CE338

Grove Cottage

An advanced refurbishment case study

energy saving trust®

Contents

1. Introduction

Home energy use is responsible for over a quarter of UK carbon dioxide (CO_2) emissions, which contribute to climate change. To help mitigate the effects of climate change, the Energy Saving Trust has a range of technical solutions to help UK housing professionals build to higher levels of energy efficiency.

The Climate Change Act (2008) requires that by 2050, the UK's annual CO_2 emissions should by reduced by 80% compared to their 1990 levels. Two thirds of current dwellings will still be standing in 2050, meaning that refurbishing existing dwellings is a crucial part of achieving the 80% CO_2 reduction target. Due to the involved nature of whole house refurbishments, major alterations typically occur on a 30 year rolling basis; this means that dwellings are unlikely to be refurbished again before 2050, and therefore it is crucial to maximise the scope and ambition of current projects. Energy Performance Certificates (EPC) provide a useful performance benchmark – ultimately, by 2050 all dwellings will need to achieve an EPC rating in the range of a high band B to band A if we are to reach our target of an 80% reduction in CO_2 emissions across the entire housing stock.

2. Project background and aims

Grove Cottage is a two bedroom, detached cottage located in Hereford. The cottage was built in 1869 for a railway inspector, and originally stood amongst open countryside.

A number of Victorian properties subsequently sprung up around the dwelling, including one built just 25mm away from the gable wall of the cottage. This, and several other features such as solid brick walls mean that it fits the 'hard to treat' mould.

In addition, a 30m^2 unheated basement is present, raising further questions as to the most appropriate course of action.

The pre-refurbishment cottage was difficult to heat and maintain at an even temperature due to draughts and excessive heat losses, despite high energy bills.

Figure 1: Grove Cottage prior to refurbishment

In summer 2007, Simmonds Mills Architects began work on the refurbishment of the property. Plans included a new rear extension, which would allow the addition of a new bedroom, along with maximisation of storage and work space. The refurbishment was to use Passivhaus principles (explained in section 3), in order to maximise thermal performance, with the aim of achieving radically improved energy efficiency.

The ambition was to reach a space heating demand of between 15 - 25 kWh/m^2.yr and a targeted reduction in CO_2 of 80-85% over a typical existing house of the same size, without the aid of renewable power generation technology. Underpinning these ambitions was the desire to ensure that the finished result was in keeping with the cottage's original character.

3. Design strategy

The design team approached the project from 'first principles', drawing on AECB (the Sustainable Building Association) CarbonLite design and construction guidance for maximising fabric efficiencies.

3.1 The Passivhaus standard

Passivhaus refurbishment
The very recently developed 'Passivhaus refurbishment standard 'EnerPHit' is now being trialled by the Passivhaus Institute (PHI) in Germany. For the purposes of this refurbishment, the project team targeted performance as close to the Passivhaus new build standard as possible, and has recently been talking to the Institute about using the house as a UK trial for the EnerPHit Standard.

Passivhaus Standard (new-build)
Passivhaus is a German construction standard, widely viewed as one of the most advanced available. The standard is administered and developed by the Passivhaus Institute in Germany and can be applied to both houses and non-domestic buildings. Passivhaus's must be designed using the Passivhaus Planning Package (PHPP), a spreadsheet-based calculation tool.

The main requirements – or 'Passivhaus principles' - are as follows:
- A maximum space heating and cooling demand of less than 15 kWh/m^2.year or a maximum heating and cooling load of 10W/m^2.
- A maximum total primary energy demand of 120 kWh/m^2/year.
- An air change rate of no more than 0.6 air changes per hour @ 50 Pa.

To achieve the Passivhaus Standard in the UK typically involves:

- Very high levels of insulation.
- Extremely high performance windows with insulated frames.
- Airtight building fabric.
- 'Thermal bridge free' construction: differences in measurement conventions between the UK and Germany mean that this isn't directly numerically comparable to UK thermal bridging standards; however in UK terms this is close to a y-value of 0.04 W/m^{2}K, and is defined by the PHI as less or equal to 0.01 W/m^{2}K.

To achieve the excellent fabric U-values required by Passivhaus, and to avoid any reduction in room sizes and disruption, the project team made external insulation their chosen approach, and specified a high performance Neopor expanded polystyrene (EPS) and render to the main part of the dwelling, with highly insulated timber studwork to the rear.

High performance triple glazed units were specified for all windows and doors, and in order to create a new room in the roof, a complete re-roofing above existing rafter level was planned, with super-insulation in the roof plane. The ground floors (timber and solid concrete) would be upgraded as far as possible, with solutions being chosen to avoid significant and expensive alterations.

Planning restrictions related to the new extension combined with the aim to incorporate south facing glazing for solar gain also meant that the dwelling's built form would ultimately be quite complex, with a relatively high surface area to volume ratio. To offset the increased heat loss, the design target U-values for both walls and roof became particularly challenging.

Top tip – working with planning authorities
Eco-renovation may change the 'look' of a dwelling, in certain subtle ways – for example, the planned insulation measures at Grove Cottage meant that the dwelling would effectively become 'wrapped' in insulation, leading to much thicker walls and roof. To avoid any problems with the planning authority at later stages – for example, once the build is actually underway - it's worth highlighting any such issues on plans and elevations. This approach was used at Grove Cottage and, combined with the project team's attention to detail in preserving the original character of the cottage, this helped ensure that the project plans got the go ahead from the local planning authority.

3.2 Attention to detail – preserving the original character of Grove Cottage

An externally insulated approach offers significant thermal benefits, but in the case of Grove Cottage, it also meant that existing surface details such a sills and stone lintels would be lost. The lintels and sills, which formed an important part of the cottage's vernacular aesthetic, were badly decayed and had previously been covered over with cement based render; in addition they had been painted over, along with the brick walls of the house.

To counteract the loss of surface detailing, the finishing render was worked to replicate original details such as window sub sills and expressed stone lintels (lintel areas will also be painted a different colour to the walls). On site, it was agreed to remove and re-fix the original stone sub sill scrolls and to reposition them below the new sub sills. This proved an effective method for affordably retaining an important detail. In addition, the original house plaque will be re-created, and the timber porch will be re-built against the insulated front wall.

