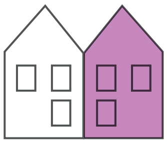
6

Case studies

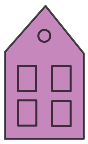
Archetype case studies

The following archetype studies focus on how properties with different form factors can be successfully retrofitted in a variety of ways. They aim to provide real life examples for the illustrative archetypes shown in Chapter 4.

SIGNPOST *Chapter 4 - LETI home retrofit targets*



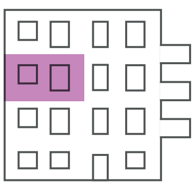
Semi-detached



Detached

Mid-terrace

End-terrace



Flat

Archetype 1, mid-terrace: Haddington Way

Location: Aylesbury

Description: Mid-terrace mid-1990 house

Completion year: 2010

Architecture: MEPK Architects

Energy and sustainability consultants: Rickaby Thompson Associates, Viridian Solar

Contractor: Willmott Dixon

Space heating post-retrofit (modelled): 41 kWh/m²/yr

Energy Use Intensity post-retrofit (modelled): 40 kWh/m²/yr

Project summary

Haddington Way, Aylesbury was comprehensively retrofitted in 2010, upgrading the thermal envelope in conjunction with a package of renewables. As part of the Technology Strategy Board Retrofit for the Future programme (TSB-31), it was monitored for 2 years after completion.

Pre-retrofit the external envelope consisted of:

→ insulated cavity walls with face brick exterior
→ suspended concrete beam and block ground floor
→ double glazed windows
→ pitched tiled roof enclosing both loft room and cold attic spaces.

Space heating was provided by a dual tariff electric storage system and hot water via a dual immersion cylinder. The property is ventilated via opening windows, with extract fans serving the kitchen and bathrooms.

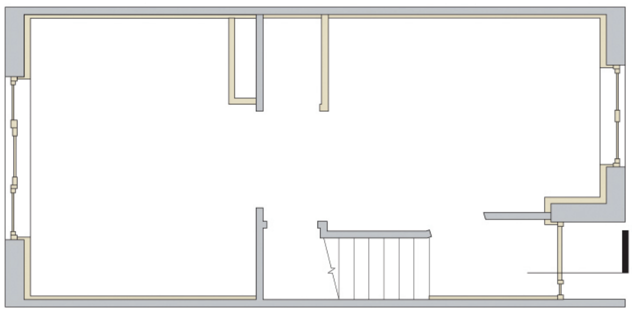


Figure 6.1 - Plan, MEPK Architects

Figure 6.2 - Front after, MEPK Architects

Figure 6.3 - Rear after, MEPK Architects

Fabric upgrade

The principle of fabric first was applied. The external walls were lined internally with Spacetherm PP, a laminated panel composed of 40mm thick aerogel insulation, 6mm plywood and 9.5 mm plasterboard interior facing. Aerogel is a very high performing insulation type, allowing a good level of improvement to be obtained whilst keeping loss of internal floor area to a minimum. Post retrofit wall U-value 0.23 W/m^2.K.

The beam and block ground floor was overlaid with 75mm Kingspan Kooltherm K3, a rigid phenolic foam insulation board under 18mm tongue and grove chipboard flooring. As this raised the floor level, the internal doors needed to be cut short and re-hung. Post retrofit floor U-value 0.17 W/m^2.K.

Existing double-glazed windows, rooflights, and external doors were replaced with new, argon filled, ultra-low-e double glazed window units (U-value 1.10 – 1.24 W/m^2.K) and insulated doors (U-value 1.6 W/m^2.K).

Roof insulation was added at rafter level in the sloping soffit ceilings; 150mm Celotex (rigid PIR insulation board) fitted between the rafters and soffits renewed with insulated plasterboard, to mitigate thermal bridging across the rafters.

Above the roof insulation, a vapour permeable breather membrane was installed with a minimum 25mm ventilation gap maintained between the insulation and the underside of the roof tiles to protect the timber roof structure from potential degradation due to condensation.

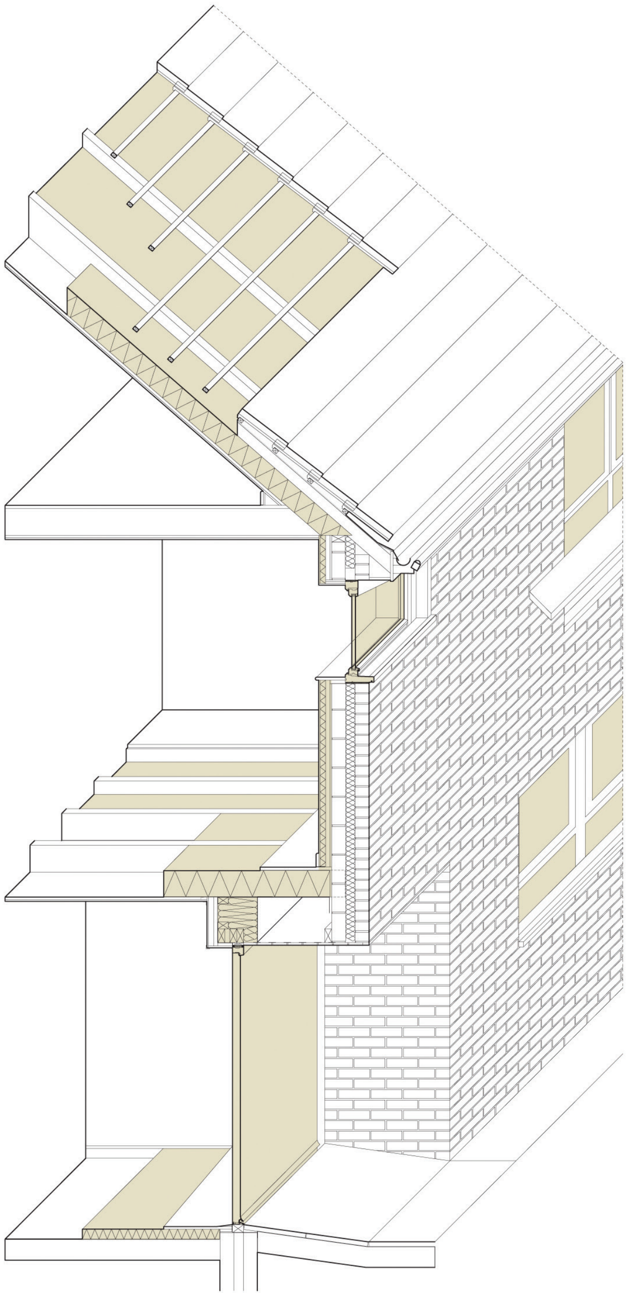


Figure 6.4 - Detailed section post retrofit, from: Baeli, M., 2013, Residential Retrofit: Twenty Case Studies. RIBA Publishing, London[6.1]

Significant measures were undertaken to eliminate unwanted air permeability and maintain a continuous air tightness layer, including: wrapping of joist ends; sealing of window reveals with Pro-Clima Tescon tape; and use of grommets where pipe penetrated air barrier layers. The measured air tightness of the house was reduced from 13 to 5 $m^3/m^2/hr@50Pa$.

Two sun-pipes were fitted between the roof and the internal bathrooms to bring in natural daylight and reduce the need for artificial light during the day. The attic space is contained within the building's thermal envelope and accommodates the new building services installations.

Building services

The space heating, hot water supply and background ventilation have been met by a combination of complementary active and renewable systems. These are to limit the amount of electricity needed to meet the dwelling's needs.

An exhaust air heat pump unit (EAHP) supplies both hot water and warms incoming ventilation air. This unit contains a 180 litre hot water cylinder and fans for the fresh air intake and stale air exhaust for the kitchen and bathroom. The EAHP recovers heat from the extracted air to produce hot water. During winter, any excess heat not needed for water heating is used to warm the fresh air supply. The design team has moved away from using this type of unit on future projects since it was heavy and hard to find space to accommodate. It struggled to meet the energy demand for space heating and hot water heating. A single direct electric panel heater is installed in the hallway of the property, to provide top-up space heating. 9m^2 photovoltaic panels by Viridian Solar provide electricity to preheat hot water for the EAHP.

A solar thermal system, 4.5m^2 of flat plate solar collector panels on the roof and a 250-litre storage cylinder in the attic supplies pre-heated water to the EAHP unit. Monitoring showed between mid-spring to mid-autumn, the solar thermal panels supplied most of the hot water.

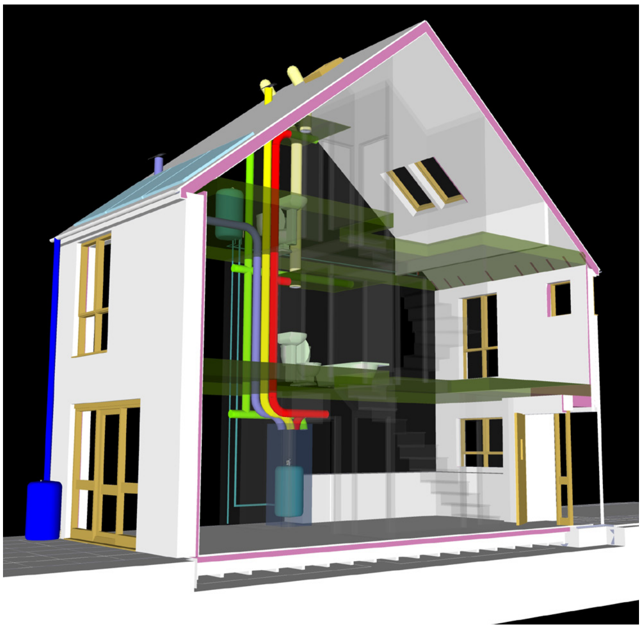


Figure 6.5 - Schematic of building services, MEPK Architects

Archetype 2, semi-detached: Zetland Road

Location: Chorlton, Manchester

Description: Pair of Victorian semi-detached - pre-1919, solid wall, uninsulated

Completion year: Autumn/winter 2018

Client, developer, project manager, building services engineer, contractor, and Passivhaus consultant: Ecospheric

Architecture: Guy Taylor Associates with Ecospheric

Structural engineer: Studio One Consulting

Electrical contractor: Environmental Building Services Ltd.

Space heating demand post-retrofit: 12.5 kWh/m^2/yr

Heat load post-retrofit: 10.4 W/m^2

Renewable energy generation post-retrofit: 41.6 kWh/m^2/yr

Heat loss form factor (PHPP): 2.20

Building type: Two Victorian semi-detached homes built in 1894, combined internal floor area of 374.3m^2 (187m^2 per house)

Budget: £887,000 (for the pair of semi-detached)

Certification or standard achieved: EnerPhit Plus certified (the two combined dwellings certified as one building, party wall not thermally insulated).

