57	23	–	22
Airtightness (m^3/m^2h @ 50 Pa)	5.1	–	1.78	1.6
Type of glazing	–	triple	triple	triple
CO_2 emissions ($kg\ CO_2/m^2/yr$)	–	–	–	–
Annual gas use (kWh)	19,349	–	4,437	5,910
Annual electricity use (kWh)	4,120	–	3,181	3,244

Exposure of EWI above balcony section undergoing repairs



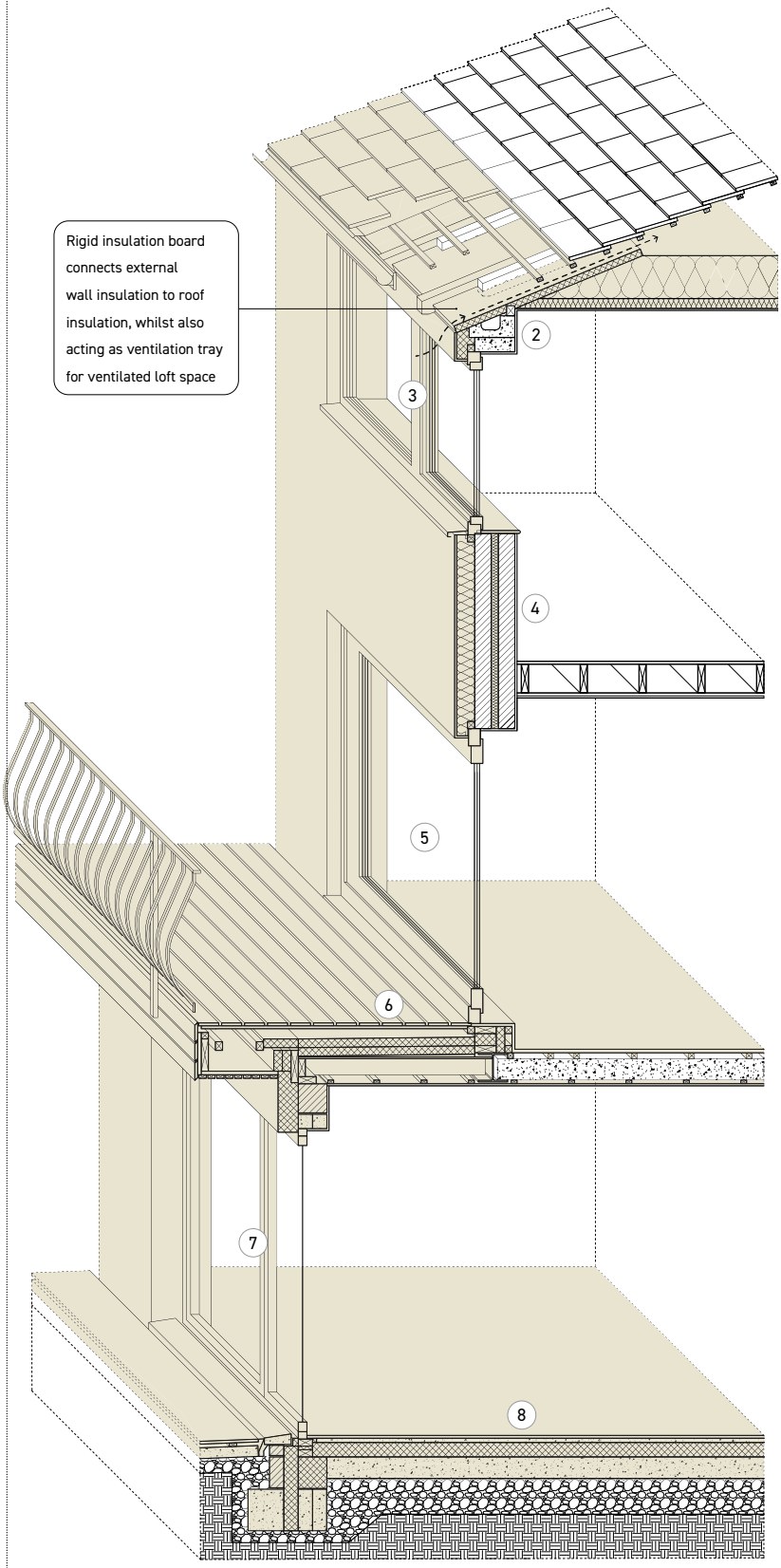
MVHR unit



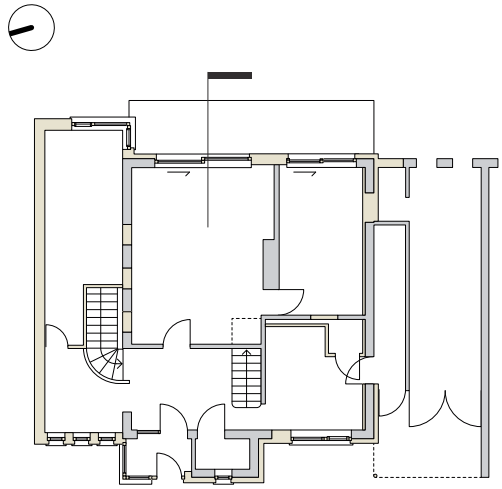
Cellulose roof insulation covering the MVHR ducts



Detailed section (1:50)



Key ground floor plan (1:250)



1 ROOF
Existing glass wool between joists removed. All penetrations in ceiling sealed with Pro Clima proprietary airtightness products. Warmcell cellulose insulation blown between and over joists to a depth of 400mm

2 EXISTING CONCRETE GUTTER
Existing concrete gutter cut back to allow for unbroken line of insulation. Existing rafters extended to facilitate external wall insulation and new rainwater gutter

3 SECOND FLOOR WINDOW
Triple-glazed timber frame window unit and new sill

4 WALL

INSIDE Plaster
Existing dual-leaf concrete block wall construction with cavity filled with Ecobead insulation
5mm Sand Cement parge and airtight layer
2 x 60mm Kingspan Kooltherm K5 rigid insulation with staggered joints

OUTSIDE 10mm through colour silicon render with mesh reinforcement

5 FIRST FLOOR DOOR
Triple-glazed timber sliding door unit

6 BALCONY

OUTSIDE Wallbarn support pavers with Wallbarn Sucupira timber decking tiles
PVC-free single ply flat roof membrane
Min. 110mm tapered Kingspan insulation
Pro Clima Intello Plus Vapour Control and Air tightness barrier
20mm Plywood sheeting
150 x 50mm C16 timber joist at 450mm centres

INSIDE 12mm Magnesium Oxide Board

7 GROUND FLOOR DOOR
Triple-glazed timber bi-fold doors

8 GROUND FLOOR
30mm Lafarge Gyvlon Flow Screed
100mm Kingspan Kooltherm K3 Floorboard
175mm Concrete Slab
1200g Visqueen Radon Membrane DPM
Compacted and graded hardcore

MONITORING AND COMFORT LEVELS

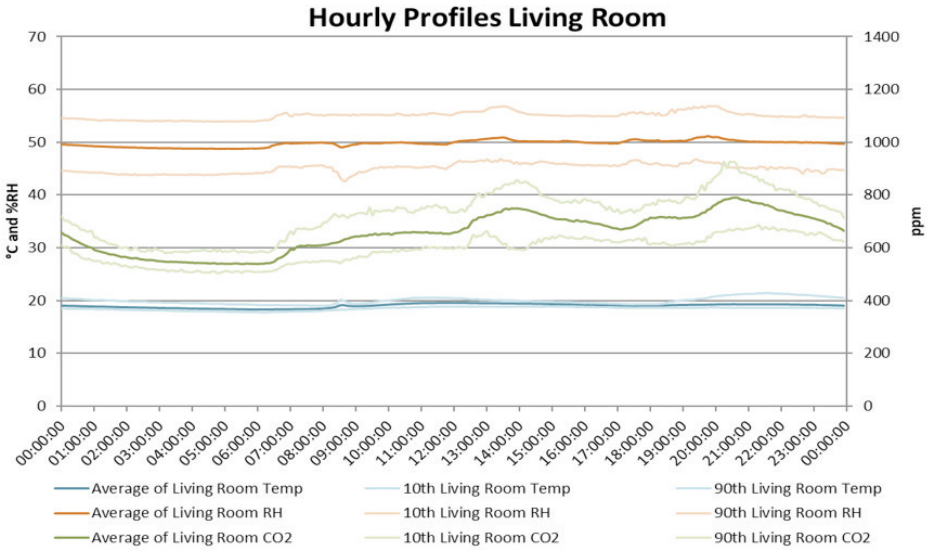
The conditions in the home are considered by the occupants to be comfortable. Temperature in winter is maintained to their desired comfort setting, and the application of EWI and use of triple-glazed windows has helped to reduce the pre-retrofit overheating conditions.

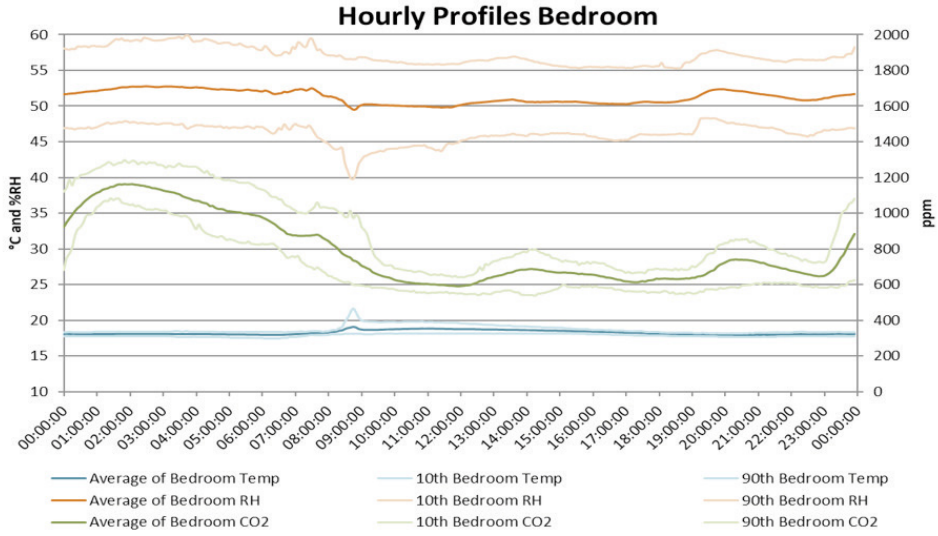
SPECIAL FEATURE

This project is an example of how a house of this age can be retrofit without removing all the original features. As noted above, 1960s houses often have challenging concrete details causing thermal bridges. This project demonstrates innovative detailing solutions that don't necessarily completely remove thermal bridges, but offer significant improvements that along with the building envelope enhancement create a very well performing house.