As a result of the external insulation and render, the final appearance of the walls and roof would be significantly thicker than those of surrounding properties. To maintain the 'thin eaves and verge' profile of the original house, the timber slating counter battens were extended and the ends tapered to form 'false rafter feet'.

Using these strategies, the project team aimed to achieve a result in sympathy with Grove Cottage's surroundings.

For more information on eco-renovation and historic homes, see *Energy efficient historic homes – case studies (CE138)* which can be downloaded from the Energy Saving Trust website.

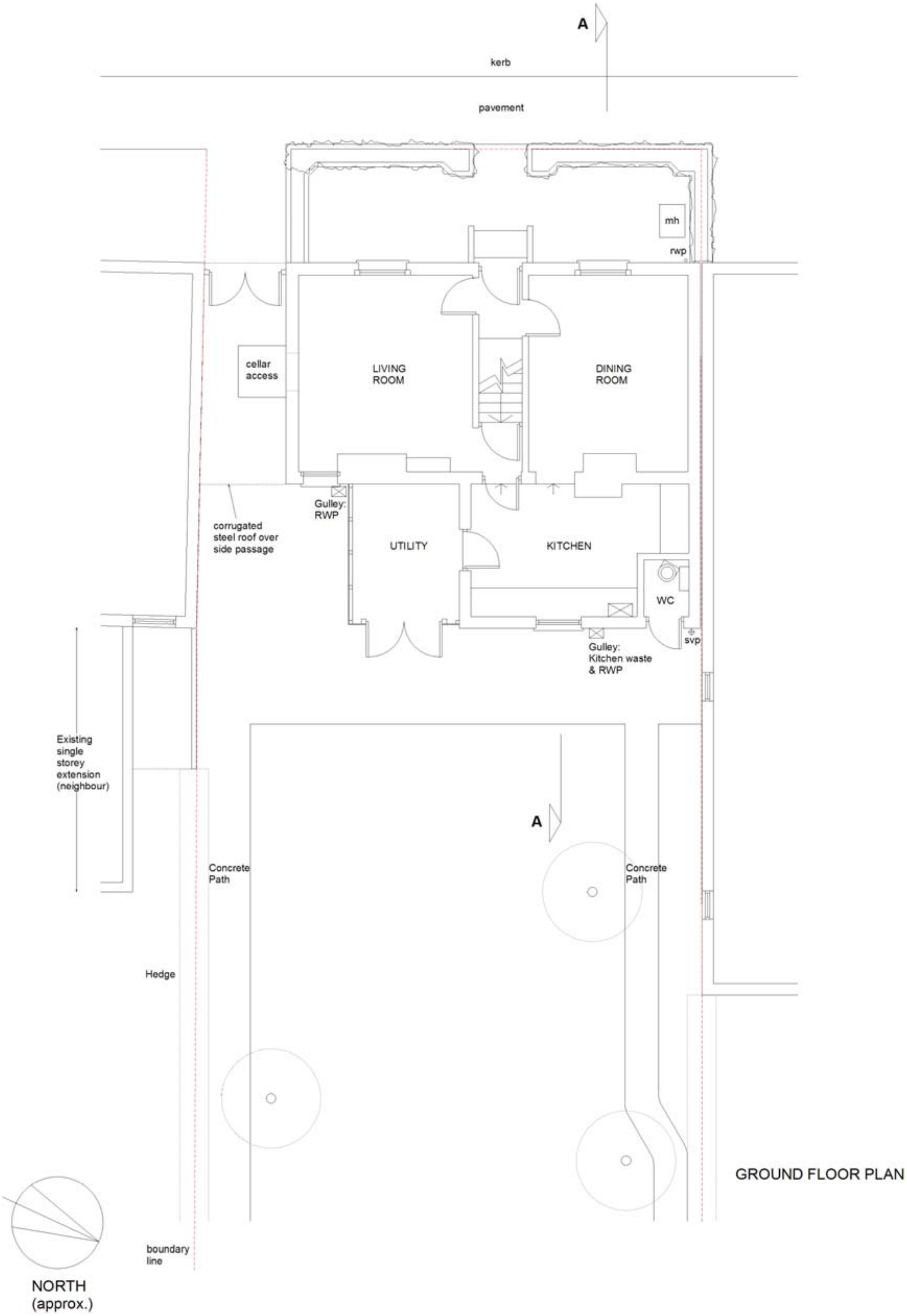


Figure 2: Ground floor plan pre-refurbishment