Energy Use Intensity (EUI) for the two houses

Predicted EUI (modelled): 32.4 kWh/m^2/yr

Actual EUI (measured):
Year one – 42.2 kWh/m^2/yr
Year two – 34.0 kWh/m^2/yr

Note EUI: One of the dwellings was occupied for 18 months before the other. As the original building form prevented significant party wall U-value upgrade this resulted in increased energy demand whilst the second dwelling was vacant. The results for Year 2 show the actual energy demand decreasing and it is expected to further decrease for the first whole year that both are occupied.

Electricity generated by PVs

Predicted: 53.1 kWh/m^2/yr

Measured: 48.2 kWh/m^2/yr

Note PV: The designers predicted demand and generation figures from PHPP and associated measured figures from the meters. 80% of electricity is generated when the house does not need it and is exported to the grid. There are no smart meters in either building so it has been assumed for calculation purposes that only 20% of the PV generation is consumed on site based on average usage patterns. The PV generation was lower than expected as there was a fault shortly after commissioning. Energy generation has increased since the fault resolved.

Project summary

The project included the re-conversion from flats to the two original semi-detached homes. The internal layout was reconfigured, the fabric improved thermally with new services.
The design proposed super insulating and sealing the whole envelope. In addition, the project was a test bed for technologies. Some of the project's interesting technologies are:

→ Fully breathable fabric to every external wall, floor and roof of the house
→ Electromagnetic field free electrical design and smart meter
→ Thermocline control (hot water tank that avoids de-stratification of water in tank and saves energy).

The project was uncompromising and as a technology test bed there were successes and failures with associated wastage which would result in a much more economically viable project if repeated. The technologies and specifications used are applicable to a wider class of building on future projects. The PHPP energy model, continuously updated during the project, was a useful tool and critical to the project's success. Using practically no petrochemicals, the embodied energy within building materials used in the refurb was kept to a minimum.

New external walls and roof include insulated Steico I-joists clad in Organowood. Existing brick walls at the front were modelled in WUFI where it was determined no brick creams were necessary. This was further ratified when in-situ moisture measures showed nearly all have the moisture content of a typical wall of this type. Thermalime was applied to the wood fibre boards on the side walls.

Figure 6.6 - Front after retrofit, photo by Rick McCullogh

Figure 6.7 - Rear after retrofit, photo by Rick McCullogh

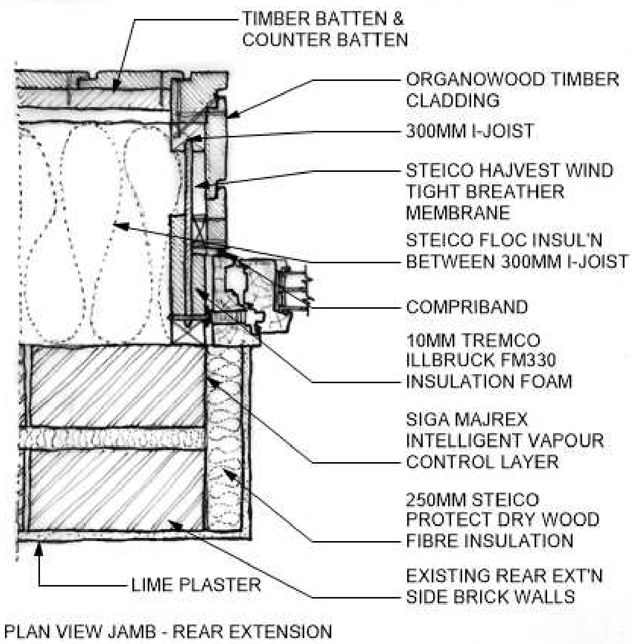
Insulation is a combination of recycled newspaper insulation blown between Steico I-joists and Steico woodfibre insulated board fixed to insulated I-joists on front, side walls and roof. The air tightness layer internally to the new I-joists, walls and roof is a Siga Majrex intelligent vapour control membrane with plasterboard on top. A parge coat of Thermalime created a consolidated level wall over which the cork lime and graphene enhanced lime paint for a fine finish capable of acting as the vapour control layer for all of the existing external brick walls. In recognition of inevitable imperfections in construction the strategy was to ensure every layer in the building fabric would be as breathable as possible to allow the fabric to dry quickly if wetted.

New windows and doors were developed with Viking. Seasonal overheating was also a concern at design stage, so to exploit the existing brick thermal mass of internal walls they were parged with cork lime plaster and painted with Graphenstone paint. In addition, a thermostatically controlled roof light with rain sensor provides effective passive cooling as part of the hybrid ventilation system. Typical U-values after completion:

→ Walls: 0.175 - 0.116 W/m^2.K
→ Floors: 0.165 W/m^2.K
→ Roof: 0.108-0.148 W/m^2.K
→ Windows: 0.68 W/m^2.K (uninstalled U-value[6.2])
→ Doors: 0.72 W/m^2.K (uninstalled U-value)
→ Roof windows: 0.81 W/m^2.K

Building services

→ Heating system: integrated 2kW electric post heater on the MVHR ventilation system, DiBT accredited Wiking log burning stove. Domestic hot water electrically heated in a Mixergy 300L tank.
→ Ventilation: Paul Novus 300 (PHI certified) heat recovery ventilation system.
→ Renewables: 30m^2 area of photovoltaic (PV) panels were added to the roof of each house to power the lighting and appliances but also heat the hot water tank.



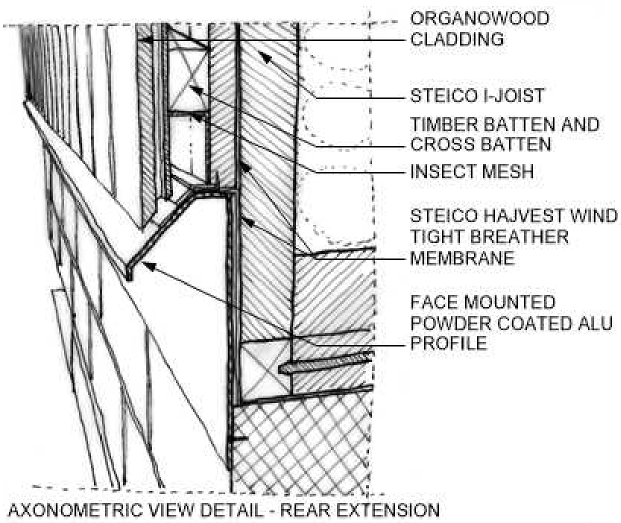
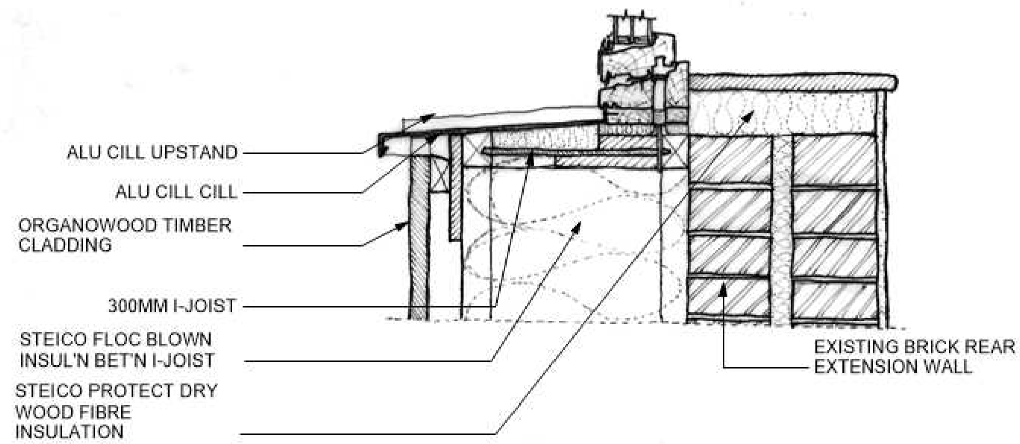
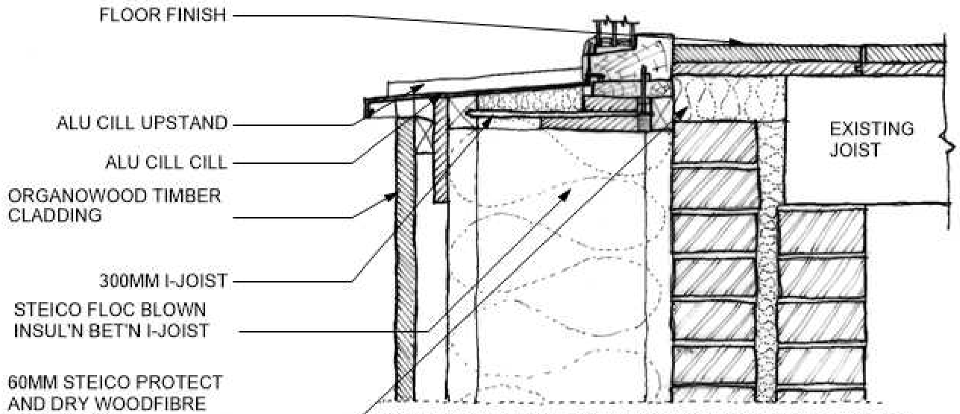


Figure 6.8 - Construction section details by Chris Rodgers, Guy Taylor Associates



SECTION CILL DETAIL REAR ELEVATION



SECTION CILL DETAIL TO FRENCH DOORS REAR ELEVATION

Archetype 3, detached: The Nook

Location: Preston Village, Brighton

Description: Detached villa - pre-1919, solid wall, uninsulated

Completion year: 2010

Client: Two Piers Housing Co-operative

Architecture: BakerBrown Studio Ltd

Consultants: Green Building Store

Contractor: Earthwise Construction

Budget: 'all-in' £166,500, and out-turn of £172,000

Certification or standard achieved: EPC B

Energy Use Intensity post-retrofit (measured): 73 kWh/m²/yr

Project summary

The Nook is a two story, detached Victorian villa' in multiple occupation (HMO), housing six adults. It has been chosen as a typical example of housing stock in Brighton and along the south coast. Prior to the retrofit it was largely uninsulated with single-glazed windows. The project aimed for a realistic, replicable and robust 'whole house' solution to retrofitting solid wall Victorian housing, demonstrating deep cuts in CO_2 emissions, and moving the property from "hard to treat" EPC F rating to EPC B by dramatically reducing space and water heating demand, and electrical consumption. The building is not listed but sits within a conservation area under an Article 4 Direction, meaning change to the appearance of the façade was restricted and the team had to deal with a number of technical, procedural and programme challenges for the retrofit.