Costs 2010	
Fabric (insulation wall, ground and roof)	£18,250
Windows + doors	£19,600
Services (MVHR and replacement heating system)	£14,800
Other costs for retrofit	-
Subtotal	£52,650
Non-energy saving measures	£133,850
TOTAL	£186,500

Costs exclude:
VAT; contractor's prelims + design fees.





RETROFIT REVISIT:

Blaise Castle

SIGNIFICANT CHANGES SINCE THE ORIGINAL RETROFIT

Occupancy: No change
Building: The hot-water cylinder was replaced in 2019 (see below). Flat roof repairs were carried out in 2023 (see below).

ENVELOPE

Overall performance: The fabric still performs well despite some emerging concerns about the stability of the phenolic EWI system (see rectifications). The HTC measured was approximately equivalent to the design (SAP) value. U-value found to perform similar to design calculations.
Airtightness integrity: There is a small increase since original retrofit of 0.3 m^3/m^2h @ 50 Pa, which is due mainly to wear on external door seals, particularly due to tilt/slide doors and the minor misalignment on bi-folding door sections.
Further investigations: Some degradation has occurred to the EWI, where outer panels have bowed slightly. It is suspected to be caused by solar gains as inner panels are unaffected. The impact on performance has not been evaluated. The thickness of the roof/loft insulation results in a low U-value. However, this also results in a cold loft with high RH in winter (RH is above 85% during colder periods).

Swab tests taken by UCL from the rafters within the loft void confirm a high concentration of mould spores present *(aspergillus versicolor)*. This finding will trigger an intervention to increase the level of ventilation in the loft.

Rectifications needed: A small hole had been made in the new flat-roof membrane, probably at the time of the retrofit, but the associated water ingress had been concealed due to a high performing VCL. A recent investigation (January 2023) revealed this has caused substantive damage, resulting in the replacement of the roof and timbers above the VCL (May 2023).
Key lessons learned: Check performance and stability specifications when using phenolic insulation material for EWI applications. Be cautious when specifying thermal specifications too low, where there will be a cold void.

SERVICES

Heating: There have been no modifications since the original retrofit. The system delivers the desired comfort levels, although efficiency is slightly compromised due to undersized radiators. ASHP planned for 2024, which may require some radiator sizes to be increased.
Hot water: The domestic hot-water cylinder was replaced under warranty due to premature failure in 2019. The replacement cylinder is vacuum insulated and has a single coil (the original solar, hot water option now abandoned). Interventions were made in 2022 to improve efficiency.
Ventilation: The MVHR system was originally commissioned in December 2013 and further fine-tuned in April 2015. There have been no adjustments since then and the system has been maintained in continuous operation since installation, including during unoccupied periods as the property is in a radon area (radon accumulates if MVHR is off).

ENERGY PERFORMANCE (2022 VALUES)

EUI: 45.3 $kWh/m^2/yr$
Gas: 5,910 kWh/yr
Electricity: 3,244 kWh/yr
Space heating demand: 22.1 $kWh/m^2/yr$

INDOOR ENVIRONMENTAL PERFORMANCE

Conditions monitored through February and March 2023 in three rooms: main bedroom, living room and kitchen. No issues found with temperature, RH or CO_2.
Temperature (March 2023): Mean internal temperature (MIT) was maintained above set point temperature (18°C) during daytime occupied periods. At night (11:00pm to 7:00am) the heating sets back to 16.5°C. The MIT fell below the 18°C threshold during these periods for 10% of the time, with a minimum MIT of 17.2°C.
Relative humidity (March 2023): The mean RH values ranged between 48% and 51% for the bedroom and living room respectively, and 57% for the kitchen. The max RH recorded was in the kitchen at 63.2%. The performance criteria for a 24-hour rolling mean below 85% and a weekly rolling mean below 75% were not exceeded in any room at any time.
CO_2 concentration: The eight-hour rolling mean (applied to the bedroom CO_2 data for occupied hours) was 898 ppm during March 2023. This is within the threshold applied for bedrooms of 1,240 ppm based on a steady-state CO_2 concentration whilst sleeping in a room with a ventilation rate of 3.5 litres per second per person (this being the background ventilation rate in dwellings). The ventilation rate in the

bedroom during the occupied period was measured at just over 6 l/s (3 l/s/p). The exceedance above the threshold was for 5.5% of the occupied hours, or 14 hours in total.

In summary, the CO_2 concentration is within thresholds, and within expectations for the ventilation rate and level of occupancy.

COMMENTARY ON PHYSICAL FINDINGS VS USER FEEDBACK

The conditions in the home are considered by the occupants to be comfortable. Temperature in winter is maintained to their desired comfort setting, and the application of EWI and use of TG windows has helped to reduce the pre-retrofit overheating conditions.

SERVICES STRATEGY

Hot water: The gas energy used for hot water was 1,811 kWh/yr in 2014. The cylinder was replaced in 2019 with a more efficient unit, which reduced the hot water energy to 1,563 kWh/yr in 2022. In June 2022, the cylinder stat was reduced to 50°C (with a weekly one hour at 60°C for sterilisation), arising from the rising energy cost crisis. This intervention will also be reflected in the reduced energy between 2014 and 2022. Note: hot water energy demand is estimated by applying the average gas energy use during the summer months, minus the metered data for gas hob use, across the 12-month calendar year.

Space heating: The gas energy for space heating for the first year post-retrofit (2014) was 2,254 kWh/yr, equivalent to 12.5 kWh/m^2/yr (accounting for boiler efficiency), and is slightly less than the SAP-calculated space heating prediction of 13 kWh/m^2/yr.[19] The energy used for space heating has increased over the last few years and, in 2022, was 3,983 kWh/yr (22.1 kWh/m^2/ yr).

Electricity: The electrical installation is fully sub-metered. The highest consumption circuits are non-regulatory socket circuits, with the ground-floor being the highest consumer. The two occupants work from home full time, so there will be atypical IT energy patterns compared to other homes. Interventions were made during 2022 to reduce energy use for this circuit. It was found that the standby power for IT equipment and other electronics on the same circuit amounted to 430 kWh/yr. These savings, made by fitting simple plug-in timers, are approximately equivalent to the annual energy use for operating the MVHR system, which typically uses 330 kWh/yr, and the boiler pump/ancillary circuit which typically uses 115 kWh/yr.

Ventilation: Measurements of the MVHR flow rates and specific fan power performed during March 2023 were found to match or better the performance values from either the design or the manufacturer's declared values. Air flow rates for the normal use setting were measured to be 175 m^3/m^{2}h and for other, higher occupancy settings, 235 m^3/m^{2}h and 275 m^3/m^{2}h. The imbalance between intake and exhaust is 5.7%, which is within the recommended 10%.

The specific fan power in normal setting was found to be 0.77 W/l/s, which is the same value declared by the manufacturer.

Renewables: No renewables at present. There was a plan to install solar thermal, but this has since been abandoned owing to technological advances with solar PV.

There is a plan to install a 5.7 kWp PV array, connected to a 10-kWh battery store.

USER FEEDBACK

The owner/occupier/evaluator purchased the property to demonstrate the potential of a fabric first deep retrofit. By living in the property both pre- and post-retrofit, they appreciate the challenges in undertaking such a project, but have detailed knowledge about the building and how to optimise its performance.

QUESTIONNAIRE FINDINGS

The SOAP score was 96%, so the house scores 'very well'. Comfort conditions in winter reported as excellent. In summer, the responses suggest an average benchmark score for temperature and air movement. Some drawbacks were:

- proximity to amenities and local transport;
- utility costs due to recent £/kWh increases;
- high temperatures in bedrooms on hot summer days.

BPE TECHNIQUES: LESSONS LEARNED

Core BPE tasks were undertaken with some additional tests and measurements performed, which included thermography, MVHR measurements, and ambient and surface mould testing.

Airtightness testing (blower door and Pulse): The values tested on this property are close between fan method and Pulse. Further cases are needed to demonstrate robustness of the Pulse method in low leakage buildings.

Views on methodology: This is the only case study where ventilation air flow rates were measured. These can be used in conjunction with CO_2 measurements to make judgements about the performance of the ventilation for maintaining the intended IEQ conditions. The CO_2 measurements in this case study are higher than those found in other case studies. However, as the evaluator resides in this case study property, there was much more context to enable the evaluator to assess, e.g. window opening patterns in the CO_2 analysis. More rigour is needed for consistency of CO_2 measurements (placement of sensors, occupancy density/behaviour/ patterns), and analysis of data, e.g. using occupied periods only and applying rolling eight-hour averages.

Roof monitoring: This has proved to be valuable, particularly in conjunction with UCL swab samples. The spores present and the higher RH will now trigger an intervention for this property, e.g. to increase ventilation in the roof space.

Roof refurbishment: Shortly after the Retrofit Revisit study concluded, the owners opted to address the high relative humidity (RH) level observed in the loft during monitoring. The works were accelerated when Storm Bert caused damage in November 2024, resulting in water ingress.

The project involved a full strip of the roof back to rafter level, replacing the original concrete tiles and bitumen underlay with new tiles and a low-resistance, moisture-open membrane. Although high RH was observed in the original loft, the timber rafters were sound with no evidence of decay. As part of the refurbishment, an in-roof solar photovoltaic installation was added. This required increasing the ventilation path beneath the tiles and panel trays from 25 mm to 50 mm by using counter-battens. Additional over-fascia ventilation was installed alongside the original soffit ventilation to further improve airflow into the loft.

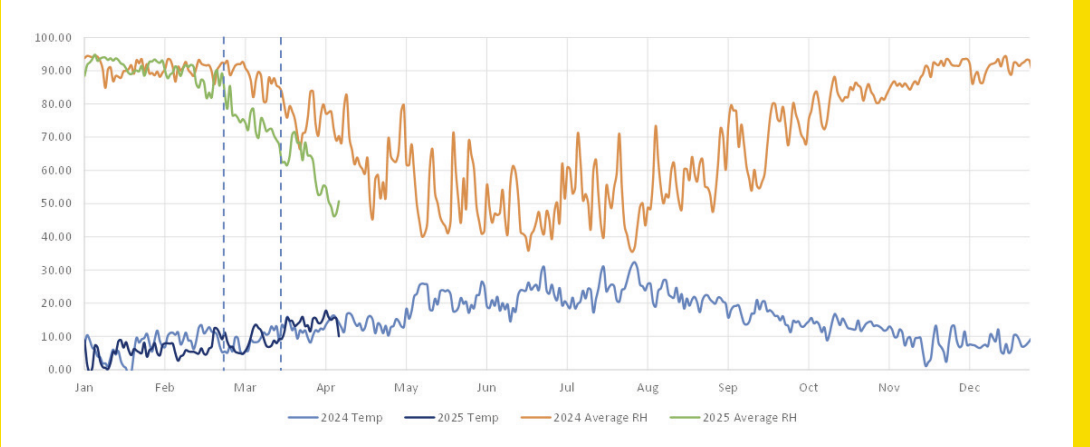
Roof works began toward the end of February 2025 and were completed by mid-March, as indicated between the blue dotted lines on the chart. The membrane replacement itself took just two days and was completed early in the programme.