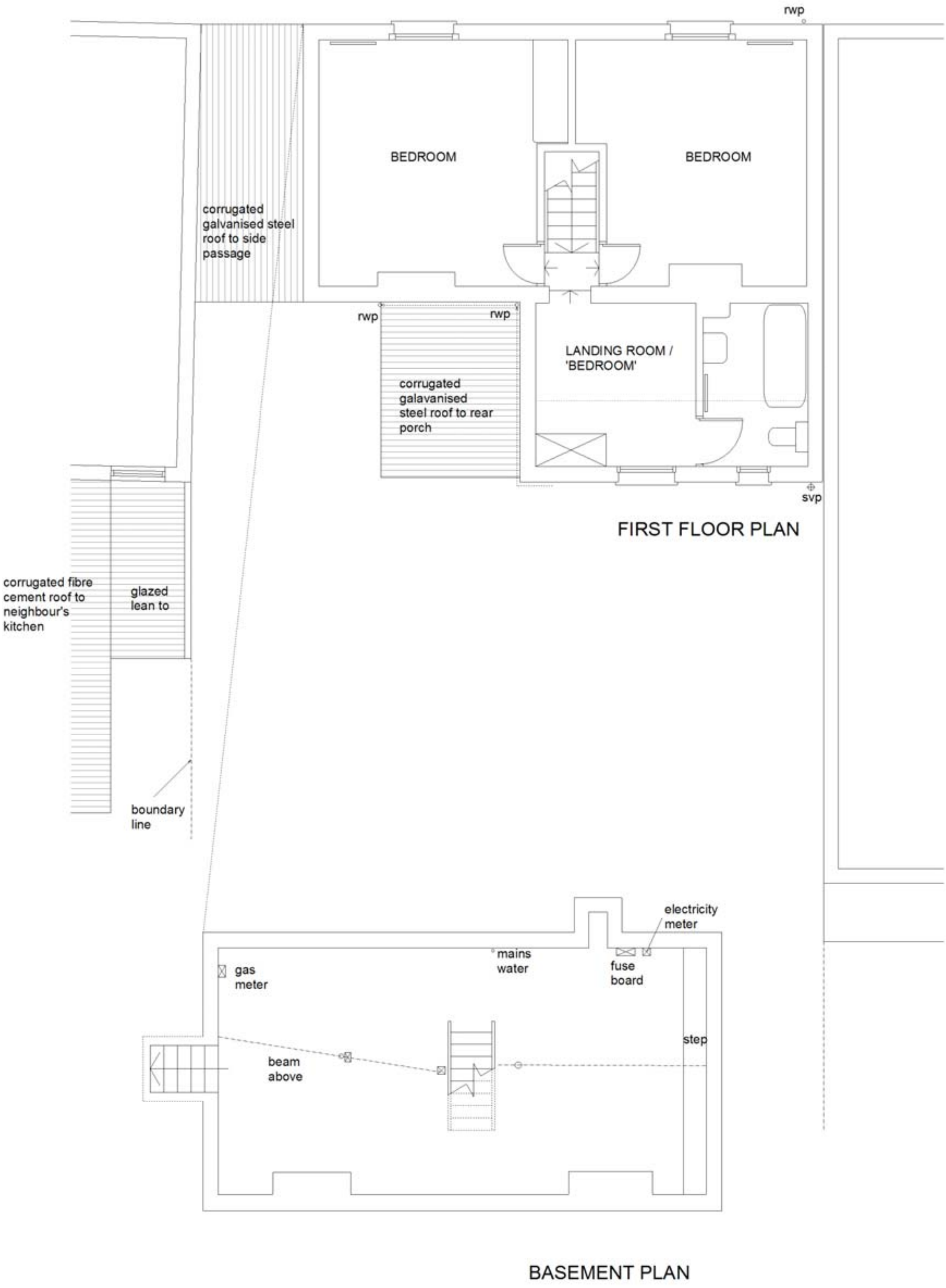


Figure 3: Basement and first floor plan pre-refurbishment

Figure 4: East and west elevations pre-refurbishment

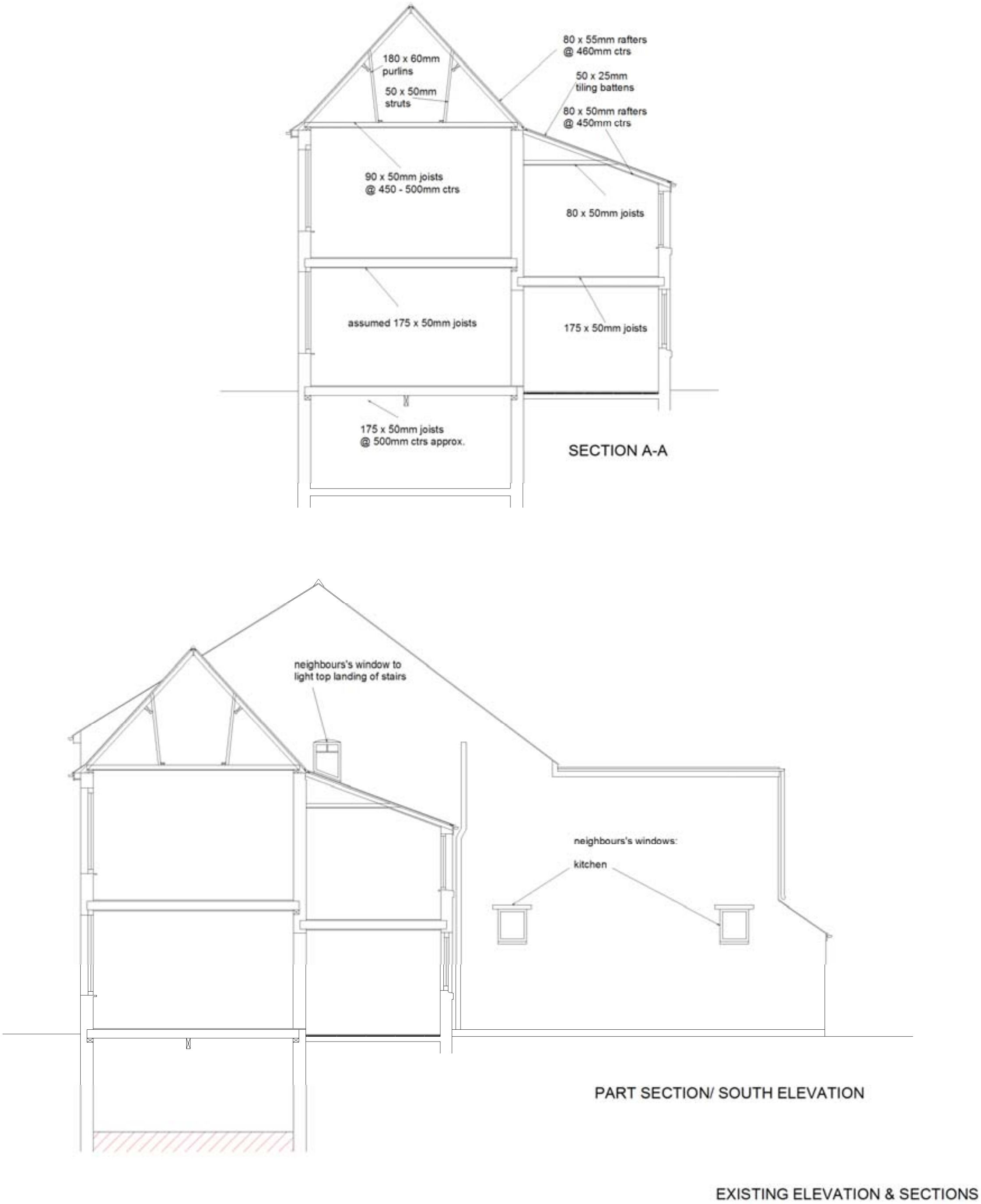


Figure 5: Sections and elevations pre-refurbishment

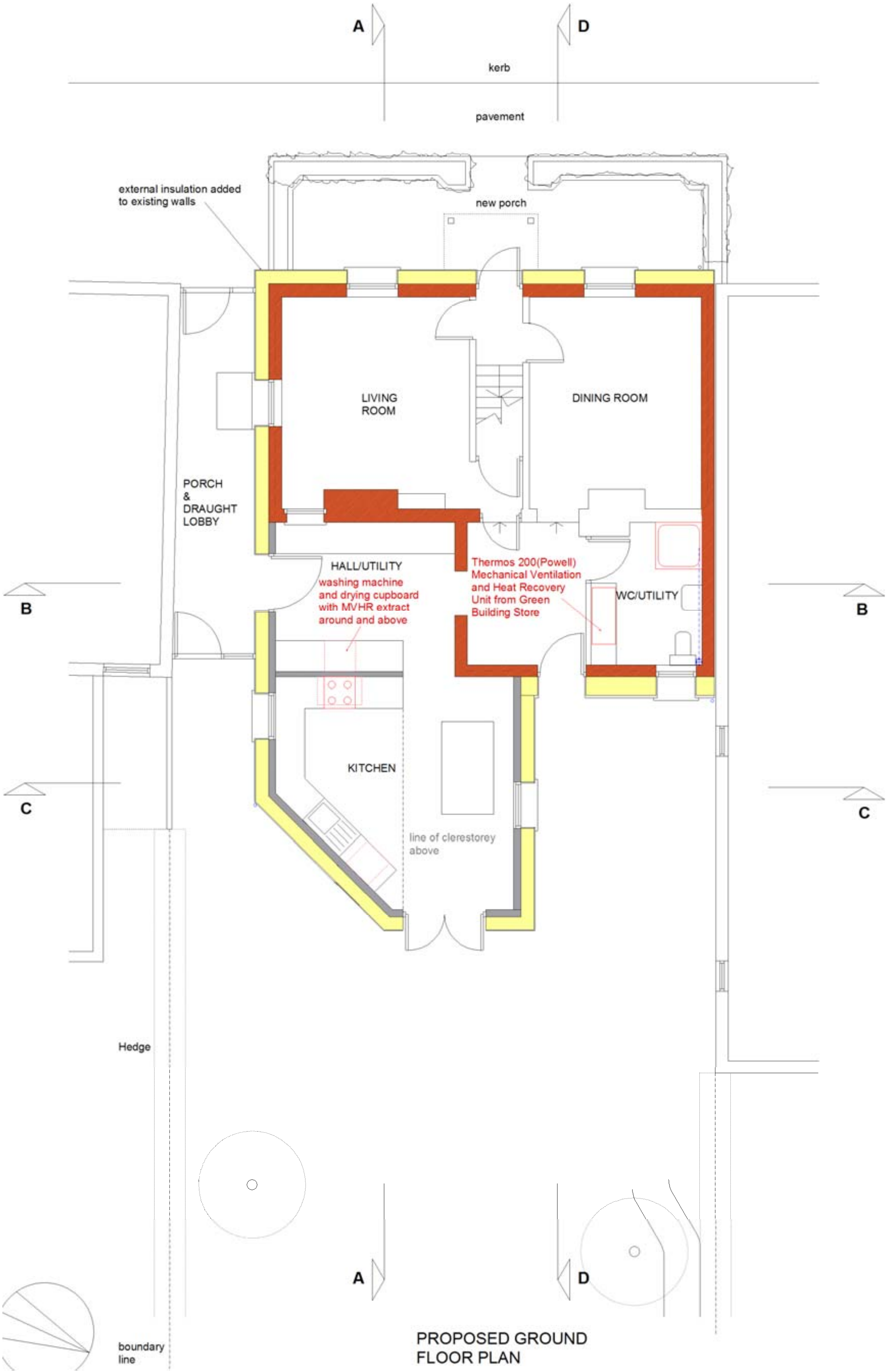
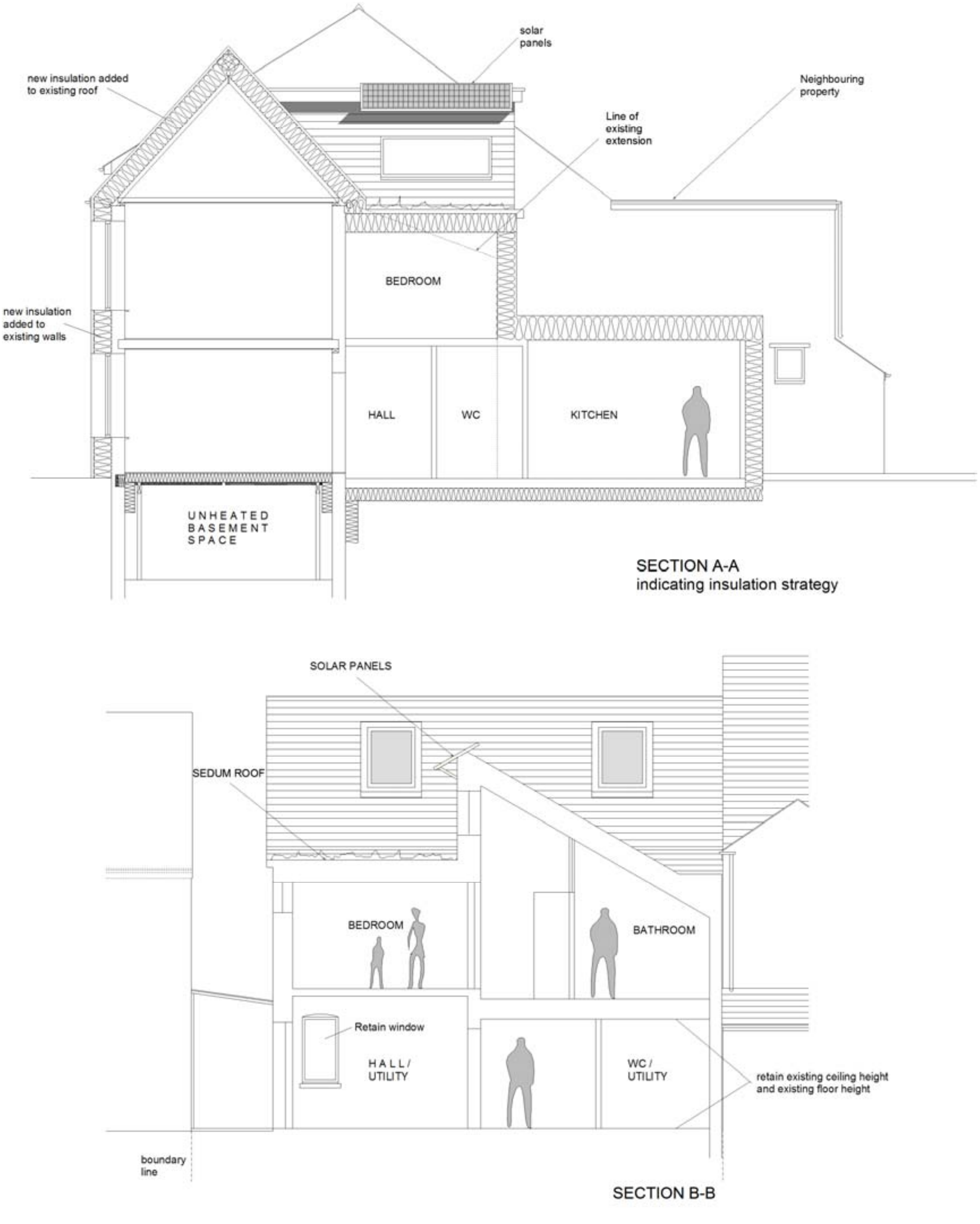