Figure 6.9 - Front after retrofit

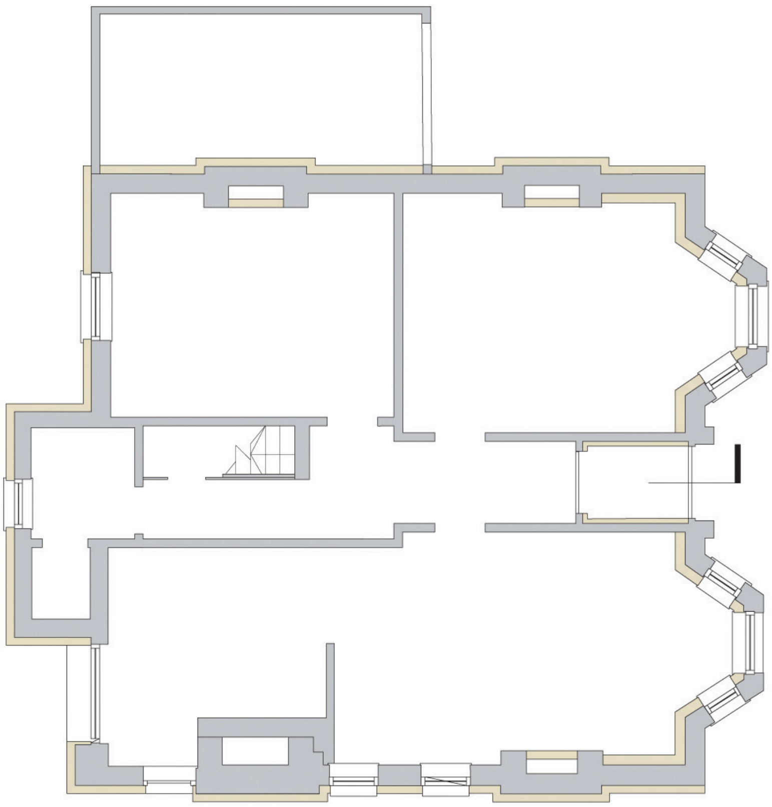


Figure 6.10 - Ground floor plan - Marion Baeli and Paul Davis + Partners[6.3]

Fabric

The retrofit introduced a 120mm internal insulation to the front façade, 120mm (2x60mm Kingspan Kooltherm) external solid wall insulation to the sides and rear, 120mm PUR ground floor insulation, and a mix of 188mm cold roof insulation, with an additional 50mm warm roof insulation, triple glazed windows to side and rear elevations and double-glazed sashes to the front. The project also employed an air tightness layer around the whole house, a Paul Novus [F] 200 DC MVHR, a condensing gas boiler, a 450L twin-coil highly-insulated hot water tank, and two Thermomax DF 100 roof-mounted evacuated tube solar thermal arrays. The heating system provides domestic hot water and top-up space heating, re-using the existing radiator circuits. Additional features included energy efficient appliances and lighting with compact fluorescents.

Planning and heritage

Resolving the planning and heritage concerns was a key challenge in the project. The internal insulation and choice of windows to the front was developed to respond to the constraints of the Article 4 Direction without undue cost. Replicating the historic features of the façade in over-cladding was cost-prohibitive. During feasibility, triple glazing had been proposed all round but was not acceptable to the Conservation Officer. After two planning applications and considerable work by the architect in collating and presenting convincing energy data on the options and in-depth work on the details, the windows were finally granted approval. The discussions with planning and the Conservation Officer delayed the start on site by over four months with significant 'knock-on' impacts.

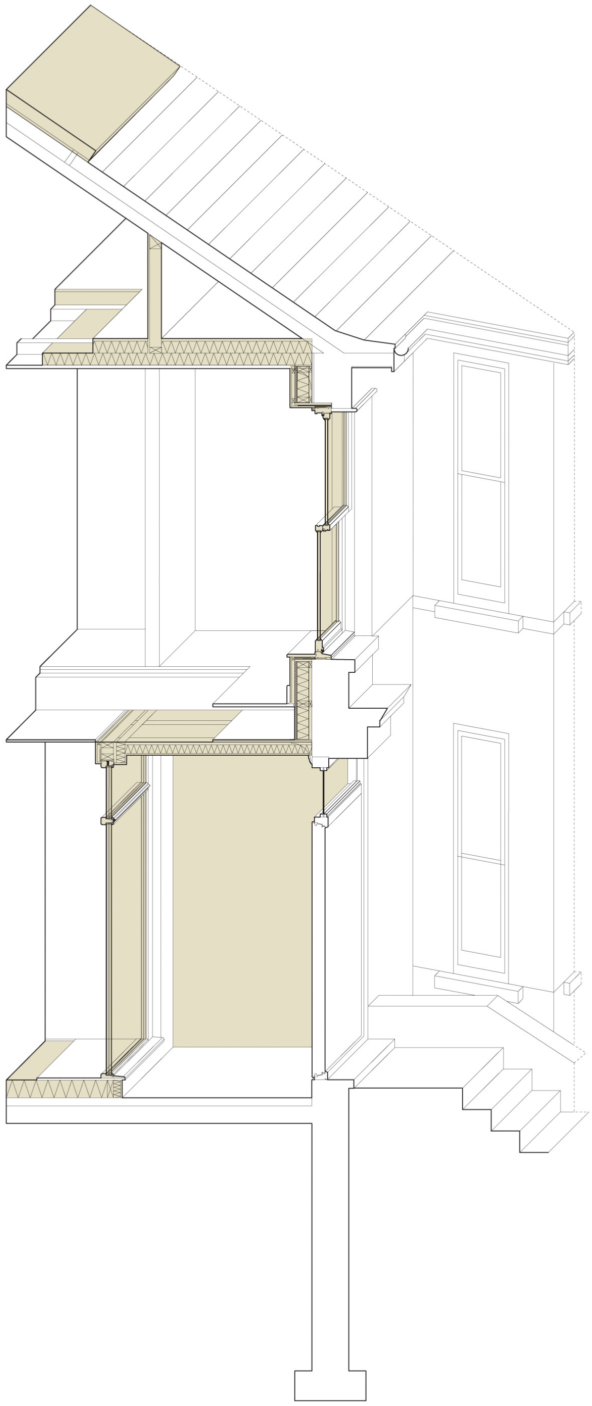


Figure 6.11 - Detailed section - Marion Baeli and Paul Davis + Partners[6.3]

The insulation strategy, including EWI to sides and rear, internal insulation to front and internal flanking returns, and a thick layer of PUR overlaying the solid floor to avoid the need to break up the ground floor slab, introduced technical challenges to avoid thermal bridging at interfaces but the resultant U-values achieved come close to Passivhaus standards. Ensuring continuity of the insulation and airtightness layer, and insulation of the internal projection of the entrance lobby into the building, required careful detailing and site workmanship, as is typical in retrofit.

Whilst the work to the building was extensive, it had to allow the occupants to remain living in the accommodation for as long as possible during the build. They remained for all but three weeks of the period during which the most invasive works were undertaken.

Budget including design fees, prelims and VAT was £166,500 and the project achieved an all-in out-turn cost of £172,000 allowing for asbestos being discovered and removed and the loss of the Low Carbon Buildings grant for solar thermal.

Key watch points were:

→ Ensure enough time in the project for negotiation with approving bodies and manage expectations.
→ Material availability: 120mm Kooltherm was subject to minimum order, making two layers of 60mm necessary and resulting in increased labour, cost and duration of installation.
→ Complexity of detailing to ensure continuity of air-tightness layer and insulation, and elimination of thermal bridges – the project team were keen to understand long-term how effective the installation has been.

Figure 6.12 - Installation of external wall insulation - BBM Sustainable Design

The completed project achieved its aims as a viable, efficient retrofit which significantly improved the energy performance of the property and could readily stand as a model for future work.

Archetype 4, flats: Wilmcote House

Location: Somerstown, Portsmouth

Description: 1960s flats (prefabricated LPS construction). 107 existing flats + 4 new ground floor flats added during the retrofit.

Completion year: staggered completion of blocks during 2017-2018

Client: Portsmouth City Council

Architecture: ECD Architects

Structural engineer: Wilde Carter Clack

Quantity surveyor and project management: Keegans

Building services: NLG

Contractor: Engie

Contractor's design team: GSA Architects; Design Buro; Curtins Engineers

Certification or standard achieved: Step-by-step EnerPHit

Space heating demand pre-retrofit (modelled): 188 kWh/m²/yr

Space heating demand post-retrofit (modelled): 23 kWh/m²/yr

Project summary

Wilmcote House is a housing estate located in Portsmouth, consisting of three 11-storey interlinked towers, with a combined treated floor area (TFA) of 10,233 m². The blocks were originally constructed as a concrete prefabricated structure in 1968, using a large panel 'Bison REEMA' variant system. With no place to relocate the residents within the existing 107 flats and maisonettes, Portsmouth City Council commissioned ECD Architects[6.4] for the building's regeneration to be achieved with the residents in occupation. The project aimed to achieve over 80% reduction in space heating demand and was designed to the EnerPHit standard; it was, at the time of completion, the largest residential EnerPHit delivered with residents in occupation in the world.

Figure 6.13 - Courtyard side completed. ECD Architects.

The existing concrete 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. Many of the residents could be classified as experiencing fuel poverty, as shown in residents' feedback carried out before the works. Studies by Teli et al.[6.5] at the University of Southampton showed economic constraints factored into many residents underheating their homes below WHO recommendations also exacerbating damp risk and mould growth.

The architect's thermal and airtightness strategy involved the simplification of the thermal envelope, with a new load-bearing steel frame erected on the garden-side elevation. This allowed the external corridors to be enclosed and allowed the living rooms to be extended to meet the new simplified external envelope. The existing stair cores were left uninsulated and outside the thermal envelope, which improved the building's form factor significantly. The 3 blocks were externally insulated with 300mm non-combustible mineral wool insulation, which wrapped the entirety of walls and roofs. The retrofit included the installation of triple-glazed windows and high-efficiency individual MVHR units in each flat.

The client partnered with the London School of Economics (LSE) in a research project which interviewed residents before, during and after the works. University of Southampton continued to monitor internal temperatures to determine the impact of the works on winter fuel poverty and summer overheating risk.

Figure 6.14 - Courtyard side during construction, showing new EWI and triple-glazed windows being fitted. ECD Architects.

The thermal performance of the building fabric was radically improved, with the estimated space heating demand reduced from 188 kWh/m^2/yr to approximately 23 kWh/m^2/yr. Initial post-occupancy evaluation conducted by University of Southampton suggests that performance is in line with predictions. Results for the 2018-19 heating seasons suggest that the building can provide WHO temperature standards in order to maintain health with little to no active heating[6.6].

Thermal comfort surveys conducted during the first round of monitoring after the insulation works were completed (2017-18) suggested a low heating usage amongst tenants, with 60% of participants utilising their heating less than once per week. Whilst 36% had not used their heating at all over the winter period.