Early findings (as of April 2025) indicate a 14.5% average reduction in RH in the loft space compared to the same period in 2024 (March to early-April), despite similar loft temperatures. Peak RH during this period was 78% in 2025, down from 93% in 2024, bringing levels below the 80% threshold for mould risk and the 85% threshold for timber decay. Monitoring and evaluation will continue through the year.

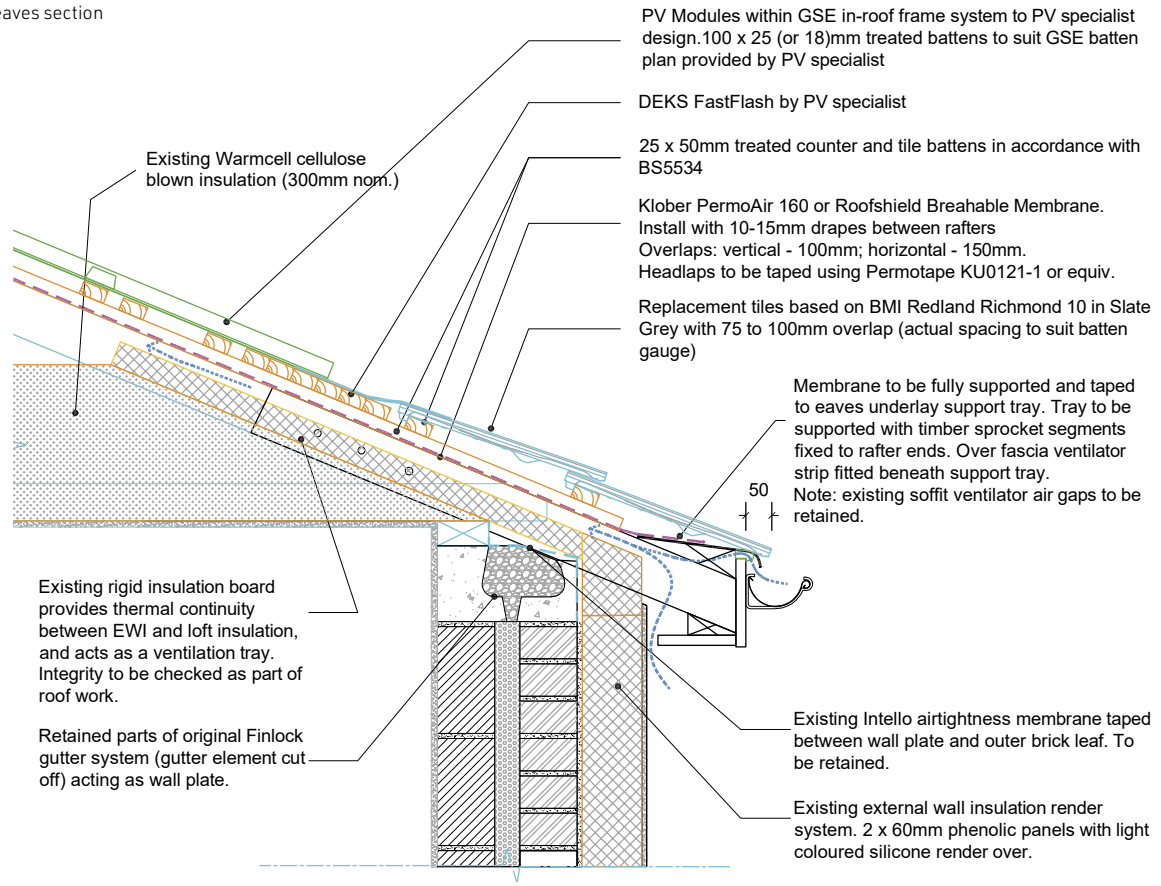
Solar photovoltaic: The system comprises 16-inch roof panels, each rated at 460 W providing approximately 7.4 kWp capacity. The hybrid inverter allows direct connection to a 10-kWh battery, expandable to 33 kWh if required.

Since commissioning in mid-March 2025, the system has delivered 97% self-sufficiency, with most of the 3% imported energy required to maintain inverter synchronisation with the grid. Approximately 60% of total generation has been self-consumed, with the remainder exported. While the system has benefited from a sunny start, it is expected to meet over 90% of the property's annual electricity demand.

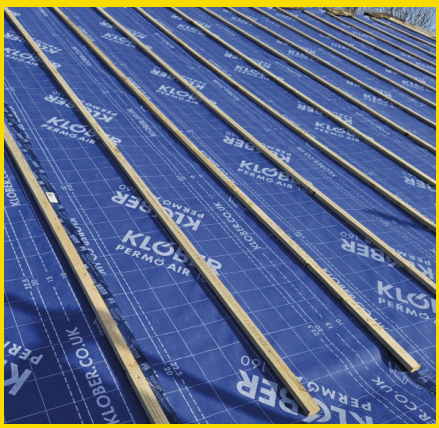
Loft conditions daily mean



Roof refurbishment construction drawing
detail of eaves section



New, low-resistance vapour-open membrane installed on front slope



Completed front slope with 10-inch roof modules



Completed rear slope with 6-inch roof modules



CHAPTER 4

Comparative commentary

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The Retrofit for the Future competition was a response to the challenge laid down by the UK Government's target to reduce greenhouse gas (GHG) emissions by 80% by the year 2050. The competition sought retrofit strategies that might achieve very significant reductions in CO2 emissions and primary energy consumption.

Three targets were set:

- 80% reduction in CO_2 compared to 1990 emissions;
- CO_2 emissions limited to 17 kg/m^2/yr (20 kg/m^2/yr for PHPP);
- primary energy limited to 115 kWh/m^2/yr.

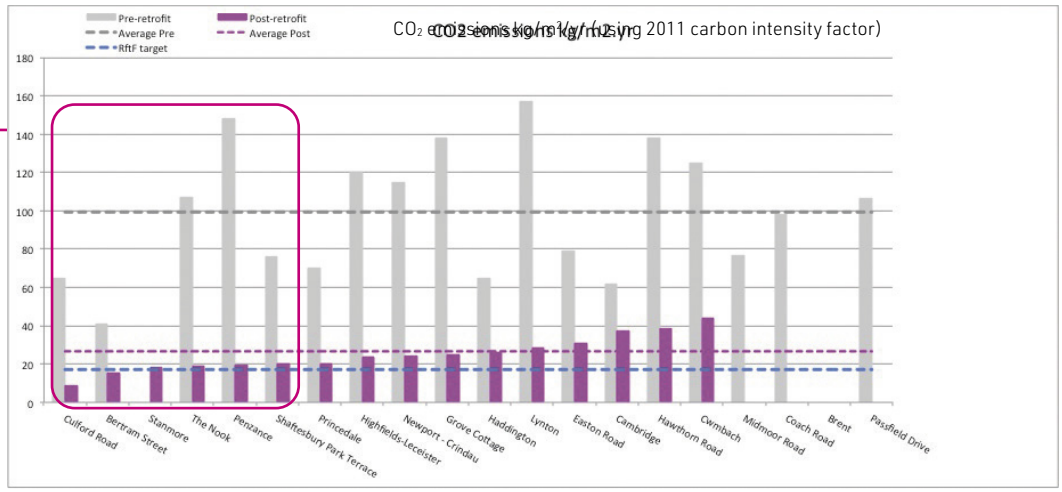
These targets were extremely ambitious as prior to this programme only a few retrofit projects in the UK had ever claimed a similar level of energy efficiency. One such project, Grove Cottage (see p50), was shown to participants of the competition. It had been designed using the PassivHaus strategies of fabric first and whole-house design.

The monitoring data drawn from the 24 case study projects showcased here has shown very impressive results, further confirming that reaching, or coming close to, these challenging targets is achievable. Since these 24 case studies were selected to illustrate various typical UK construction types (solid brick, steel, concrete, cavity wall, etc.), these results should give confidence to the industry that retrofitting the UK housing stock effectively is possible, no matter the construction type.[20]

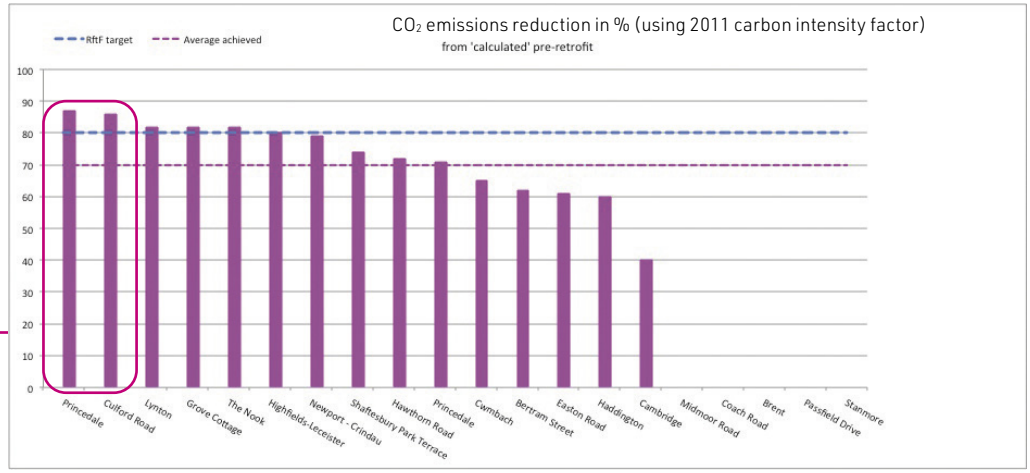
The average figures for the 24 projects were as follows:

- CO_2 emissions reduction reached 70% from pre-retrofit, just 10% short of the target;
- CO_2 emissions were 26 kg/m^2/yr, 15% above limiting target;
- primary energy demand was 161 kWh/m^2/yr; although 40% above the limiting target, this still represents a 67% reduction from the primary energy demand average pre-retrofit.