Figure 6: Ground floor plan post-refurbishment

Figure 7: First floor plan post-refurbishment

Figure 7: West and east elevations post-refurbishment



PROPOSED SECTIONS

Figure 8: Sections of the property post-refurbishment

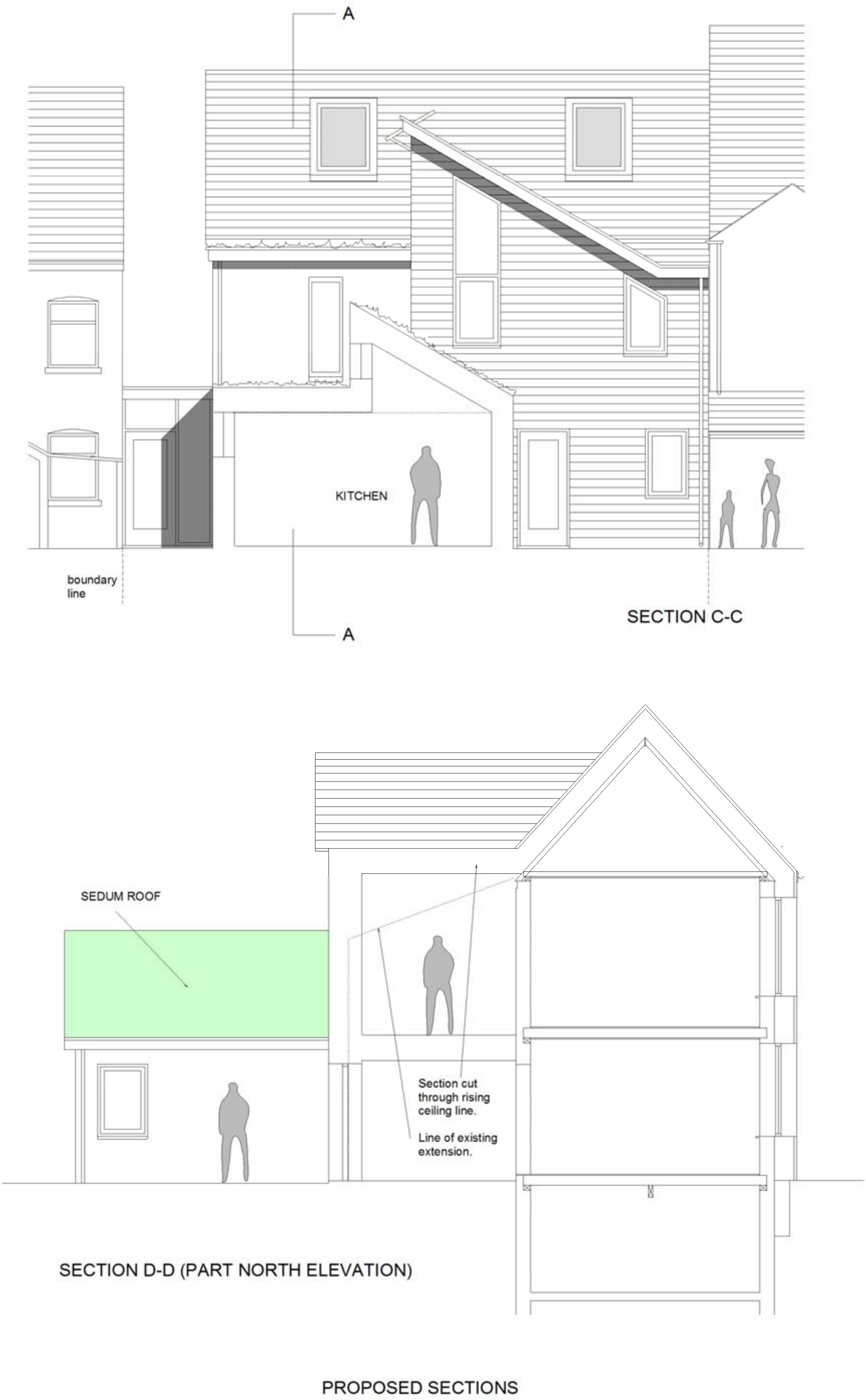


Figure 9: Sections post-refurbishment

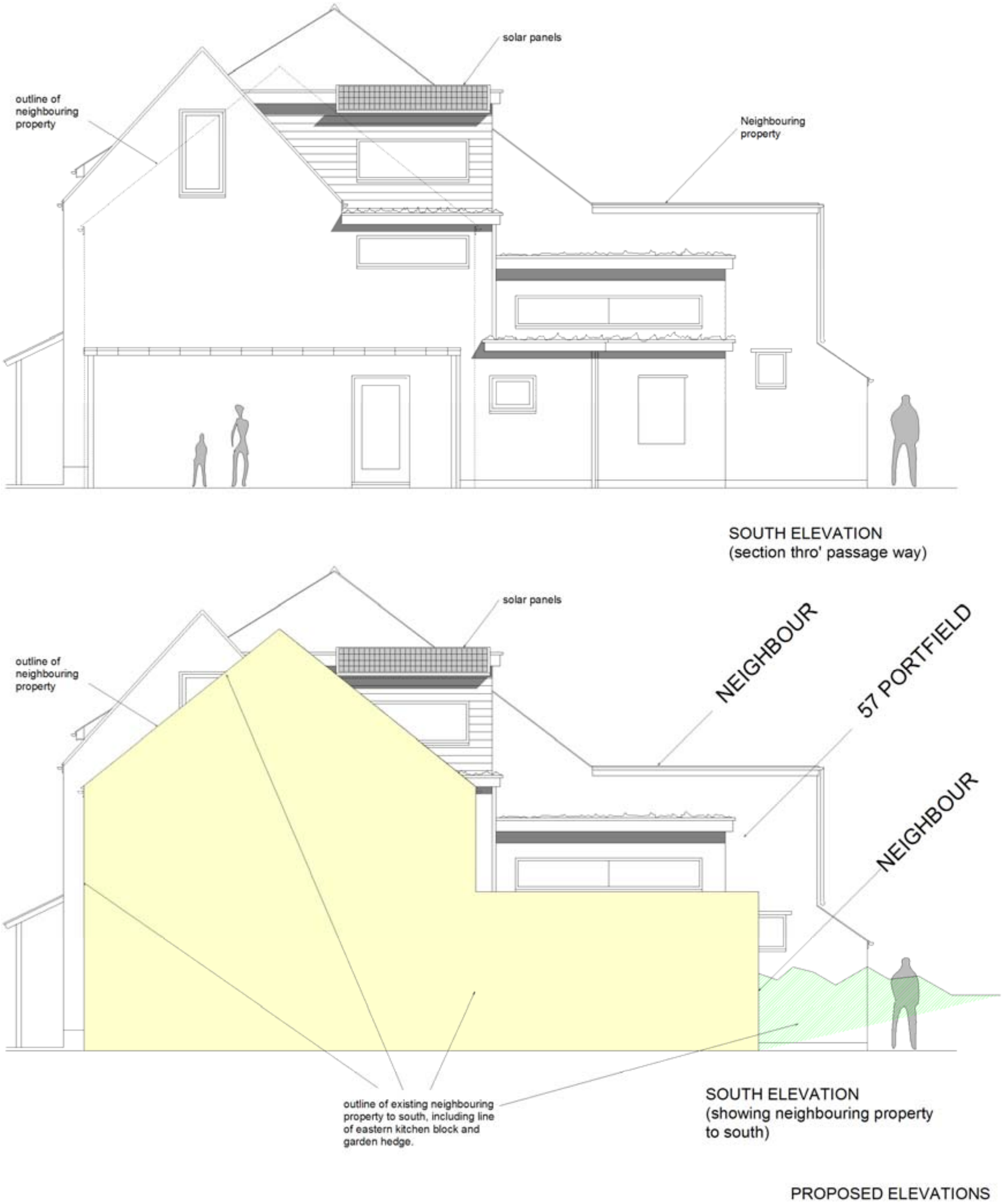


Figure 10: Elevations post-refurbishment.

4. Detailed specification

	Pre-refurbishment		***Post- refurbishment***	
	Description	**Performance**	**Description**	**Performance**
Walls	- Original dwelling: solid brickwork - Existing rear extension: solid brickwork - Gable wall facing adjacent neighbour's property: 25mm gap	- 2.10 W/m^{2}K - 1.38 W/m^{2}K	- External insulation (250mm EPS) to main walls - 'Larsen' timber trusses to rear extension. - 25mm gap between dwellings injected with PU foam to create insulated 'party wall'.	**Main** 0.12 W/m^{2}K **Ext.** 0.12 W/m^{2}K **Party** 0.40 W/m^{2}K
Floors and cellar	Suspended timber floor over cellar (main) Solid concrete floor (extension)	- 0.75 - 0.85	- Suspended timber insulated with 225mm sheep's wool - Existing concrete floor upgraded with 100mm PU - New concrete floor insulated with 250mm EPS	- 0.17 W/m^{2}K - 0.19 W/m^{2}K - 0.13 W/m^{2}K
Roof	- 50mm existing MW loft insulation with 100mm top up to approximately half of the loft - Slate roof to rear extension with 500mm MW - Tin roof to lean-to at rear of house	- 0.67 W/m^{2}K - 0.80 W/m^{2}K - 2.71 W/m^{2}K	- 400mm mineral wool between I-beams	0.09 W/m^{2}K
Windows	**Front** UPVC double glazing **Back** single glazing	**Double** 2.7 W/m^{2}K **Single** 4.8 W/m^{2}K	- Triple glazed units (Internorm *Edition*) - Triple glazed FAKRO rooflights	- 0.9 W/m^{2}K (average) - 2.0 W/m^{2}K
Doors	Solid timber front door Half glazed extension door	- 4.4 W/m^{2}K	Fully glazed, insulated doors throughout (Internorm *Edition*)	0.9 W/m^{2}K (average)