The fabric first approach significantly improved thermal comfort conditions for residents that did not engage

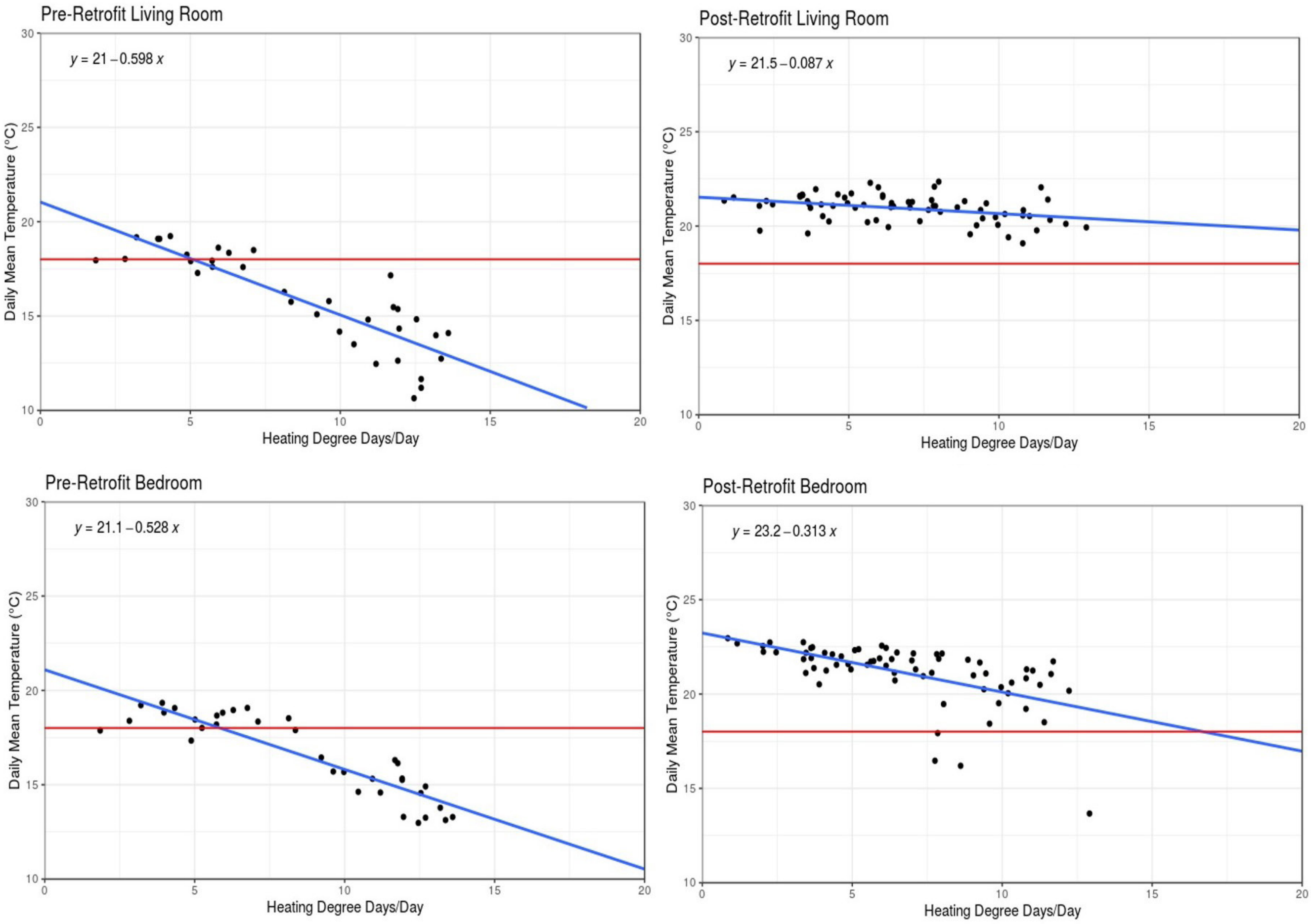


Figure 6.15 - Scatter plots show a single dwelling (living room and bedroom) that are under-heated prior to the retrofit, and currently maintains significantly better internal temperatures utilising the same heating practice post retrofit[6.6].

in a 'typical' heating strategy. In order to maintain "safe and well-balanced indoor temperatures to protect the health of general populations during cold seasons" (WHO), a minimum 18°C is utilised as the target benchmark in their study.

Figure 6.15 shows a pre- and post-retrofit comparison of a dwelling (living room and bedroom before and after the retrofit) where the resident did not use the heating in their home, possibly due to economic constraints. The point of intersection of the blue and red lines estimates a threshold for which some form of heating may be required in order to maintain a daily average of 18°C. The shift of point of intersection between pre- and post-retrofit indicates the Heating Degree Days threshold change. Prior to the retrofit, this dwelling would experience approximately 160 days annually that would require heating (in varying magnitudes) in order to maintain 18°C. Post retrofit, this dwelling in particular is able to maintain 18°C without the requirement for active heating. This study exemplifies the tangible benefits in quality of life for residents who are experiencing fuel-poverty and can transition from living in cold, draughty, mouldy flats, to living in warm, comfortable and healthy homes.

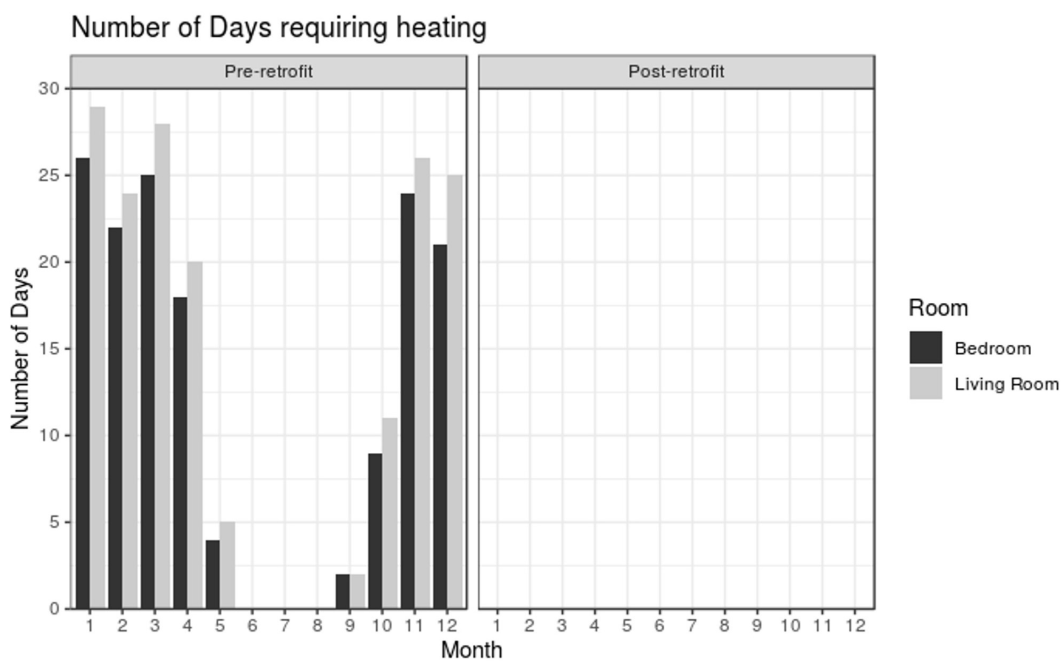


Figure 6.16 - Bar graph showing hypothetical performance under a TMY (Typical Meteorological Year). Showing the number of days that would typically require some form of heating in order to maintain 18°C[6.6]. This graph shows that no active space heating is required post-retrofit to maintain 18°C.

Archetype 5, end-terrace: Gloucester Place Mews

Location: Marylebone, London

Description: Grade II listed 'end of terrace' Mews House, pre-1919

Completion year: 2018

Client: The Portman Estate

Architecture: Feilden + Mawson LLP

Building services: Leonard Engineering Design Associates

Energy consultant: Sturgis Carbon Profiling

Structural engineer: Furness Partnership

Quantity surveyor: STACE

Contractor: Richardsons of Nyewood

Budget: £700,000, including full interior refurbishment

Certification or standard achieved:
EPC B, BREEAM Excellent, certified Passivhaus (EnerPHit) standard using the elemental method

Space heating demand post-retrofit (modelled):
37 kWh/m²/yr

Project summary

Gloucester Place Mews is in a conservation area, which made the planners resistant to any external alterations to the house. Therefore, the project included a complete reconfiguration of the internal layout. The client has a large property portfolio of rental properties. The brief was for a high quality retrofit for rental accommodation. The client wanted to test a fabric-first approach whilst monitoring costs along with their supplier's readiness and skills. The improvements would benefit tenants with improved internal comfort levels, lower energy costs and improve air quality. It was the first listed building in the UK to be certified to EnerPHit standard.

Figure 6.17 - Open plan kitchen/dining post retrofit, Feilden + Mawson LLP

Figure 6.18 - Passivhaus certified rooflight, Feilden + Mawson LLP

Figure 6.19 - View along mews to front elevation, , Feilden + Mawson LLP

The new internal layout retained the garage at ground level, which led to a larger than average form factor; the heat loss area is 396m^2 and TFA (treated floor area) is 121m^2. The fabric upgrade was robust; the internal walls were insulated with 40mm Aerogel to avoid a reduction in internal floor area, an airtightness membrane with 30mm service void and magnesium oxide board finished with lime plaster and breathable paint. The airtight layer in the build-up of the building envelope had to be carefully detailed around the interfaces between new and existing elements. This included connections between existing external walls and new structure. Likewise the insulation was carefully detailed to eliminate thermal bridges, in particular, around the internal garage volume. Existing windows were refurbished and new triple-glazed secondary glazing fitted along with Passivhaus certified front door and rooflights.

The only element of the existing interior retained was the stairs, which itself presented challenges in achieving adequate insulation and airtightness against the external wall behind the stringer, affecting the detailing of the window when reinstalled against the front wall. Given the small and relatively complex form, the completed airtightness result of 0.7 was well within the EnerPHit threshold. A new heating and hot water system was installed along with an MVHR (mechanical ventilation and heat recovery) as well as the provision of monitoring equipment to give the client feedback to inform future projects.

The fabric first approach centred around specification, procurement/availability and quality control. Some materials were somewhat specialist and subject to long lead times. Site detailing of complex junctions and interfaces with historic fabric and detailing require very close attention. An adequately detailed survey prior to and during design would have eliminated some of the issues experienced on site.

The energy, water and indoor environment of the resultant property were monitored during 2018/2019, although the property was not fully inhabited – only one of three double bedrooms were occupied – data analysis offers some useful conclusions.