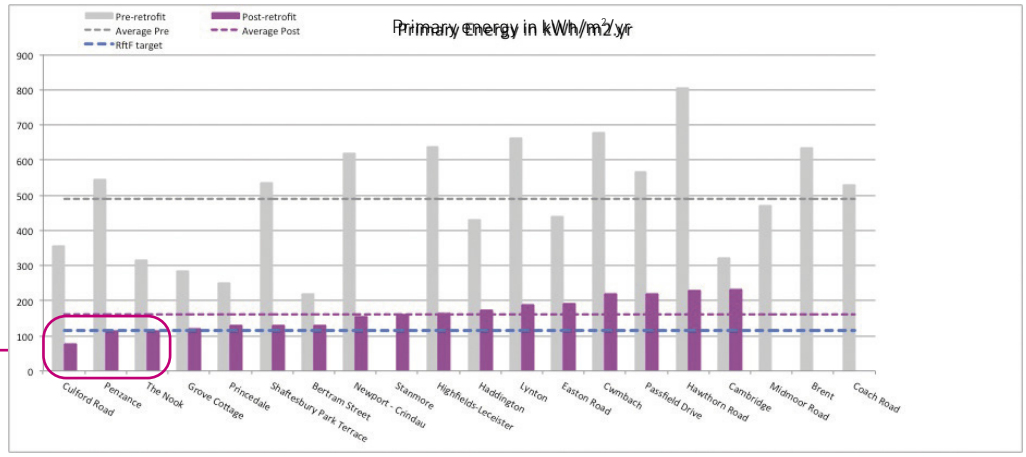
Six projects met the target



Two projects met the target



Three projects met the target



WINDOWS

Windows play an essential role in minimising heat loss from buildings and providing a sense of internal comfort for occupants. The radiant surfaces of the frames and glazing should be kept warm (above 17°C) otherwise temperature asymmetry, draughts and the pooling of cold air is created within the room.

For most projects, the choice of window type has been an exercise of balancing the desire to conserve architectural heritage (voluntarily or as enforced by planning requirements) with the desire to reduce energy waste and provide high levels of occupant comfort.

In response to these considerations, the 24 teams installed a wide range of solutions including:

Casement windows

The casement window is accepted by most as the best way to achieve the glazing performance. This is in part due to the development of high performance windows in northern Europe where the inward-opening casement dominates culturally. It is also due to the predisposition of the casement frames to accommodate heavy, thick triple glazing units and provide good airtightness by virtue of the window mechanism. It is no surprise therefore to see that teams tended to use casement windows wherever they could, only resorting to alternatives where forced to. Projects like Midmoor Road used double-glazed sash windows in the sensitive front elevations but adopted classic triple-glazed casements at the rear. Grove Cottage, interestingly, used triple-glazed casements at the front, but incorporated fake mid-rail sections to imitate the original sash pattern.

Sash windows

The sash window is seen by many as the *bête noire* of retrofit. Fitting triple-glazed units into sashes was almost unheard of before the Retrofit for the Future programme and airtightness around sliding sashes is subject to some degree of scepticism. Several pre-1919 projects, such as in Shaftesbury Park Terrace, replaced original single-glazed sash windows with new timber-framed double-glazed replicas. At Bertram Street the team re-used the existing timber frames and replaced the single glazing with new thin vacuum glazing, achieving a similar appearance from the pre-retrofit units but with substantial thermal benefit. Highfields went as far as prototyping triple-glazed sliding sashes, although the tenant found these to be a little heavy to use.

Princedale Road went one step further and created a window that looked like a sash but performed like a triple-glazed casement. Excellent U-value and airtightness were delivered in a window that looked almost identical to its neighbours.

Secondary windows

Only one project investigated the potential of secondary windows, Easton Road. A double-glazed casement window installed in combination with a double-glazed sliding sash window created a quadruple-glazed unit. The actual U-value has not been measured but it is presumed to be below 0.8 W/m^{2}K.

As an interesting aside, some recent work by Historic Scotland ('Five Tenement Flats, Edinburgh Wall and Window Upgrades') has measured centre pane U-values as low as 0.56 W/mK for a double-glazed secondary window installed in complement of a single-glazed sash window.[20]

Overall, the performance of all windows installed in these 24 projects varied between 0.8 and 1.9 W/m^{2}K. Unfortunately direct comparisons based on airtightness are not possible. Interestingly the Midmoor Road team reported that the sash windows they used made no perceptible difference to their airtightness results (having tested once with polythene sheeting in front of them and once without). This result indicates how effective quadruple draught stripping of sash windows can be. It would be interesting to repeat the test three years hence to see if the seals are still working as well.

As a general design principle, all teams favoured the casement window type, even in challenging circumstances.

Recent advancements in glazing technology have started to shift this delicate balance between heritage preservation and energy performance. One standout innovation is vacuum glazing, such as Fineo, which offers a transformative solution for retrofitting historic and conservation-area properties. Unlike traditional double or triple glazing, Fineo uses a vacuum-sealed layer between two panes of glass, achieving thermal performance close to triple glazing but with a profile as thin as single glazing. This makes it possible to retain slim timber frames or replicate historic window detailing without compromising on energy efficiency. In projects where aesthetics and planning constraints limit the use of bulky modern units, Fineo has proven to be a game changer, providing the warmth, comfort and carbon savings needed for deep retrofit, while respecting the architectural character of Britain's historic homes.

WALL INSULATION

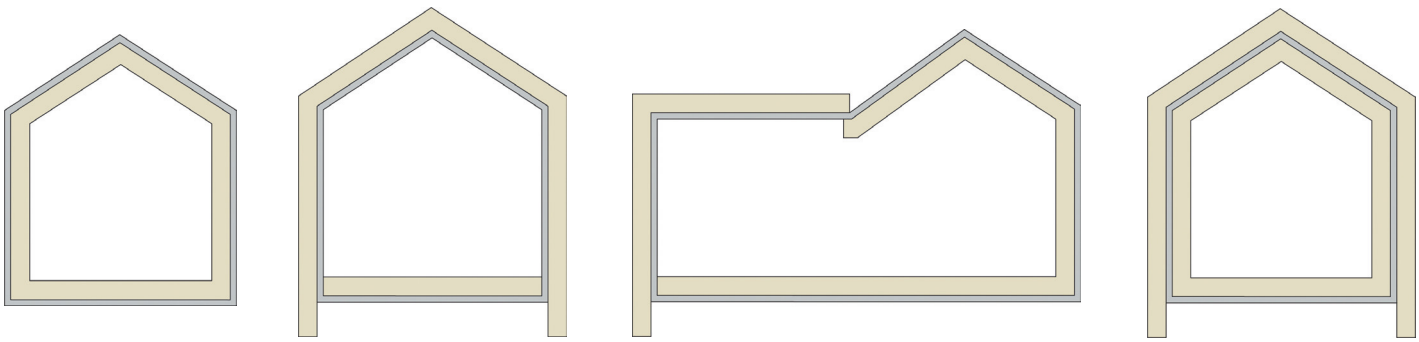
One of the bedrock principles of the fabric first approach is to insulate walls. Each of the teams approached this principle in different ways, which can be divided into four categories.

- The 'internal lining' approach as exemplified by Princedale Road. This project showed that potentially it can deliver completely continuous insulation and airtightness with very little impact on street character. Of course this approach tends to be very disruptive for the tenants, although Bertram Street demonstrated that it can be done with residents in situ if one is prepared to accept a less perfect building envelope.
- The external wrap approach as exemplified by Grove Cottage fits the insulation to the outside, away from the residents and annoying issues like joist ends. From a building physics perspective the wrap is seen as an inherently safer proposition and potentially allows residents to remain in occupation as at Passfield Drive. Difficulties do arise though in relation to externally mounted services (cables, conduits and drainage pipes), which need careful coordination during the process. One of the challenges with this concept is how to avoid cold bridging at the wall to ground-floor junction.
- The hybrid approach consisting of a mix of the two. Hawthorn Road and others adopted this approach in order to hold on to the architectural features of the existing fronts while maximising insulation gains externally at the rear. This approach is especially effective on Victorian terrace houses where there is a much larger wall area at the rear and the internal planning is particularly tight.
- The multi-layer approach consisting of filling the cavity wall with blown insulation combined with internal wall insulation (Stanmore, Haddington Way).

Internal wall insulation (IWI)

Internal wall insulation is usually adopted (either voluntarily or under pressure exerted by planning guidance) in order to preserve the external appearance of the building. Certainly this was true of projects like Culford Road, The Nook, Bertram Street and Hawthorn Road.

For the experienced retrofitter, internal wall insulation also has the attraction of being able to provide an entirely continuous layer of insulation from floor to wall to ceiling. This approach was taken to the extreme in Princedale Road, where thermal bridging was all but eliminated and the airtightness layer made so effective that a figure of below 0.6 ACH was achieved for the first time in the UK on a retrofit.



Internal insulation | External insulation | Hybrid insulation | Multi-layer insulation

However, unless planned with care, IWI can compromise room usability with the loss of floor area and create technical difficulties when the insulation layer is interrupted by structural elements such as load-bearing walls, foundations or floor joists. Well-judged detailing is essential to ensure minimum air and heat loss paths. There is, in the industry, an ongoing debate in respect of the risks associated with moisture in relation to IWI. The issue of interstitial condensation and reduced temperature gradients across walls that may leave them damper in the winter are matters that do not seem to have easy answers. There isn't even a consensus about whether vapour open (breathing) IWI systems are more robust than non-breathing ones, although those in favour of breathing fabric have put forward some very strong arguments in recent years.

Designers of IWI systems need to assess the risk factors on a project-by-project basis, taking into consideration the nature and state of the building fabric, the orientation, the degree of shelter and the effectiveness of the rainwater and drainage goods. Dynamic software tools are increasingly being used as part of this risk assessment process. WUFI is perhaps the best known and can model thermal and moisture parameters in two dimensions for construction build-ups. Historic Scotland Technical Papers and the AECB are both engaged in research programmes that include monitoring of real installations and should deliver precious findings in due course.

The choice of material used for the IWI was mainly driven by three factors: the space available, the breathability and hygroscopic properties, and the cost. The Hawthorn Road team chose natural materials such as wood fibre and sheep's wool insulation. This was a deliberate decision that came at a cost. Although these materials are breathable and have a comparatively low embodied energy, they have additional thickness and a lesser performance when compared with the most commonly used foam insulation board.

Where space was the team's stronger focus, such as in the Stanmore project, materials such as aerogel were used. Aerogel provides high thermal performance with minimal thickness but it comes at a considerable cost. Others such as the Midmoor Road team used aerogel more judicially for areas such as bay window reveals where space was at a premium.

JOIST ENDS

Moisture risk and timber joist ends in retrofits

In spite of long-standing concerns about moisture risks in relation to internal wall insulation (IWI) systems, many retrofit teams have opted for non-vapour open insulation materials. This decision is often driven by the imperative to achieve very low U-values, as vapour-open systems generally entail higher costs and thicker build-ups. However, the risk of moisture accumulation – particularly at embedded timber elements like joist ends – remains a critical consideration in solid-wall retrofits.