Thermal bridging	Typical existing building bridging problems, including solid lintels, intermediate floors and corners	0.15 x total exposed surface area	- External insulation to eliminate many major bridging paths, - Therm modelling to address specific areas. - CarbonLite details for new construction	Not fully assessed, assumed 0.04 x total exposed surface area
Airtightness	No specific airtightness measures installed	Not measured; existing dwellings typically achieve average airtightness of 15m^3/hr.m^2	- External face of brick walls parged with cement based slurry to create airtight layer. - New timber framed walls include air barrier. - Careful detailing around all service penetrations.	0.82 m^3/hr.m^2 (measured via pressure test)
Ventilation	Natural ventilation via windows; two flues and two chimneys	High levels of air infiltration from basement via ground floor into living rooms.	- Mechanical ventilation with heat recovery (Paul Thermos 200) - Chimneys incorporated within airtightness barrier zone	- 90% heat recovery efficiency - 0.53 W/l/s specific fan power (SAP Appendix Q figures)
Space heating	Gas boiler with radiators	67% efficient	- Vaillant EcoTEC plus 415 - VRC430 weather compensator - Grundfoss Alpha2 15-50 external pump	90.5% efficient (SEDBUK figure)
Water heating	Separate gas water heater for kitchen, main boiler for bathroom.	Not measured	Boiler heats hot water	
Renewables	None	n/a	No renewables currently installed.	n/a
Lighting	50% low energy lighting		100% low energy lighting	

5. Walls

Three insulation strategies were used for the refurbishment:

- External insulating EPS and render (majority of dwelling).
- Timber studwork (‘Larsen trusses’) with mineral wool (rear of dwelling).
- Polyurethane foam between Grove Cottage and adjacent dwelling’s gable walls.