Figure 6.20 - Installation of internal wall insulation (40mm Aerogel applied to the internal walls to minimise loss of space), Feilden + Mawson LLP

Key issues identified in the occupancy study were:

→ Reliability of monitoring – meters showed some data loss, possibly due to loss of internet connectivity.

→ Habitation affects quality of data and further monitoring of different tenancies would help build better understanding of performance issues.

→ Occupant understanding of building operation is key to energy efficiency.

→ Monitoring had not been installed in downstairs bedrooms, so no data exists for those portions of the accommodation. No conclusions could be drawn for these rooms in terms of thermal comfort, particularly in a summer heatwave.

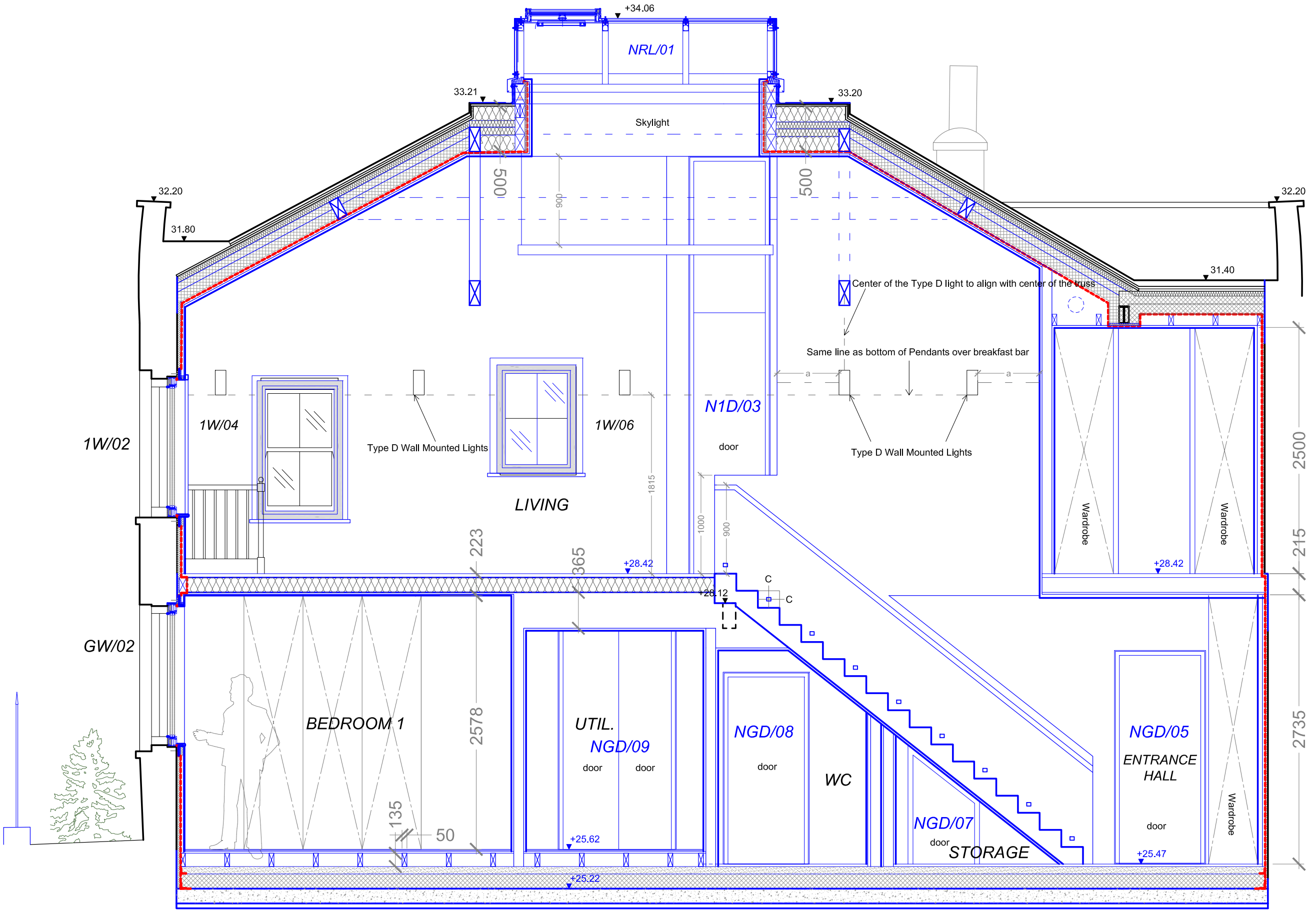


Figure 6.21 - Section, Feilden + Mawson LLP[6.7]

Thematic case studies

The case studies provide real-world examples of retrofits that align with the general themes that we have set out in the archetype pages. They may not conform fully with the archetypes, but demonstrate what can be achieved, as well as the techniques used and challenges that need to be overcome.

Deep and step-by-step retrofit

Stakeholder engagement

Windows

Insulation

Thermal bridging

Airtightness

Moisture

Case study 1: Sterndale Road

Location: Notting Hill, London

Description: Victorian mid-terrace house

Topic: Stakeholder engagement and communication

Client: Notting Hill Housing with United House Developments Limited

Architecture: Baily Garner

Contractor: United House

Budget: £108,987.00

Certification or standard achieved: EPC B

Project summary

This property in Sterndale Road[6.8] aimed to inform eco-refurb specifications for Notting Hill's Property Services and Development Department. Intended to form the basis of future mass refurbishment of Victorian, Edwardian and Georgian properties. It sought to identify technologies and products that would perform best environmentally whilst also being commercially viable.

Pre-work thermographic surveys and air pressure testing showed poor results: air leakage of 17.5 $m^3/m^2/h$ @50Pa, excessive draughts around windows and doors, numerous thermal bridges, cold spots and a minor insulation defect in the recently refurbished roof.

65mm of insulation backed plasterboard was fitted to walls to achieve 0.32 $W/m^2.K$. The flat roof, renewed and upgraded prior to the project with 240mm wood-fibre insulation, was designed to achieve 0.15 $W/m^2.K$. Existing windows were replaced with double-glazed, low-E glass to achieve 1.2 $W/m^2.K$. The lower ground floor was remediated with 220mm lightweight expanded clay aggregate, under limecrete solid floor with 55mm screed. A new A-rated gas boiler, radiators with thermostatic radiator valves, and underfloor heating in the lower-ground floor were fitted, plus a twin-coil thermal store (to accept solar hot water feed). Solar Thermal panels give half of the annual hot water demand. A 0.875 kWp photovoltaic array was installed. Lighting was upgraded to low-energy fittings throughout.

Figure 6.22 - Front post retrofit

Improvements included acoustic privacy, rainwater harvesting to toilets, water saving sanitary appliances, recycling facilities and innovative technologies (such as a smart voltage management system). The internal layout largely was unchanged but a new habitable space in the lower-ground floor created a new bedroom, home workspace and living room with access to the garden. Post-works air tightness tests showed 5.9m^3/h.m^2@50Pa, and the Energy Performance Certificate (EPC) moved from band G to band B.

Stakeholder involvement was critical. A notable element of the project was the measuring, monitoring and engagement strategy, which included gathering feedback from contractors on buildability and the value of different improvement measures. The Notting Hill's Residents Repairs Working Party (RRWP) was involved in the project throughout, including setting project aspirations, attending contractor interviews, and engagement in the workshops held to assess suitability of the many options of materials and technology considered for inclusion in the building. Green features specified were strongly influenced by feedback from RRWP. Operational costs were important to residents and an open day was held part-way through, which visitors were encouraged to comment and ask questions.

	Pre-refurbishment	**Post-refurbishment**
SAP	13	**90**
EPC	Band G	**Band B**
Annual running costs	£2020	**£220**
Annual CO_2 emissions	12.3 tonnes	**1.95 tonnes**
EcoHomes XB	7	**91**

Figure 6.23 - SAP rating post retrofit

Case study 2: Pavillion Road

Location: Hans Town Conservation Area, Chelsea, London

Description: Mid-terrace, mews house

Topic: Windows

Client: Cadogan Estate

Architecture: Latitude Architects

Structural engineer: ConisbeeMEP

Building services: HITEK

Project manager and cost consultant: The Trevor Patrick Partnership

Passivhaus Designer and BREEAM assessor: Sturgis Carbon Profiling

Passivhaus Certifier: CoCreate

Historic buildings consultant: Donald Insall Associates

Planning advisers: Gerald Eve

Contractor: Richardson's (Nyewood) Ltd.

Budget: The client reported a 6% increase above business as usual

Certification or standard achieved: BREEAM UK Domestic Refurbishment 2014 "Outstanding" and PassivHaus EnerPhit certification using the elemental method

Space heating demand post-retrofit (modelled): 32 kWh/m^2/yr

Energy Use Intensity post-retrofit (modelled): 96 kWh/m^2/yr

TFA (treated floor area): 128m^2

Project summary

This two-storey Hans Town Conservation Area, solid-wall, mews house was fully demolished internally, with façades retained and reconstructed anew as a three-storey, two-bedroom modern dwelling, to high thermal performance and quality of interior fit-out. This pilot project is part of Cadogan's sustainability strategy, reducing environmental impacts across the Estate.

The project targeted a high BREEAM rating and Passivhaus EnerPhit certification. Pre- and post-completion monitoring was extensive, including energy at meter/sub-meter level, thermal comfort, indoor air quality (IAQ), moisture/damp levels, and occupant feedback.

Retention of the historic façades introduced some issues with detailing and spatial planning, which were resolved in the finished project by internal insulation, replica triple-glazed windows, replacing doors in the same style, as well as repairing and repointing the original brickwork. The most significant challenge appears to have been obtaining Conservation Area consent for the changes to the external appearance and specifically the windows, together with some complex detailing of the insulation interface between the retained rear façades and the new mansard roof construction, impacting on the configuration of the internal space.

A 'fabric first' approach was taken:

→ A glass mineral wool insulation system was applied to the internal face of front and rear façades, rigid PIR insulation was used in the new warm-roof mansard and to the new ground floor slab, and aerogel was used to ensure appropriate visual detailing of the dormer windows to suit the aesthetics of the Conservation Area.

- → Timber sash triple-glazed windows met the conservation requirements.
- → An airtight membrane was introduced, and the contractor's workforce was specially trained in the correct use of the special sealing and bonding tapes prior to work on site. Airtightness responsibility was assigned to a designated member of site staff to help ensure every area was properly sealed prior to being covered up by subsequent construction.

Heating and ventilation was achieved using a gas boiler and a Renovent Excellent-400 (Plus) MVHR. Smart meters were installed so occupants can see usage directly.