Different teams approached the challenge of protecting joist ends from exposure to potentially wetter environments in various ways, including:

- setting joists away from the external wall and supporting them on steel beams spanning from party walls (Princedale Road);
- using joist hangers within a narrow cavity between brickwork and insulation (Midmoor Road);
- wrapping joist ends in breather membranes (Highfields, Leicester);
- injecting timber preservatives (Easton Road);
- retaining joists in place but using capillary-active insulation (Shaftesbury Park Terrace, which used wood fibre insulation between joists).

To inform future guidance, several of these projects – such as those at Bertram Street, Princedale Road and Hawthorn Road – installed moisture monitoring equipment to track conditions around and within the joist ends.

Recent findings from the UK government's Demonstration of Energy Efficiency Potential (DEEP) project further reinforce the importance of moisture management in retrofits. The DEEP project assessed multiple solid-wall homes fitted with IWI across 14 case studies, using both hygrothermal simulations and *in situ* monitoring. The key lessons and recommendations include:

To manage these risks effectively, the DEEP study recommends:

- a detailed pre-retrofit assessment of moisture pathways and risk zones;
- use of vapour-permeable or capillary-active materials where possible;
- maintaining or improving ventilation, particularly in sub-floor voids;
- monitoring of timber moisture content post-installation to detect early signs of decay;
- avoiding thermal bridges through consistent insulation detailing;
- reliance on empirical data for energy modelling and performance validation.

Both Hawthorn Road and Shaftesbury Park Terrace provided valuable insights into this issue. At Hawthorn Road – a solid brick construction retrofitted with IWI – the interface between joist ends and the external wall was specifically identified as a potential risk area. While the retrofit included moisture and thermal risk assessments – such as thermal imaging and monitoring – some areas behind finishes, including joist ends, remained difficult to assess directly. Although no failures were observed in this case, the risk associated with cold bridging at joist bearings was acknowledged. The project highlighted the limitations in current monitoring techniques, especially when access to critical structural junctions is restricted. Importantly, it was noted that ongoing ventilation and robust internal environmental control played a role in mitigating any serious moisture build-up.

Similarly, the Shaftesbury Park Terrace case study – another Victorian terraced property retrofitted with IWI and airtightness measures – demonstrated a comparable risk profile. Here, the thermal bridge issue at the joist ends was actively considered during design, but practical constraints during implementation meant that full mitigation measures – such as isolating or insulating joist ends – were not feasible without major structural intervention. Monitoring post-retrofit revealed slightly elevated relative humidity levels at the floor-to-wall junctions, consistent with expected cold bridging in those areas. However, like at Hawthorn Road, there was no evidence of timber decay. The findings instead reinforced the importance of maintaining adequate ventilation and carrying out regular checks to manage the potential long-term risks.

Together, these two case studies underscore a broader lesson for retrofit practice: while timber joist ends embedded in masonry may not always show immediate signs of failure, they represent a latent risk that should be carefully considered at the design stage. Passive monitoring techniques have their limits, especially in detecting issues concealed within the structure. Proactive design detailing and robust maintenance regimes remain essential strategies in managing this type of thermal bridge and preventing moisture-related deterioration over time.

External wall insulation (EWI)

While it is generally agreed that EWI is the safer option there are some potential weaknesses to this approach:

- Heat loss paths created at party wall junctions for a mid-terrace house where adjacent houses are not insulated. Projects like Passfield Drive implemented mitigation measures such as localised internal wall insulation on party walls.
- Heat loss paths at the foot of the facades between EWI and internal ground-floor insulation. This weak point was addressed by the Lynton teams (amongst others) by installing a perimeter layer of vertical insulation into the ground and Grove Cottage with foam glass blocks in the masonry wall.
- Between the EWI and roof insulation, addressed in Passfield Drive with an internal fillet insulation strip at ceiling level.

In spite of these hidden extras overall, EWI was considered a very successful and cost-effective measure that most teams would recommend and repeat in other projects.

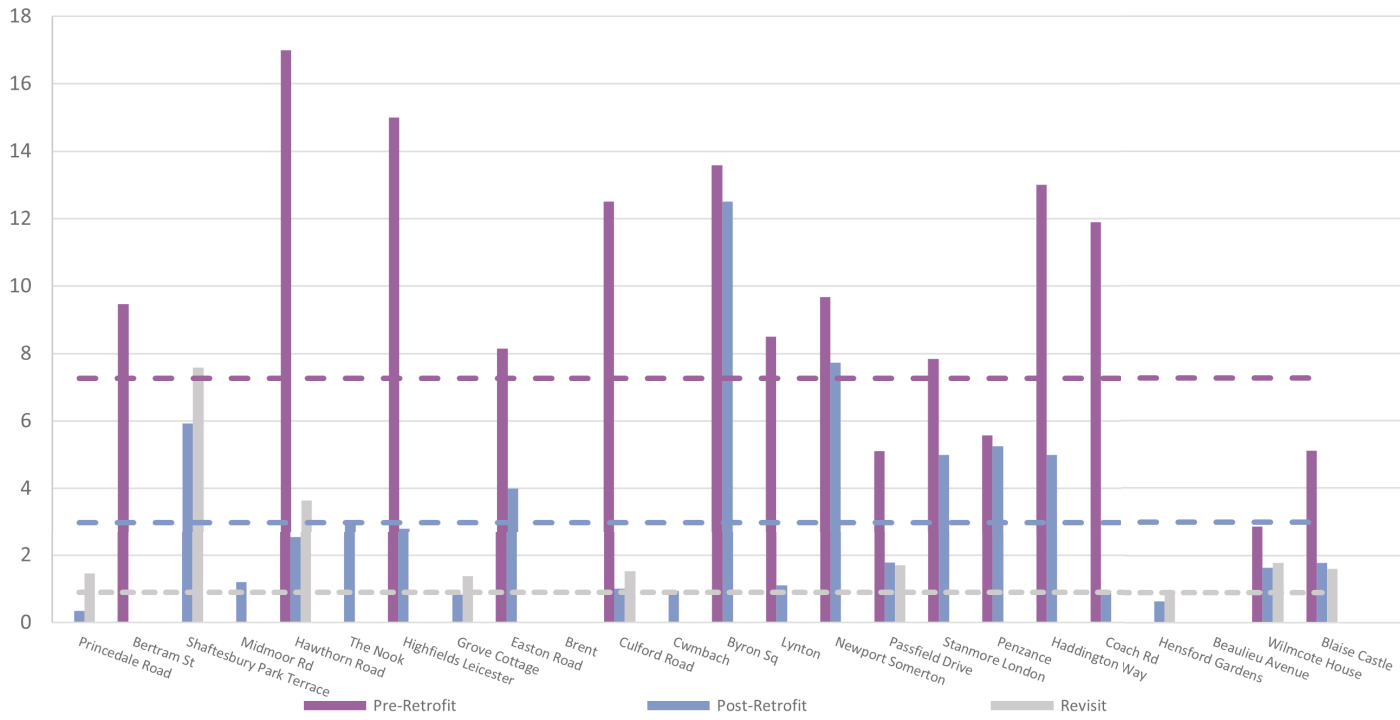
AIRTIGHTNESS

Most of the projects missed their airtightness targets by a large margin. While the targets were usually around the 1 m^3/m^2h @ 50 Pa mark (see graph below), actual measured results varied from 0.49 m^3/m^2h @ 50 Pa to approximately 7.7 m^3/m^2h @ 50 Pa. The average for all case studies was 4.1 m^3/m^2h @ 50 Pa. The teams held the least amount of knowledge and experience on this area of the works, so the fact that results are disappointing are not so surprising. It is worth remembering that the building regulation standard for new build housing still stands at a rather less than ambitious figure of 10 m^3/m^2h @ 50 Pa.

In the Retrofit for the Future programme, most contractors had little experience of installing airtight layers to the standard desired and had to learn as they went along. It is worth noting that the teams who undertook multiple air tests were often the ones with the best results upon completion. An air pressure test performed when the airtight layer is still visible can highlight air paths at a stage when it is not too late to remedy them before the finishes are in place. Princedale Road, Hawthorn Road, Culford Road, Midmoor Road and Grove Cottage all carried out several air pressure tests.

While overall success was not as good as might be hoped, it is reasonable to suggest that the targets many teams set were simply beyond the skill level available at the time. A clutch of very high performing projects demonstrate that airtightness is not impossible as long as a clear strategy is set out at the start and followed by a team who have experience and due care.

Regarding materials used to achieve airtightness targets, it was found that robust elements such as well jointed and taped OSB boards were the easiest to install and particularly reliable when installed as a sole material for the airtightness layer. Most difficulties came about either: when several materials were combined to achieve the airtight layer, or when the airtight layer had to follow complicated geometries such as corner with serval service pipe passing through.



Air permeability m^3/m^2h @ 50 Pa

FEEDBACK FROM 10 YEARS POST-RETROFIT

One of the central themes to emerge from the Retrofit Revisit project was the importance of careful and robust airtightness detailing in achieving long-term building performance. Across the 10 case studies, airtightness was generally well executed at the time of retrofit, with several properties achieving impressive results – such as the Princedale Road project, which recorded an air permeability of just 0.33 m^3/m^2h @ 50 Pa in 2011. However, subsequent testing revealed a decline in performance over time, with Princedale Road's 2023 result increasing to 1.45 m^3/m^2h, primarily due to degradation of simple components like door seals. This underlines a critical lesson: airtightness is not a one-time achievement but requires regular maintenance and inspection to retain its integrity.

The study also drew valuable comparisons between different testing methodologies. While the blower door test remains the standard for quantifying overall airtightness and identifying specific leakage paths, the Pulse test offered useful complementary insight by assessing air leakage at lower pressure ranges (2–15 Pa), which are more representative of real-life conditions. There was a good correlation between the results from both tests, but each had unique strengths. The key takeaway here is that combining test methods provides a fuller picture of building performance and can help identify issues that might otherwise be missed.

A recurring detail across multiple case studies was the significance of junctions – points where building elements meet, such as wall-to-floor junctions, window reveals, service penetrations and doorframes. These areas often proved to be weak points in the airtightness strategy, not due to the failure of materials themselves, but because of small oversights or workmanship challenges during installation. In many cases, issues arose in locations that were hard to access or inspect once works were completed, reinforcing the need for rigorous quality control during the retrofit process. The lesson here is that airtightness success hinges on precision at these vulnerable details, which should be carefully considered, mocked up where necessary and thoroughly checked on-site.