5.1 External EPS and render

- The majority of the existing brickwork walls and all the new concrete blockwork walls of the extension to the property were externally insulated using the PermaRock EPS-Platinum insulated render system.
- This system utilises 250mm high performance expanded polystyrene (Neopor), which is fixed to the existing brickwork before being coated with a self-coloured proprietary render.

Figure 16: EPS external insulation detail

Figure 17: External insulation

- The approach adopted at Grove Cottage uses a full coverage adhesive bonding of the insulation boards, rather than the more common ‘ribbon’ of adhesive, eliminating any risk of air movement behind the insulation boards.
- Mechanical fixings are needed to provide additional support for the thick insulation boards whilst the adhesive cures; fixings can potentially be removed after the process is complete.
- However, the existing brick substrate had been painted, which might have compromised the adhesive bond between the insulation and the wall, and hence the decision was taken to leave mechanical fixings in place.
- Heat lost via repeating thermal bridging from mechanical fixings can be very significant, and so a specialised Ejotherm STR U 295 anchoring system manufactured by EJOT UK was used.
- In this system the anchor is recessed into the insulation in a one-step process, so that the washer face is 25mm below the surface of the insulation, minimising thermal loss. A 25mm thick disk of polystyrene insulation, or rondelle, is placed over the fixing head so that any cold spots due to thermal conductivity through the anchor are eliminated.
- The installers were made aware of the importance of minimising heat loss on this project and asked to minimise their use of any additional fixing required. The end result was that only four fixings were used for each square metre of insulation fixed.

Figure 18: Anchor and rondelle

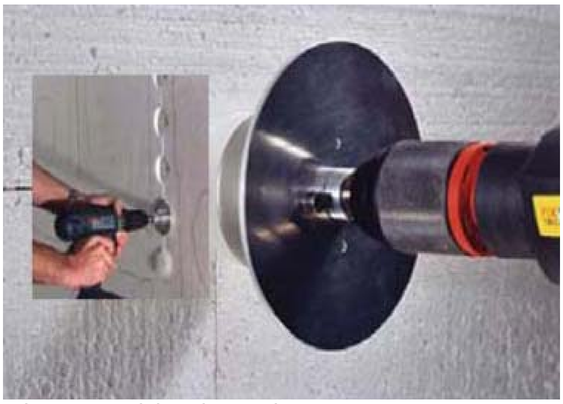


Figure 19: Fixing the anchor system

Figure 20: The completed external façade

Figure 21: Surface detailing to reflect original lintel

Lessons learnt

This was an effective and fast system, which provided a good finish. To reduce scaffolding costs, it was important to ensure that it could be used for both roof works and also for wall insulation installers – clearly the exact positioning of scaffolding to allow for both is crucial. Planning this in advance saved money on this project.

Another success was designing the wall to floor detail to avoid digging trenches around the base of the house which would have introduced complications and added cost.

5.2 Timber studwork with mineral wool

- The new extension to the rear of the dwelling was constructed using a blockwork/timber 'Larsen truss' structure as shown in the images below.
- It was insulated with 350mm of mineral wool.
- The extension was partially rendered, with the remainder being timber clad.

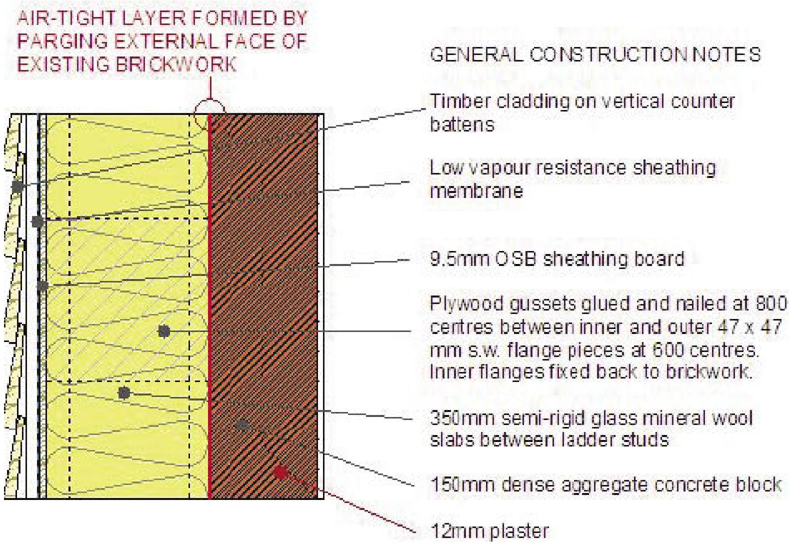


Figure 22: Larsen truss construction notes

Figure 23: Larsen truss unfilled

Figure 24: Larsen truss filled

Figure 25: timber cladding to rear of dwelling

Figure 26: rear of dwelling

Lessons learnt

Again this system was straightforward to build and thermally effective. The timber cladding was more time consuming than the direct render system, although more appropriate perhaps for self build / general builders' skills.

An advantage was that the timber box construction allowed the mechanical ventilation heat recovery (MVHR) intake pipe up to the roof terminal to be incorporated and hidden, and the wall is easier to fix onto (e.g. aerials / downpipes than the EPS system. It also allowed the use of more cost-effective non-rigid insulation and a different type of cladding finish – the latter being an important architectural factor in this project.

5.3 Polyurethane foam to gable walls

- The gap between Grove Cottage's gable wall and the neighbouring property varies between 25 to 40mm in width.
- Because the gap was relatively narrow, and in its unfilled state led to the entire gable wall being exposed to heat loss, it was decided to inject polyurethane foam in order to eliminate air movement and provide what would effectively be an insulated party wall between the two properties.
- This was also the only feasible airtightness solution, given that the air barrier was the external face of the existing brick walls and that access to the gap to parge brickwork was not possible.
- It was not known if the filling of the gap would affect sound transmission between properties, but the assumption was that as relatively dense PU foam was chosen it would probably make little difference.