The project is considered by Cadogan to have been very successful and achieved BREEAM 'Outstanding' as well as PassivHaus EnerPhit certification. After living in the property for over a year, the occupiers report noticeably good indoor air quality, greatly reduced noise and significantly lower energy bills than in their previous residences – with a gas bill of only £200/year for all heating, hot water and cooking. Cadogan is taking lessons from this project into future developments, increasing building efficiency on their journey towards net zero.

Figure 6.24 - Front post retrofit.

Case study 3: Shaftesbury Park Terrace

Location: Shaftesbury Park Estate Conservation Area, Wandsworth, London

Description: Pre-war (1870s) mid-terrace house

Topic: Insulation

Client: Peabody Estate

Architecture: Feilden Clegg Bradley Studios with Bill Gething

Consultants: Max Fordham, Rickaby Thompson Associates

Contractor: Wates

Budget: £80,791 of which energy saving measures and collateral costs were £78,876

Energy Use Intensity pre-retrofit (modelled): 341 kWh/m²/yr

Energy Use Intensity post-retrofit (modelled): 87 kWh/m²/yr

Project summary

This two-bedroom house is located in a conservation area. Peabody's aim for the project was to find solutions that could be applied to their 21,500 other homes in London. The occupants were to remain in situ during the majority of the works.

Pre-retrofit, the house was largely uninsulated, with solid brick walls, single-glazed sash windows, and suspended timber ground floors. Employing the principle of 'fabric first':

→ Windows were replaced with double-glazed sashes to the front and triple-glazed casements to the rear with trickle vents in line with the strategy of providing natural ventilation.

→ Internal Aerogel insulation was introduced to front and rear walls, and returned along both party walls.

→ 80mm external PUR insulation was added to the rear kitchen extension and over-clad with timber rainscreen board.

→ Insulation was provided on the ceiling line within a cold roof void.

Figure 6.25 - Front elevation. Feilden Clegg Bradley Studios

→ The suspended ground-floor timber joists originally were supported on timber wall plates bedded in the brick wall. The joist ends were cut back and new joist ends spliced on, re-supported on foam glass. The void under the joists was filled with blown polystyrene bead cavity wall insulation after re-routing services to ensure cabling did not overheat and gas pipes were not run through unventilated voids. The need to re-route services incurred additional costs for the project.

The team decided MVHR would have taken up too much space, being problematic to install through the existing structure, also its benefits would likely have been limited due to the practicality of achieving the necessary high levels of airtightness. The strategy was efficient boiler installation, heat pump recovering heat from an integrated Passive Stack Ventilation system. The ventilation strategy consisted of trickle vents on windows and a fan-assisted passive stack ventilation from the kitchen and bathroom. The passive stack vent used an experimental heat pump recovering heat from the exhaust air and an exhaust air heat pump (EAHP). The heat is fed back into the domestic hot water thermal store. Solar thermal panels pre-heat hot water for the existing retained condensing boiler, connected to radiators.

Originally, Passivhaus certified triple-glazed casements were proposed; however, these were not acceptable to the planners, due to their visual appearance impacting on the heritage value of the conservation area. Double-glazed casements were considered an acceptable balance.

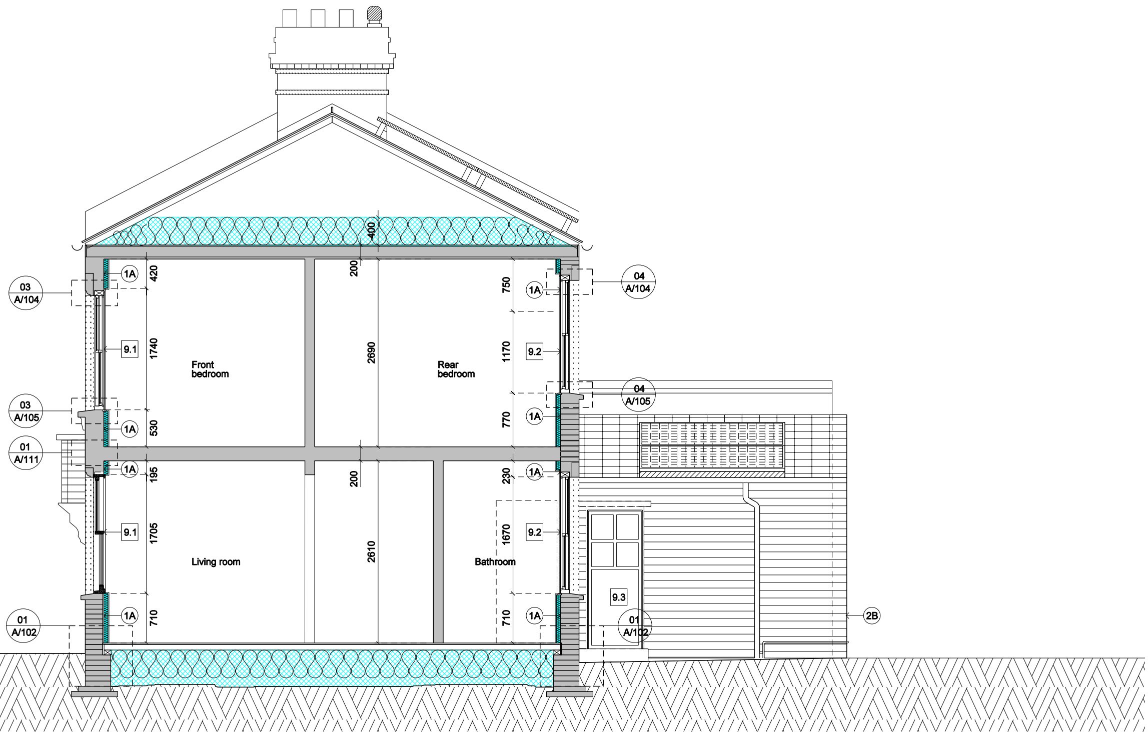


Figure 6.26 - Section - Feilden Clegg Bradley Studios

Case study 4: Passfield Drive

Location: Tower Hamlets, London

Description: Post-war (1960's) mid-terrace

Topic: Deep retrofit with residents in-situ

Client: Southern Housing Group

Architecture: bere:architects

Building services: Alan Clarke

Structural engineer: Galbraith Hunt Pennington

Contractor: AD Enviro

Budget: Design stage £89,618, Out-turn construction £115,957 (£14,943 of which was client enhancements)

Certification or standard achieved: 'Quality-Approved Energy Retrofit with Passive House Components' as set out in the certification criteria by the Passive House Institute (PHI)

Space heating demand pre-retrofit (measured): 315 kWh/m²/yr

Space heating demand post-retrofit (measured): 31 kWh/m²/yr

Energy Use Intensity pre-retrofit: 385 kWh/m²/yr

Energy Use Intensity post-retrofit: 54 kWh/m²/yr

Floor area: 96m²

Project summary

The three-storey mid-terrace house was occupied by three generations of a single family. The project, completed in 2011, aimed to establish principles of carrying out works with the occupants remaining in occupation.

Pre-retrofit, the property was under-heated, suffered damp and condensation problems. Windows were single-glazed with metal frames. Walls were solid brick (rendered externally), and the roof had minimum insulation. The ground floor was a solid concrete slab. Clear communication managed expectations from the outset, the occupants were keenly engaged in the process, and in the post-completion monitoring. Site-work took approximately 8 months from start on site to full completion.

200mm of insulation was added to the loft space prior to the start of the retrofit works. Subsequent retrofit works comprise:

→ 200mm and 250mm EPS external insulated render system to front and rear walls.

Figure 6.27 - Front post retrofit, bere:architects

→ The external insulation was extended one metre below ground to foundation level, to limit the heat losses through the ground slab.
→ A further 200mm mineral wool insulation was provided to the attic to give 490mm total thickness.
→ High performance vacuum insulation and protective boarding to floor slab beneath finishes. Internal wood fibre insulation to flank walls and details to eliminate cold bridges from neighbouring façades and party walls.
→ Continuous airtightness membrane was installed in the attic, sealed to cementitious parge coat to walls. Continuous airtight seal from parge coat to airtightness membranes in extension. Windows sealed to a parge coat with continuous tapes. Airtightness grommets fitted to all new and existing service penetrations.
→ Passivhaus certified triple-glazed windows and doors with U-value of 0.8 W/m^2.K.
→ New timber-framed rear extension with 375mm wood fibre insulation to walls and 225mm mineral wool and 150mm wood fibre insulation to roof.
→ 92% efficient mechanical ventilation with heat recovery (MVHR) installed. Roof-mounted solar thermal array with solar cylinder and a re-configured conventional gas boiler.
→ High performance insulation (0.038 W/m.K at 40°C) to hot water pipes.

Site work took longer than planned due to a number of issues: the need to work around the occupants; delays in materials procurement; and long lead-ins for specialist materials. There were significant problems with quality of workmanship and a significant amount of remedial work had to be undertaken to achieve the required airtightness. Final measured airtightness was, however, improved from 5.6ach@50Pa to 1.9ach@50Pa. Post-project reviews identified that efficiencies could be gained by undertaking the work on a larger scale, enabling training and skills for all trades.

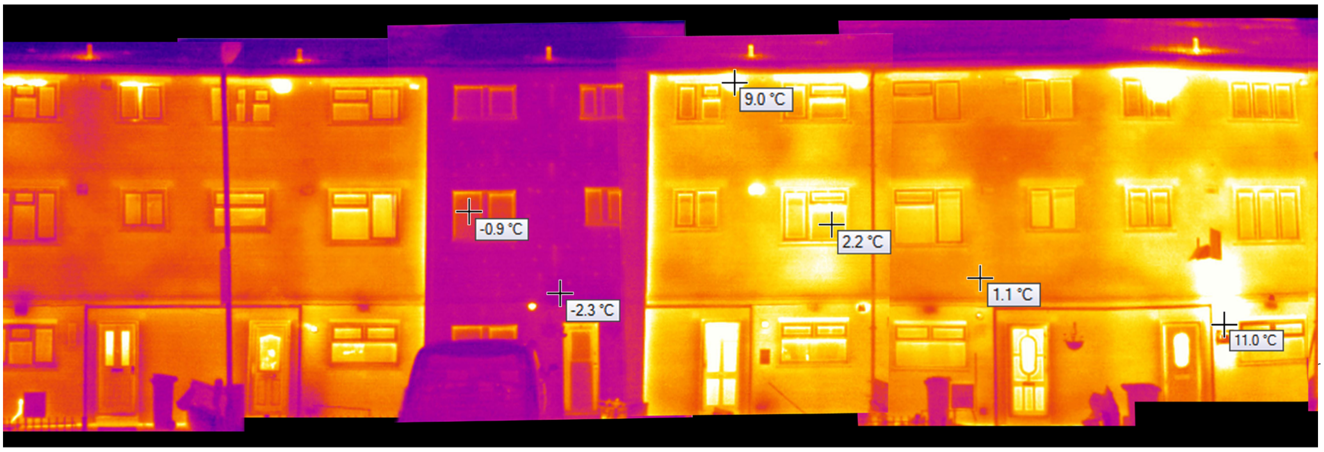


Figure 6.28 - Thermal imaging winter 2012 post retrofit, bere:architects

Case study 5: Bloomsbury House

Location: Bloomsbury, London

Description: Mid-terrace, Georgian conservation property

Topic: Windows in a listed property

Architecture: Prewett Bizley Architects

Structural engineer: Jonathan Parks

Contractor: Bow Tie Construction

Budget: Energy saving works £200k (380m^2)

Certification or standard achieved: Near miss EnerPHit

Space heating demand post-retrofit (modelled): 25 kWh/m^2/yr

Energy Use Intensity post-retrofit (modelled): 45 kWh/m^2/yr

Project summary

The 'Bloomsbury House' is a historic listed Georgian townhouse in Bloomsbury, London. It had been used as an office for some decades but was converted back to a single-family dwelling as part of this project. It has come close to meeting the EnerPHit standard even with the limitations of working with an existing grade II listed building. Given the listed status, great care needed to be taken with the historic fabric of the building. Original features were kept in-situ and fabric efficiency measures as well as new services were very carefully planned.