Another key insight was the importance of integrating airtightness from the outset of a retrofit project. Where airtightness had been included early in the design and construction sequence, results were consistently better and easier to maintain. In contrast, projects where airtightness was treated as an add-on or secondary concern often struggled with continuity and effectiveness. This highlights the need for airtightness to be embedded into the overall strategy, with clear specifications, proper sequencing and adequate contractor training.

Finally, the studies emphasised the role of building users in sustaining airtightness performance. Even well-executed detailing can be compromised by everyday actions – such as residents keeping trickle vents permanently open, blocking vents with furniture or making minor alterations that disrupt the air barrier. Therefore, engaging and educating occupants about the importance of maintaining ventilation strategies and respecting airtightness measures is essential for long-term success.

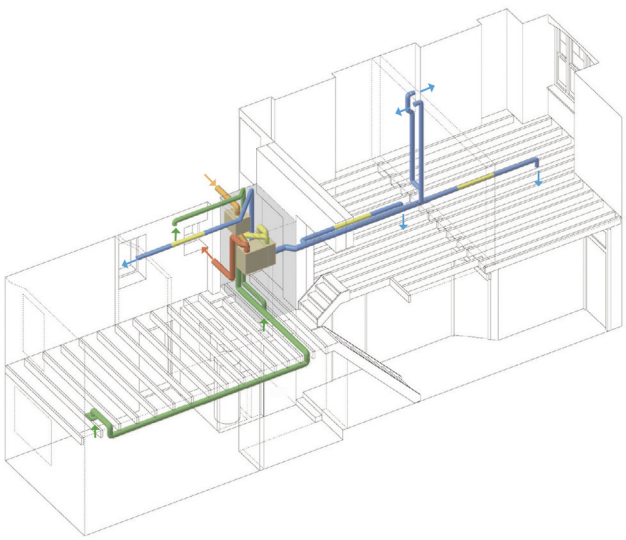
Taken together, the case studies present a nuanced picture: airtightness can be achieved to a high standard and maintained over time, but only through a combination of good design, precise execution, regular maintenance, appropriate testing and user awareness. It is not just a technical feature but a key component of durable and high-performing retrofits.

MECHANICAL AND ELECTRICAL AND COMFORT VENTILATION

In 18 of the 24 case studies, a whole-house MVHR system was installed in order to efficiently provide adequate comfort ventilation and very low heat loss. The installation of these units was mostly successful, the evidence being good monitoring results for indoor air quality of the case study projects. Areas of difficulty were encountered when trying to best locate the ductwork throughout the house without losing too much floor space or existing internal features. Ductwork arrangement should be considered early on in the design stage to avoid unsightly bulkheads and oddly placed riser-duct enclosures.

Some project teams such as Highfields, Leicester's team reported challenges in balancing and commissioning the MVHR system. Several visits were often required to get the system working properly. One project, Midmoor Road, even reported that some of the MVHR installation work had to be entirely taken down and redone. This was an opportunity for the installer (the architect in this case) to learn the intricacies of this piece of equipment.

The four case studies without MVHR units opted for a natural ventilation strategy, with trickle vents in window frames working in combination with intermittent mechanical ventilation extracts in wet rooms (such as at Shaftesbury Park Terrace). Other approaches included installing a positive input ventilation system (Stanmore), a continuous mechanical extract ventilation and a decentralised MVHR unit, one per room (Bertram Street). The reasons for these alternatives were either to test prototype systems or because space restrictions were critical and would not allow a whole house ventilation system to be installed.



Example of compact ventilation ductwork design

Indoor air quality data for Shaftesbury Park Terrace show very good results, probably due to the high level of air infiltration with an airtightness measured at 5.92 m^3/m^2h @ 50 Pa. Data is unfortunately not available for the other projects.

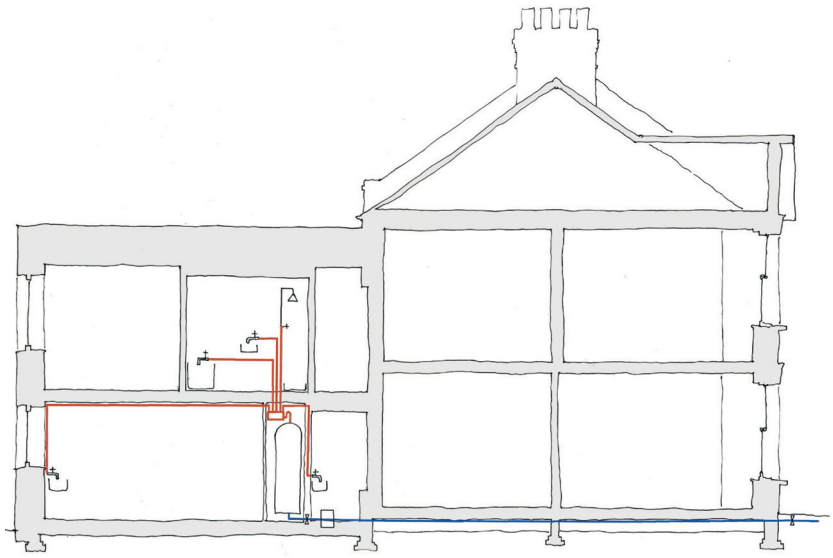
The Retrofit Revisit study offers valuable insights into the long-term performance and maintenance of MVHR systems in retrofitted homes. Across the 10 case studies, MVHR units were generally found to be reliable and effective, particularly notable given that many of these systems were installed at a time when such technologies were relatively new to the UK housing retrofit context. Their performance, over a decade later, speaks to their durability when properly specified and maintained.

A key lesson was the overall robustness and reliability of MVHR units. In contrast to other building systems –particularly more complex or less familiar renewable technologies such as solar thermal – MVHR units consistently continued to perform well, contributing to healthy indoor environments with good air quality and humidity control. This was especially evident in homes like Princedale Road, where the system helped maintain relative humidity at healthy levels even in challenging spaces such as basement bathrooms, which are typically more prone to moisture accumulation.

However, the report also highlighted that maintenance remains a crucial factor in sustaining performance. While no major system failures were reported, minor issues such as fan degradation and the need for filter replacements were noted. For instance, Princedale Road experienced a temporary fan failure in 2023, which impacted indoor air quality and temperature readings during that period. This underlines the importance of routine maintenance tasks – like changing filters and ensuring fans are functioning properly – which are often simple but sometimes overlooked.

Another important takeaway is that ease of use and user understanding are still barriers to optimal performance. In several homes, although the MVHR units were functioning technically well, residents were either unsure how to operate them effectively or unaware of how their actions (such as blocking vents or turning off systems) could undermine the system's benefits. This points to a broader need for better occupant engagement and post-occupancy support, including clear, simple guidance and follow-up to ensure systems are used as intended.

Additionally, while MVHR systems were found to support energy efficiency and comfort, the study suggested that installation quality and commissioning were essential to long-term success. Where systems had been carefully installed with consideration of ducting

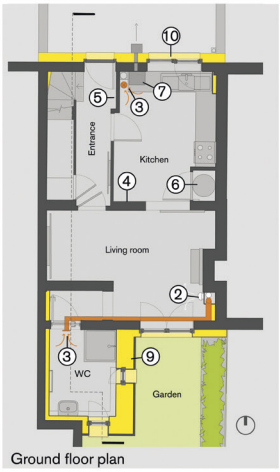


Example of compact hot water pipework design

User Guide

This Retro-fit was designed towards the passivhaus standard.





Ground floor plan

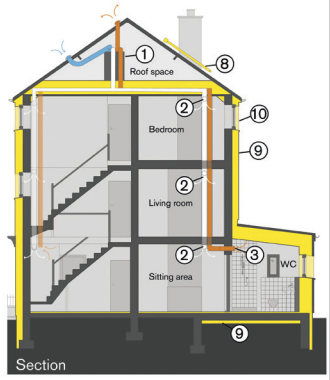
The term passivhaus refers to an advanced low energy construction standard for buildings, which have excellent comfort conditions in both winter and summer. They typically achieve a heating saving of 90% compared to existing housing. Passivhaus buildings are easy to live in and require little maintenance, but they do have some important features, which are explained in this guide. The features are simple to operate, but a full understanding will help you get the lowest energy consumption and best comfort. This guide has been design by Alan Clarke and bere:architects for you (the user) to understand how a passivhaus works and how to operate the controls in this house.
Each feature is labelled on the drawings below, highlighting their locations and briefly explaining how to operate them in the corresponding text. Please take the time to read this guide and familiarise yourself with the controls.



First floor plan



Second floor plan



Section

1 Heat recovery ventilation unit



Provides continuous fresh air to the house, and saves heat from bathrooms and kitchens to warm fresh air for living and bedrooms. The system saves about 10 times more energy than it uses! It is located in the roof space. The filter needs changing every 3 months in London because the air is so dirty.

2 Fresh air vents



The fresh air (pre-warmed in winter) is supplied by the heat recovery unit and delivered to the bedrooms and living room using these fresh air vents. The heating system (5) is automatic but you can adjust the fan speed (4) manually with the wall mounted panel in the kitchen. This will keep the air fresh during a family gathering or intensive cooking (in addition to the extractor fan).

3 Extract air vents



These vents remove possible stale and damp air from the kitchen, bathroom and WC. The heat recovery unit saves heat, which saves money. The ventilation runs continuously all year round but special motors have tiny energy consumption. The extract air vent filter in the kitchen needs to be cleaned about every 3 months depending on how much cooking is done.

4 Heat recovery ventilation control panel



The fresh air system can be left on "auto" but the fan speed can also be manually changed using this panel during cooking or if the bathrooms are steamy. If you go away for a period of time don't turn it off but leave it on the lowest speed.

5 Thermostat



The thermostat in the entrance hall sets the temperature for your house. 20-21°C is the normal temperature, but you could turn it down if you are away for a few days or just for a few hours to save energy. To adjust the room temperature, locate the room temperature display and simply, rotate the right knob up or down.

6 Solar tank and control panel



This tank stores hot water from the panels in the roof and is kept topped up by the boiler when there isn't enough sunshine. The tank is well insulated meaning there is hot water day and night. The temperate of the tank is set with the control panel below. The space heating is controlled with the Thermostat in the entrance way (5). Not via this panel.



7 Boiler and control panel



This boiler serves as back up for the solar tank (6). If there has not been enough sunshine the solar tank may not have enough hot water for heating or showering. In this instance the gas boiler will automatically top up the solar tank. To turn the heating up in cold weather snaps use the thermostat located in the hallway (5).

8 Hot water from the sun



In summer almost all the water in the solar tank is heated by the sun shining on the solar panel on the roof. In winter the panel can heat the bottom half of the tank and the boiler is used to top up the temperature. This means there is always hot water available in the tank even on a cloudy day.