Generally, the twentieth century additions at the rear of the house were the easiest to work with and it was possible to use modern triple-glazing and modern insulations. Service runs were carefully routed through these parts and within the deep floor structure of the main house.

For the main house the internal insulation strategy includes five types of moisture open insulation (cellulose, woodfibre, glass wool, aerogel and open-cell sprayed insulation). These layers generally replaced plasterwork that had been altered or damaged in the latter part of the twentieth century. The brickwork on the outside was also carefully repaired to enhance the drying potential of the fabric.

Perhaps the greatest challenge was how to tackle the very large multi-pane sash windows. While most of these were not original (in fact they were mostly

Figure 6.29 - High performance secondary glazing post retrofit. Prewett Bizley Architects

later Victorian replacements) the conservation officer would not accept replacement sashes with insulating glass.

Therefore, the architect approached a secondary glazing supplier to see what might be possible. Together they married an existing slender frame system (normally used to carry single-glazing) with evacuated insulation glass. The result was an especially high-performance type of secondary glazing that had very little impact on the appearance of the windows when viewed from either inside or outside. As well as achieving an estimated U-value of around 1.0 W/m^2.K. This solution proved to be very airtight and helped with the final air test result of 1.4ach@50Pa. The secondary glazing also almost eliminated the street noise from the interiors which creates a very serene and peaceful atmosphere.

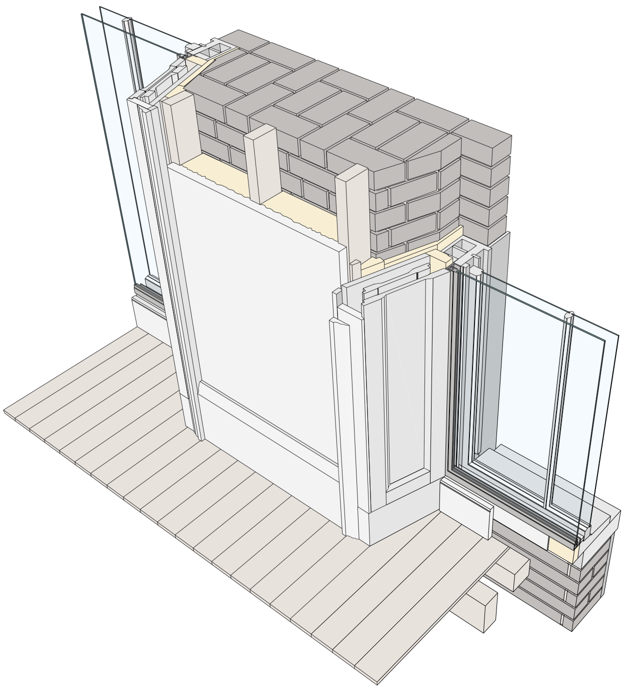


Figure 6.30 - Axonometric showing insulation to walls, shutter box and secondary glazing to existing windows, Prewett Bizley Architects

In order to minimise duct runs, two MVHR systems were fitted. The duct routes were carefully planned to have no impact on the interiors. One serves the upper part of the house and the other the lower two floors. The air quality has been measured and is especially good with CO_2 counts never exceeding 1000ppm.

The very low space heat demand enabled the radiator system to be removed altogether and the house is heated with underfloor heating. Heating and hot water are provided by an air source heat pump mounted within the ‘M’ of the mansard roof. Internal temperatures are impressively consistent even during very cold weather.

The project is testament that it does not need to be an either-or choice between improving energy performance or conservation. It is possible to conserve the planet and our historic buildings.

Case study 6: Erneley Close

Location: Manchester

Description: 32 walk-up flats in two separate maisonette blocks and six cottage style bungalows.

Topic: Thermal bridging

Architecture: Edelmann and Ebling

Developer: R-Gen Developments

Passivhaus consultant: Eric Parks

Building services: Alan Clarke

Structural engineer: Marston and Grundy

Contractor: The Casey Group

Budget: £3.1M

Certification or standard achieved: Passivhaus EnerPHit certification in 2015

Space heating demand post-retrofit (modelled): 23 kWh/m²/yr (both blocks)

Energy Use Intensity post-retrofit:
Smaller block - 73.5 kWh/m²/yr
Larger block - 76.8 kWh/m²/yr

Space heating demand (measured): 21 kWh/m²/yr (based on analysis interpolated from data collected January - April 2015)

Air pressure results:
Smaller block - 1.0@50pa over total floor area of 740m²
Larger block - 1.0@50pa over total floor area of 1228.3m²

U-values:
Roof 0.08 W/m²K
Timber Frame Infill Walls: 0.097 W/m²K
Gable End Walls: 0.12 W/m²K
Ground Floor: 0.21 W/m²K
Doors and Windows: 0.9 W/m²K

Note: the EUI is higher than the LETI targets due to the heating and hot water system being a communal gas boiler system.

Project summary

In May 2015, Eastlands Housing (now One Manchester) completed work on its retrofit to EnerPHit standard of 32 social housing flats in two blocks in Erneley Close, in Gorton, Manchester. It was intended that the development would reduce energy bills, create new community greenspace and make the area a destination of choice.

The scheme not only looked to adopt the EnerPHit standard across the site, but equally created a connection of place making between the buildings. The building works included vast improvements in the fabric U-values, airtightness and in particular, addressing thermal bridging.

Figure 6.31 - Close up after retrofit

Typical of 60s maisonette blocks, these had a number of architectural features, external horizontal walkways, balconies and vertical piers. The construction used cast through concrete, where the concrete continues from internal areas to external areas which created significant thermal bridges in the structure. The Passivhaus consultant estimated the thermal bridges contributed to around a third of the total heat loss.

The solution adopted was to wrap the balconies and features with insulation and use insulated skirting where cold spots were found. Several different variations were implemented as the building works progressed and a great deal of thermal analysis was undertaken to support the best solution.

Originally, the plan was to keep the residents in situ, with the strategy for the wall performance being to retain the inner leaf blockwork walls, applying a parge coat and then adding insulation externally. However, once major works began, the blockwork walls were found to be structurally deficient and with the decanting of the residents, the decision was taken to remove the walls entirely. In place, an insulated timber frame was installed, allowing for the use of a timber framed backing wall and easier sealing of the perimeter.

This project highlighted the importance of intrusive surveys needed from the outset of the design phase to facilitate design with the necessary level of information and enable adapting the program and procurement to suit findings.

Figure 6.32- Elevation prior to retrofit

Figure 6.33 - Elevation post retrofit

Case study 7: Hensford Gardens

Location: Sydenham

Description: Mid-terrace 1960's

Topic: Step by step retrofit

Client: Marion Baeli and Robert Prewett

Architecture: Prewett Bizley Architects

Building services: Borisa Ristic; Green Building Store (MVHR)

Structural engineer: Rodrigues Associates

Contractor: Borisa Ristic

Budget: £150,000 total budget for the build. Energy efficiency measures were about £55,000

Certification or standard achieved: Step by Step EnerPhit (not registered)

Space heating demand pre-retrofit (modelled):
150 kWh/m²/yr

Space heating demand post-retrofit (modelled):
Step 1: 40kWh/m²/yr
Step 2: 23kWh/m²/yr

Energy Use Intensity post-retrofit:
65 kWh/m²/yr

Project summary

As a step by step retrofit, this project may be helpful for other home owners who do not have the capital to carry out a whole house retrofit at once. The project also involved the replanning of the house alongside the retrofit works. To start with, the owners/ architects carried out an overview of the project potential and decided that EnerPHit would be possible but that capital restrictions would mean it would have to be done in stages.

First step:
The first stage was to carry out the most disruptive works. It consisted of removing many of the internal partitions on ground floor to form a more open plan space and to add a new loft addition that would create a fourth bedroom. This reorganisation work provided the opportunity to re-roof the whole house with a thick layer of insulation and to add floor insulation over the slab on ground. The party walls which were of cavity brickwork were insulated with blown mineral wool and also insulated internally where they form external walls. The front walls and windows were left untouched save for air tightness measures in readiness for step 2. During the reorganisation of the floors, ducting for a future heat recovery ventilation system was fitted.

Figure 6.34- Front after retrofit, Marion Baeli and Robert Prewett

Second step:
Step 2 took place over 2 weeks, 3 years after the original works. It involved the complete renewal of the front and rear façades which were infill construction between the party walls. The cavity wall infill was removed and replaced with super insulated timber framing. New triple glazed windows were fitted with attention paid to avoiding the cold bridges particularly with the party wall brickwork. A precast concrete beam at first floor which was part of the original construction, required careful insulation with thin vacuum insulation panels. Following the installation of the new windows the envelope was tested for air tightness, achieving a 0.7 ach @ 50 Pa result. It is hoped that the final compliance test will remain below 1.0 in order to achieve EnerPHit.

Third step:
The MEP strategy included replacing the 15 year old gas boiler and installing a whole house ventilation system in the new roof extension. This arrangement will stay in place for a few more years, until a fourth step can be implemented which will include the replacement of the boiler with a thermal store and external air source heat pump. The enclosure of the boiler cupboard has been designed to accommodate the dimensions of a thermal store and positioned within proximity of the future air source heat pump location.

Extra consideration:
The second step aimed to recycle materials as much as possible. For this, the majority of the bricks and blocks removed were crushed and re-used to form the base of a new terrace and landscaping. The existing 5m long oak facade cladding panels from the 1960's were re-planed; repainted and re-installed in place. Even the window panes of the original pvc glazing were re-used to form allotment glass houses.

Figure 6.35 - Internal wall insulation to original external building envelope which was mostly cavity but solid in isolated location, Marion Baeli and Robert Prewett

Case study 8: Princedale Road

Location: Holland Park

Description: Mid-terrace Victorian house

Topic: Airtightness

Client: Octavia

Architecture: PDP London

Building services: Ryder Strategy ; Green Tomato (now Enhabit)

Passivhaus consultant: Green Tomato (now Enhabit)

Sustainability consultant: Eight Associates

Contractor: Ryder Strategy

Budget: £180,683 total budget for the build. Energy efficiency measures were about £59,870

Certification or standard achieved: PassivHaus certification

Space heating demand post-retrofit (modelled): 10 kWh/m²/yr

Energy Use Intensity post-retrofit (measured): 31 kWh/m²/yr

Energy bills (actual): £1,000 (annual post retrofit, electricity only)

U-values:
Front elevation: 0.15 W/m²K
Rear elevation: 0.15 W/m²K
Party walls: 0.25 W/m²K
Windows: 0.8 W/m²K
Door: 1.2 W/m²K
Floor: 0.15 W/m²K
Roof: 0.17 W/m²K
Airtightness: 0.34 m³/ m².h@50Pa

Project summary

This project was, for social housing provider Octavia, part of the 'Retrofit for the Future' Government programme aiming to reduce carbon emissions from existing dwellings by 80%.

The house is a typical mid-19th century London terraced house located in a conservation area. The project features an internal insulation strategy, a unit combining MVHR, an exhaust air source heat pump and hot water storage, solar thermal panels, triple glazed sash look-alike windows. Like all the 100 houses of the Retrofit for the Future Programme, this house has been monitored for over 2 years and delivered outstanding energy and comfort results and achieved 80% carbon reductions.

Due to its location in a conservation area, external wall insulation was not feasible. The team therefore followed the principles of PassivHaus 'fabric-first' approach with an internal wall insulation strategy as

Figure 6.36 - Front post retrofit, Paul Davis + Partners

part of the complete upgrade of the external building fabric as the house was in a very poor condition.

It was essential that the continuity of internal insulation and airtightness layers throughout the building envelope was maintained, coupled with the installation of a robust ventilation system (build tight, ventilate right). This is to avoid any water vapour condensing within the building fabric, which can cause long-term damage to buildings and must be avoided.

In this house, the approach was to keep the strategy as simple as possible with the minimum variety of materials, combined with robust detailing. The house has been retrofitted with a thick insulated and airtight layer inset within an existing Victorian building envelope. It is a rare example of a continuous strategy where the same thickness and insulation material has been installed on all floors, walls and ceilings and where the airtightness layer is made of a single material type with taped and jointed OSB timber boards. These were also strategically positioned between two layers of insulation to ensure its protection from potential penetrations (nails) and also to enable the location of sockets and switches back boxes within the top insulation layer without compromising the integrity of the airtightness line.

The airtightness test was carried out with a small fan and was done in two steps. The first was carried out at the stage when the airtightness and windows were installed but not the finishes. This enabled the team to remediate minor leaks while they were still accessible. Another test was carried out on completion to ensure that no trade intervention affected the performance of the airtight layer as a last chance to remedy any issues. This stepped approach is really important to avoid any potential difficult remedial works which might involve abortive works and impact on cost and programme of a project.

The strategy was bold but was justifiable in a house which was in a very poor state of repair. Ten years on, there are no signs of moisture anywhere in the house's fabric and the internal conditions have been comfortable and entirely draft-free giving the house a very long lease of life.

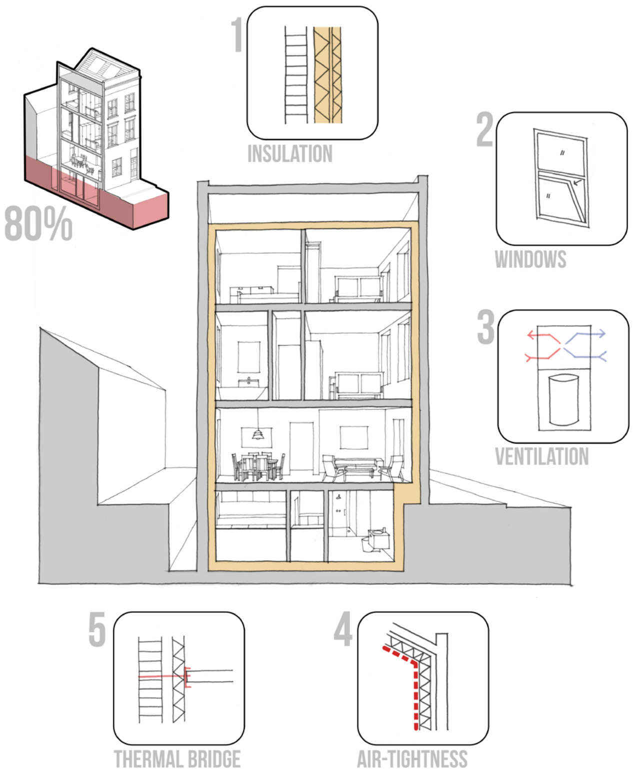


Figure 6.37 - Schematic of retrofit works, Paul Davis + Partners

Case study 9: Rectory Grove

Location: Clapham, London

Description: Semi-detached Early Victorian house Grade II listed

Topic: Internal insulation moisture content monitoring

Architecture: Harry Paticas - Arboreal Architecture

Building services: Alan Clarke

Building performance pre-design investigations: Archimetrics

Structural engineer: The Morton Partnership

Certification or standard achieved: AECB Silver

Space heating demand pre-retrofit: 180 kWh/m^2/yr

Space heating demand post-retrofit: 40 kWh/m^2/yr

Energy Use Intensity post-retrofit (modelled): 79 kWh/m^2/yr

Walls: 9 types of insulation used including Woodfibre, Aerogel, IQ Therm (between joists)

U-value range: 0.15 - 0.58 W/m^{2}K

Airtightness: All walls plastered with lime plaster as air tightness layer 1.8ach post-retrofit (9.6ach pre-retrofit).

Ventilation: continuous mechanical extract (MEV) from kitchen and wet rooms

Project summary

This project is an example of monitoring the hygrothermal performance (moisture content between existing masonry walls and new insulation) after a thermal upgrade along with repairs and fabric improvements of a Grade II Victorian house in a conservation area.

Pre-design investigations were carried out at the outset, an assessment was carried out of the existing building, including airtightness test, thermographic survey of fabric and a survey revealing actual U values of existing walls.

Figure 6.38 - Front elevation, Arboreal Architecture

Post construction monitoring of relative humidity and wood mositure equivalent was carried out using 19 wireless moisture sensors installed during the building construction. Some within the cold loft space and 15 mounted on Douglas fir wood blocks installed in the masonry behind the lime plaster and new insulation. The sensors aimed to obtain data to assess the risks on the moisture and temperature within the insulated walls and hence appraise the risks to buried existing timbers. All timbers built into the walls (including joist ends, lintels and wall plates) were treated with boron wood preservative paste.

Results showed the higher the thermal resistance of the insulation (i.e. better), the lower the temperature of the brickwork, which resulted in higher RH (relative humidity). There was also a correlation between the orientation of the wall (i.e. direction of prevailing wind and rain) and RH values. The data showed that the wet winter months were the worst, with the peak moisture content in February, then drying out occurred over the summer months aided by the vapour permeable materials (masonry, lime plaster, insulation and paint etc.). The walls continued to dry out slowly for a period of approximately 6 years after construction and have now equilibrated.

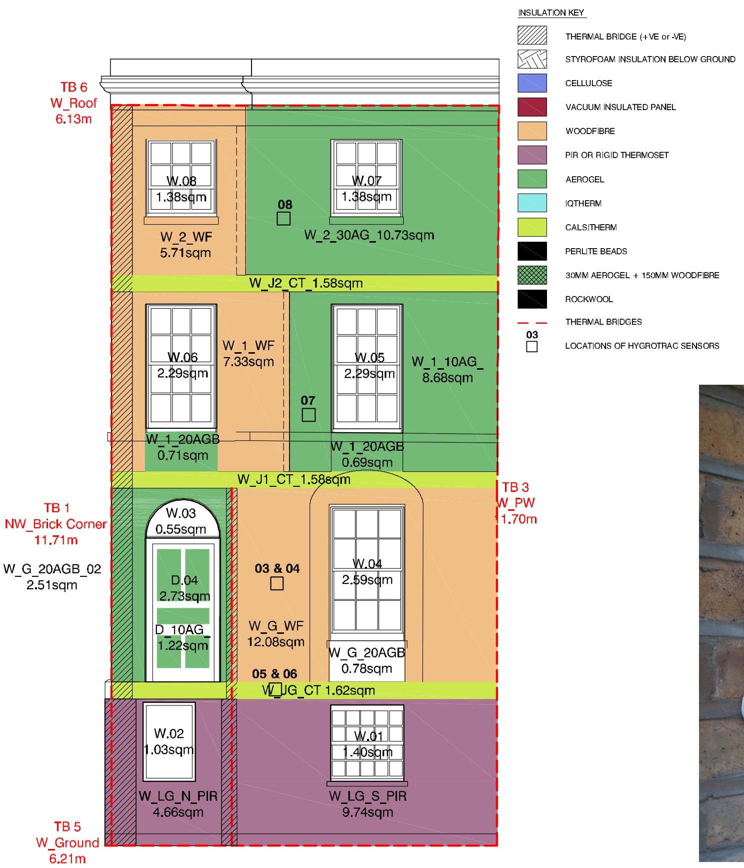


Figure 6.39 - Schematic of types of insulation to rear elevation, Arboreal Architecture

Figure 6.40 - Hygrothermal monitors between existing masonry walls and new internal insulation, Arboreal Architecture

References and footnotes

Archetype 1 - Haddington Way

6.1 - Baeli, M. (2013) Residential Retrofit: 20 case studies. RIBA Publishing. http://mepk.co.uk/project/haddington-way/

Archetype 2 - Zetland Road

6.2 - The uninstalled U-value refers to the U-value of the window or door before it is installed. This U-value includes the pane and frame, but excludes the heat loss from thermal bridging around the window/door where it meets the wall. Poor installation can reduce a window/door's U-value, as heat is lost through the frame at points where either the installation doesn't meet it, or there are thermal bridges or cold air gaps. Poor window installation can also cause condensation along window frames.

https://passivehouseplus.ie/magazine/upgrade/the-deepest-greenest-retrofit-ever

https://www.ecospheric.co.uk/zetland

https://www.passivhaustrust.org.uk/projects/detail/?cId=91

Archetype 3 - The Nook

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Archetype 4 - Wilmcote House

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