9 Insulation and draft free construction



This house has been wrapped in insulation to the floor, walls and roof. The front wall has 250mm, rear 200mm, the roof 490mm with vacuum insulation on the ground floor. Gaps in the insulation have been sealed, producing a draft free building. These improvements will help make your energy costs much lower.

10 Windows (for summer cooling)



To keep the internal temperature cool in the summer utilise the cooler night temperatures by leaving the windows open in the secure "tilt" position overnight. If the weather is hotter outside during the day close the windows and switch the heat recovery ventilation to the summer by pass mode, in the user settings of the control panel (4). The high levels of insulation, in the summer act as a buffer to repelling internal heat gains for the sun which keep you comfortable.

bere:architects

For further information regarding these features:

AD Enviro (Passfield drive building contractor)
Consult the specific manufactures guides supplied

Alan Clarke (Building Services Engineer)
Tel: 01594 563356
E-mail: alan@arclarke.co.uk

bere:architects (passivhaus specialists)
Tel: 020 7359 4503
E-mail: bere@bere.co.uk

layouts, airflows and accessibility for maintenance, performance was sustained. In contrast, poorly designed or awkwardly installed systems can lead to lower efficiency and occupant dissatisfaction, even if the core unit is functioning properly.

In summary, MVHR systems in these retrofit projects have proven to be effective, reliable and valuable tools for maintaining healthy indoor environments, but their success hinges on proper design, installation, routine maintenance and occupant awareness. When these elements are in place, MVHR contributes significantly to the comfort and durability of low-energy homes.

Domestic hot water design continues to be a key focus in retrofit, especially as we push for lower operational energy and carbon. One critical design principle that has stood the test of time is the importance of keeping hot-water pipe runs as compact as possible. Minimising 'dead legs' – sections of pipe where hot water sits and cools – helps reduce both heat loss and water wastage, especially noticeable during activities like showering, when users wait for hot water to arrive. While this is often difficult to achieve in retrofit due to existing layouts and spatial constraints, some projects have shown it can be done effectively. For example, at Midmoor Road, the team designed a compact system with small bore pipework and flow restrictors, following good practice in line with AECB water standards. Despite initial scepticism from the installer, the result exceeded expectations, delivering efficient flow rates and satisfying both the designer and the resident.

In projects beyond the national gas grid, or where a non-gas hot water strategy was needed, different approaches were trialled. One such case was Lynton, where a biomass boiler was installed, originally seen as a sustainable choice. However, with evolving understanding and recent supply chain disruptions, the long-term viability of wood pellets as a mainstream energy source has come into question. Concerns include not only fuel availability and price volatility, but also carbon accounting and air quality impacts – especially under tighter environmental scrutiny and emerging international standards. As of 2025, biomass is increasingly viewed as best reserved for specific rural or off-grid contexts, rather than a general solution.

More promising in the long term have been air source and ground source heat pumps, often paired with solar thermal or photovoltaics. These systems were used in several case studies, including Princedale Road and Cwmbach, and continue to offer a pathway to low-carbon heating. In most cases, immersion heaters were installed as a back-up to ensure consistent hot water availability during very cold weather or periods of low solar input – a practice still recommended today, although modern systems now often include smart controls to better manage back-up usage.

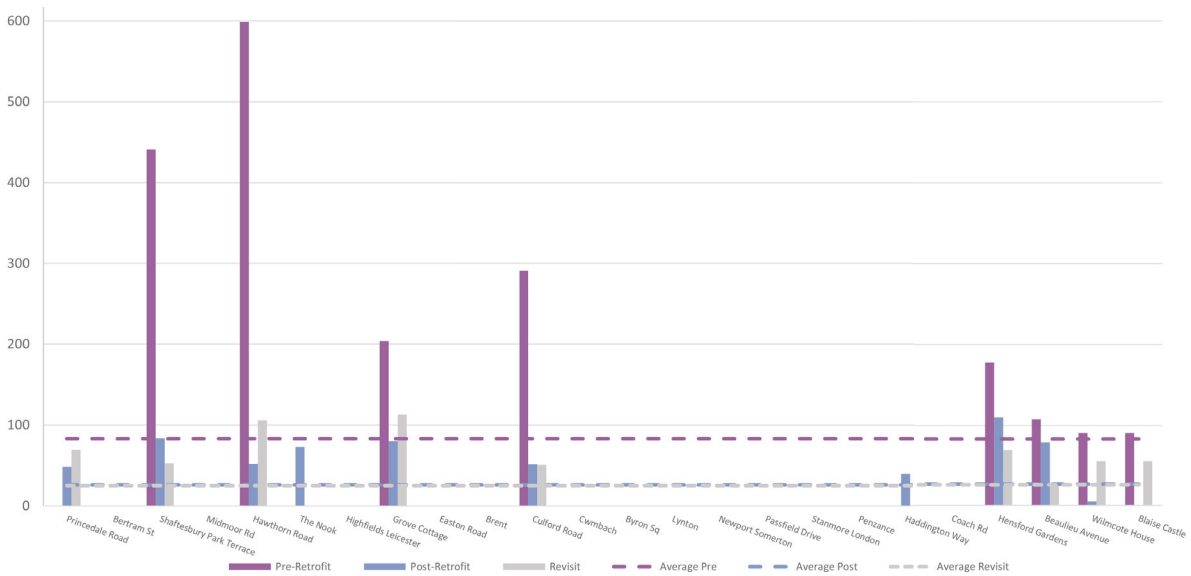
In terms of space heating, several projects explored different methods. In two homes, in-line electric heaters were added to the supply ventilation ductwork (a relatively rare solution), while more commonly, existing radiator systems were retained or upgraded, sometimes with smaller, strategically placed radiators to suit low-temperature heating systems.

The integration of renewable energy technologies was a key part of several retrofits. Solar thermal panels were widely used for hot water pre-heating, although recent experience suggests their role is now more niche – often outcompeted by photovoltaic (PV) systems and efficient heat pumps. PV systems, on the other hand, have shown increasing value with the expansion of smart inverters, home battery storage and dynamic energy tariffs. Innovative set-ups, such as at Haddington Way, aimed to maximise solar self-consumption – an approach that's become even more relevant today as the grid decarbonises and energy flexibility becomes critical.

One standout project, Somerton, Newport, installed a ground-to-water heat pump, though like several systems across the programme, the lack of performance monitoring or sub-metering has made it difficult to evaluate actual energy savings. This remains a key lesson moving forward: without robust data, it is impossible to understand system performance, ensure design intent is met, or build the evidence base for scaling retrofit technologies.

The Retrofit Revisit study revealed mixed but instructive lessons about the performance of air source heat pumps (ASHPs) in domestic retrofits. While the technology holds strong potential for delivering low-carbon heating, the case studies highlighted both the strengths and limitations of ASHPs when applied in real-world retrofit settings – especially in relation to system design, integration with other services and the end-user experience.

At Princedale Road, the home featured a fully electric system centred around the Genvex Combi 185 BP unit – an integrated ventilation and heating system that includes a mini air source heat pump. This compact unit combines mechanical ventilation with heat recovery, domestic hot water production and a small ASHP that extracts additional energy from the exhaust air. The system prioritises hot water production using a 185-litre storage tank and supports space heating via pre-warmed supply air. Although the system was innovative and compact, the study found that its long-term performance was difficult to fully assess due to a lack of detailed monitoring and sub-metering. In 2023, a temporary failure of the



EUI kWh/m³/m²yr

MVHR fan within the unit affected heating and air quality performance, reinforcing the need for regular maintenance and accessible servicing. The case highlights a broader point: while integrated systems, like the Combi 185, offer space-saving, energy-efficient solutions, they also rely on consistent maintenance and clear monitoring to ensure continued performance over time.

In contrast, Blaise Castle featured a more conventional ASHP as part of a wider retrofit strategy. The system provided effective heating, but its long-term performance was challenging to evaluate due to the integration of multiple systems, including solar thermal, and a lack of sub-metering. This reflects a recurring issue in several case studies – where heating and hot-water systems are layered or hybridised without clear system separation or monitoring, it becomes difficult to understand energy use or identify problems. Furthermore, the study found that residents were not always confident in operating the systems as intended, which likely reduced overall efficiency.

Across both homes, a number of common themes emerged. The importance of straightforward, maintainable systems was evident, as was the need for effective user engagement. Complex technologies, even when well-designed, can underperform if residents lack confidence in how to use them or if regular servicing is overlooked. Additionally, without good commissioning, metering and user support, it's difficult to verify whether energy and carbon savings are being realised in practice.

In summary, the Retrofit Revisit report underscores that air source heat pumps – and hybrid systems like the Genvex Combi 185 – can be effective tools in low-carbon retrofits, but their success depends on careful design integration, ease of maintenance, detailed performance monitoring and occupant understanding. These factors are essential to unlocking the full potential of such systems in real-world housing.

OCCUPANT INTERFACE

The subject of user interface has been well documented by studies such as those from the Usable Building Trust and also in the works of Roderick Bunn of BSRIA.

It is clear that successful projects were those who had designed simple systems (with simple and limited number of controls) and those who had provided clear explanation. In that respect, Passfield Drive is exemplary and has produced a very clear A1 board to be wall mounted in the property for ease of reference (see p122).

FORM FACTOR

While it is beyond the designer's control, it is worth reviewing the effect form factor (refer to p19) can have before and after retrofits. Compact buildings with advantageous form factors have the opportunity to fare particularily well in retrofit. Princedale Road shows very low space heat demand with only 10 kWh/m^2/yr. Properties with worse form factors may only show relative improvements on an energy demand reduction percentage basis.

SKILLS AND UNDERSTANDING

For a majority of the teams, the level of attention to detail required to deliver well-insulated and airtight buildings were new to them. Skills, knowledge and experience were lacking. To rectify this, a number of projects brought in expertise to help. Paul Jennings worked on Culford Road, Midmoor Road and Grove Cottage and helped those teams to achieve great results in respect of airtightness.

Another name that appeared frequently in project credits was Andrew Farr, who helped with MVHR design and commissioning.

There was, additionally, often at least one person dedicated to the project with more knowledge than others. The task of passing knowledge in retrofit techniques to so many tradesmen and site staff was generally reported as a difficult process, in particular because the budget did not allow for the extra time for it (e.g. as reported by the Lynton project).

GENERAL OCCUPANT FEEDBACK FROM A 10-YEAR OCCUPATION

Occupant feedback from the Retrofit Revisit study, which revisited homes 10 years after deep, energy retrofits, was largely positive, highlighting the long-term benefits of well-executed retrofit projects. Residents consistently reported high levels of thermal comfort, especially during winter. Homes were described as warm, draught-free and stable in temperature, with a noticeable improvement in general wellbeing. In properties with mechanical ventilation systems, such as MVHR, occupants also noted fresher indoor air, reduced condensation and improvements in respiratory health. These systems contributed to consistently healthy humidity levels and year-round comfort.

Many households appreciated lower and more predictable energy bills, with several expressing confidence in the long-term affordability of their homes. However, feedback also pointed to challenges, particularly around the complexity of heating and ventilation

Form factor

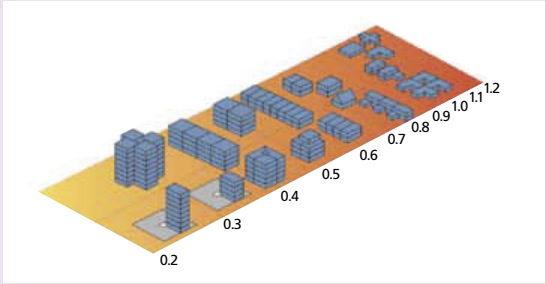


Figure 1 Surface area to volume ratio (A/V)

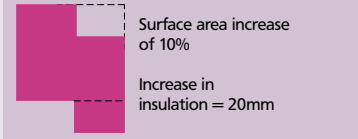


Figure 2 10% greater surface area

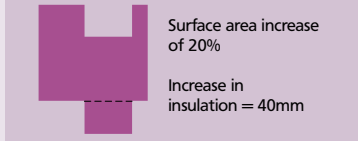


Figure 3 20% greater surface area

controls. Some residents found systems difficult to use or understand, occasionally leading to incorrect operation or reluctance to engage with the technology. This highlighted the need for clear handover information and ongoing support.

Summer comfort emerged as a growing concern, particularly in light of recent warmer summers. Some homes experienced overheating, prompting suggestions for improved shading or active cooling. Despite these issues, residents expressed pride in their homes and a strong sense of satisfaction, often associating the retrofit with improved quality of life.

The findings underscore the value of engaging residents throughout the process, simplifying systems where possible and designing with future climate resilience in mind. Overall, the retrofits have stood the test of time, delivering sustained comfort, efficiency and wellbeing for their occupants.

COORDINATION

It was recognised by several teams, including the Lynton project team, that a person with adequate knowledge of what retrofitting entails and who could coordinate and support each trade to deliver the energy performance that retrofit projects target would have been truly desirable.

This type of role has been identified in the Institute of Sustainability Retrofit Guides as a project coordinator role. It is a different role to project management, which tends to focus on cost and time rather than performance. Coordination suggests being more supportive towards consultants and contractors to facilitate understanding and teamwork in order to deliver performance. Coordinators who are present from inception to handover and at post-occupancy evaluation can provide continuity of vision and knowledge throughout, thereby predicating a more integrated and successful outcome. An experienced coordinator can also plug the gaps in knowledge and skills that are often found in retrofit teams.

PLANNING

Since the Civic Amenities Act was first introduced in 1967, knowledge and understanding of the notion of conservation has developed amongst local authorities and the construction industry. The notion of low energy retrofit, however, is very recent and few precedents are available to inform both bodies on how best to address the complexities of conserving our architectural heritage and at the same time turn the existing housing stock into a comfortable and energy-efficient one.

This lack of experience in low energy retrofit often creates frustrating situations, in particular when window efficiency matters are being discussed such as the acceptability of double- or triple-glazed systems as in Princedale Road where the triple-glazed 'look-alike' sash window was approved only after an appeal process. External wall insulation is another topic that created tensions as there was disagreement over whether the external insulation counted as a house extension. This was the case for the Midmoor Road project where external insulation was almost refused on this basis. However, the government has recently brought in new measures to extend permitted development rights for extensions for homeowners, and this should remove the hurdle of obtaining planning permission for the retrofitting of EWI when not in a conservation area.

In 2025, there is growing recognition that planning departments still face challenges in assessing retrofit projects, particularly in historic and conservation areas. While some local authorities have made progress through training and updated guidance – such as the introduction of PAS 2035-aligned policies and climate-conscious local plans – skills gaps remain. Encouragingly, a number of councils have now adopted a 'retrofit first' policy, including Westminster City Council, signalling a cultural shift towards prioritising the upgrade of existing buildings over demolition and rebuild. These policies are helping to embed retrofit within local planning frameworks, but continued professional development and cross-department collaboration are still essential to ensure planning officers can engage confidently with low-carbon retrofit proposals and support innovative, fabric first solutions.

COSTS

The cost figures for earlier retrofit pilot projects (dating from 2010) were useful for benchmarking but are no longer directly comparable with current market conditions. At the time, average project build costs were around £135,000, with energy-saving measures, such as insulation and high-performance glazing, accounting for approximately £83,000 on average. However, these figures excluded VAT, design fees, contractor overheads and monitoring costs. Importantly, many of these early projects were research and demonstration-based, and not reflective of scaled delivery.

Since then, the market has matured. A number of retrofit-specific products and techniques developed during that period have now been commercialised. The Whiscers™ internal wall insulation system, the external insulation gutter system trialled at Midmoor Road and bespoke elements like the 'look-alike sash' window at Princedale Road have all evolved and are available at broader scale. Nevertheless, cost remains a barrier, particularly in the absence of long-term grant support or aggregated delivery models. Until the market is further industrialised and supply chains fully geared to retrofit, high upfront costs – especially for deep retrofit – are likely to persist.

CONCLUSION

The Retrofit for the Future programme set ambitious performance targets well ahead of its time. In retrospect, it is remarkable that so many of the projects achieved – or came close to achieving – those goals. Comfort levels have exceeded typical expectations and, most notably, they have been delivered with very low energy demand, often closely aligned with the original design intent. These outcomes remain impressive and continue to contrast sharply with the persistent performance gap in the new-build sector, where energy use often exceeds predictions and in-use emissions remain high.

Yet, these successful case studies also raise timely and unresolved questions for 2025 and beyond:

- What targets should retrofits aim for today? Some argue that achieving deep CO_2 cuts on a per-property basis is less critical as the grid decarbonises, proposing instead that we target a 60% reduction and rely on grid improvements for the rest. Others advocate for absolute energy demand targets (e.g. in kWh/m²/yr) to drive fabric-first efficiency and reduce reliance on energy infrastructure.
- Are the costs of a deep retrofit justifiable? While initial projects were expensive, there is growing belief that scaling up delivery, standardising components and strengthening supply chains will drive costs down and improve affordability.
- How should heritage and conservation be balanced with climate goals? Many projects were constrained by conservation policies that limited low-energy interventions. As climate urgency intensifies, the question is increasingly being asked: should we now prioritise carbon over conservation – or find smarter ways to deliver both?

The Retrofit Revisit study provides strong evidence that deep retrofits can deliver sustained performance over time. Ten to 15 years after completion, the homes reviewed continue to demonstrate excellent levels of comfort, low energy use and improved indoor air quality, with most residents reporting high satisfaction. Key fabric measures – such as insulation and airtightness – have held up well, and systems like MVHR have proven reliable when maintained. While some technical challenges were observed, particularly with complex systems and overheating in warmer summers, these were generally manageable.

Importantly, the study shows that well-designed, fabric-first retrofits work – not just in theory, but in practice, across diverse home types. However, achieving these outcomes consistently requires good design, quality installation, resident engagement and ongoing maintenance.

Scalability remains a challenge, particularly due to costs, supply chain limitations and inconsistent planning support. Yet, the findings offer real hope and a practical foundation: many of the materials, techniques and technologies used are now more readily available and better understood. With proper support, these approaches can be adapted and replicated. The conclusion is clear: deep retrofit is a viable, effective route to achieving low-energy, climate-ready homes from our existing housing stock. The task now is to scale it up.

ABBREVIATIONS

Abbreviations that are defined

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
DPM	Damp-proof membrane
EAHP	Exhaust air heat pump
ECO	Energy Company Obligation
EPS	Expanded polystyrene
GIA	Gross internal area
GSHP	Ground source heat pump
HMO	House in multiple occupation
LGSF	Light gauge steel framing
MEV	Mechanical extract ventilation
MMC	Modern methods of construction
MVHR	Mechanical ventilation with heat recovery
NIU	Neighbourhood Investment Unit
OSB	Orientated strand board
PIV	Positive input ventilation
RftF	Retrofit for the Future
SBRI	Small Business Research Initiative
SHHA	Self Help Housing Association
TFA	Treated floor area
UB	Universal beam
VHR	Ventilation with heat recovery

These abbreviations are used but no explicit definitions

AC	Air conditioning
AECB	Sustainable Buildings Association
BISF	British Iron and Steel Federation
BMS	Building management system
BREEAM	BRE Environmental Assessment Method
CIBSE	Chartered Institution of Building Services Engineers
DPC	Damp-proof course
IES	Software – Integrated Environmental Solutions
JCT	The Joint Contracts Tribunal
LEAP	Low Energy Architectural Practice
LED	Light-emitting diode
M&E	Mechanical & electrical
MCD	Miniature circuit breaker
ODYSSEE	Project coordinated by ADEME and supported under the Intelligent Energy Europe Programme of the European Commission
PHI	PassivHaus Institute
PHPP	PassivHaus Planning Package
PIR	Polyisocyanurate (insulation material)
PP	Polypropylene (insulation material)
PU	Polyurethane (insulation material)
PUR	Rigid polyurethane (insulation material)
PV	Photovoltaic
RIBA	Royal Institute of British Architects
SAP	Standard Assessment Procedure
SIP	Structural insulated panels
SW	Softwood
T&G	Tongue and groove
THERM	PC-Program for calculating the coupled heat and moisture transfer in building components
TRV	Thermostatic radiator valve
TSB	Technology Strategy Board
UCL	University College London
WBP	Weather and boil proof
WUFI	Wärme und Feuchte Instationär. PC-Program for calculating the coupled heat and moisture transfer in building components
XPS	Extruded polystyrene (insulation material)

IMAGE CREDITS

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13. Note weather adjustment has been applied to the 2014 energy use to 2022 weather data using heating degree days. This suggests that the heating demand would be very similar between these years, with 2022 being slightly milder. However, even allowing for the increase over the years, the 2022 heating demand still represents a 75% reduction compared to the pre-retrofit heating requirement of 18,043 kWh/yr (120.1 kWh/m2/yr) in 2011.

14. Note that the monitoring data may not be representative of the performance of the whole Retrofit for the Future programme. For a full overview, please refer to the data analysis on the 100 projects carried out by the Technology Strategy Board. 'Retrofit Revealed : The Retrofit for the Future projects – data analysis report', Technology Strategy Board, 2013 <https://ukgbc.org/wp-content/uploads/2018/10/Retrofit-Revealed-The-Retrofit-for-the-Future-projects-data-analysis-report.pdf> [accessed 15 May 2025].

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