Lessons learnt

Currently only the attic wall area and the bathroom wall areas have been filled (approximately 70% of the wall's total area), but it is planned to compete the first floor bedroom walls and the ground floor room walls as soon as possible. However, the strategy appears to have worked well so far with respect to reduced air leakage and warmer wall surfaces, but it has proved to be an expensive element compared to other measures.

There remains some uncertainty whether or not the foam has fully filled the void in all areas of the cavity, with thermographic imaging indicating one or two potential small void areas. The gap consumed a greater volume of foam than was calculated, which increased costs beyond the original budget. Indeed at one point checks were made to ensure that the foam had not been expanding onto the neighbours' property in some way. The additional foam used was ultimately attributed to the variability of the gap width between properties.

Ideally it would have been better to have been able to measure the total volume of the gap more accurately and also to have found a cheaper way to foam fill the gap between properties. However using a 2-part PU foam DIY system did provide a good result and gave on-site flexibility for carrying out the work around other operations.

There also appears to have been a very small reduction in sound transmission through the walls.

6. Floors and cellar

The pre-refurbishment property had a cellar and suspended timber floor in the main part of the house, with a solid floor for the existing extension.

6.1 Suspended timber floors and cellar

Because the cellar was unheated, the decision was taken to thermally separate it from the rest of the dwelling, whilst still allowing door access from both inside and outside the house via existing internal and external staircases. To achieve this, the internal stairwell in the centre of the dwelling was isolated from the surrounding cellar by studwork walls, in the process becoming part of the airtightness zone.

This area of heated space includes the consumer unit, wireless router, some storage space, and area for a small freezer. There is an external-quality doorway off this space into the unheated cellar.

The additional cost of converting the rest of the cellar into fully habitable rooms was not affordable, but the steady temperatures afforded by the natural insulation effect of the surrounding soil means that the unheated basement can still be a useful space.

To allow for future use, the earth floor was replaced with a concrete slab on a damp proof membrane (DPM), with the existing clean stone/gravel subsoil being mixed with cement in-situ to make the slab. This also had the effect of reducing the rate of water vapour entering the basement and created a useable dry floor for storage, etc.

Deciding where to locate the insulation and air barrier was the next task. The easy access afforded by the cellar, coupled with the fact that the existing timber / lathe and plaster internal walls were built up directly from the floor boards, meant that the simplest course of action was to insulate and make airtight from underneath – despite the fact that this meant the air membrane could not be put in the conventional position, relative to the floor insulation.

The timber wall plate (built into the brickwork of the cellar wall below), which was supporting the floor joists, had rotted and was replaced with a course of cellular glass load bearing bricks and cavity batt insulation.

This new construction formed a thermally efficient junction, which was modelled with THERM to ensure that it was likely to be 'thermal bridge free' and also to check that surface temperatures would be high enough not lead to any mould growth (see section 9 - Thermal Bridging for more details).

The joist ends, some of which were rotten, were cut short of the damp wall and four new timber beams supported by posts were added in the basement to support the timber ground floor construction. Because the air membrane would extend across the underside of the floor joists, small squares of membrane were inserted between the beams and joists, to seal to the main areas of membrane later.

175mm of sheeps wool insulation was placed in two layers between the floor joists, which was then covered with a layer of oriented strand board (OSB) which was drilled with large holes to ensure 'breathability'.

The air membrane was spanned across the underside of the OSB. The membrane was stapled in place and all joints carefully taped. The barrier was sealed down to the walls (see section 10 on airtightness for method).

The primary function of the membrane is to ensure airtightness, but its breathability also allows the safe movement of water vapour through the construction without giving rise to interstitial condensation. As the membrane could only be installed on the colder side of the insulation, rather than the warm side an 'intelligent' vapour variable membrane (INTELLO) was chosen to help manage the risk.

In theoretical terms this arrangement still presents a small degree of risk, but the use of a vapour variable membrane, combined with the use of continuous mechanical ventilation in the house meant that the project team felt that long term risk was acceptable. Recent modelling using the hydrothermal software 'WUFI' provides further support for this conclusion.


Figure 27: Insulation to underside of timber floor

Figure 28: Air/vapour barrier installation

An additional 50mm of sheeps wool insulation was placed between 50 x 50mm softwood battens (at 90 degrees to the joists above) spanning across the underside of the floor construction to reduce the repeating thermal bridging of the timber floor joists.

To assess the success of this overall insulation and airtightness strategy, visual checks are planned for one corner of the living room adjacent to a known thermal bridge. This will allow the condition of the insulation and the adjacent timber materials to be appraised and should highlight any problems.

Lessons learnt

Longer-term observation will be needed to judge success here; however, a good U value was achieved with excellent airtightness. After completion of works, problems with the street's public sewer and a historical lack of maintenance by the water utility company continued to plague several properties, and foul water from the leaking mains sewer puddled in the basement for several weeks: the excellent airtightness between basement and living rooms above was appreciated during this period.

6.2 Existing solid floor

- The existing floor slab was upgraded by painting with a liquid DPM, then adding a dry concrete mix self-levelling compound.
- 100mm of polyurethane foam board was laid, with all wall edges sealed using expanding zero ozone depletion foam.
- The construction was covered with the INTELLO vapour variable membrane for vapour control.
- The existing concrete slab was considered airtight as well as its junction to the existing walls. The base of the walls was parged with cement based slurry to ensure no air leakage before the insulation was placed.
- The entire construction was finally covered with two layers of glued and screwed WBP plywood to take the floor finish (thin travertine stone on flexible adhesive).
- Some areas were left without the membrane as an experiment to assess the difference between constructions with respect to long term moisture related risks.

Lessons learnt

A more robust approach would have been to remove the existing slab, excavate and recast a new slab over insulation, however the floating floor was anticipated to be a cheaper option. In the final analysis costs would have been similar, and in retrospect a new slab over insulation and DPM would have been the preferred option, for performance and long term robustness.

Figure 29: The new roof during construction

6.3 New solid floor

A new solid floor was constructed for the new build extension, as follows:

- A shallow excavation to clean subsoil, with a compacted 40mm stone base which was levelled with a skim of concrete.
- 250mm load-bearing 'Jablite' EPS.
- 200mm reinforced concrete raft.

7. Roof

As part of the refurbishment the property was completely re-roofed.

- The original rafters were turned into A-frames tied at floor level, and the purlins and props were removed to be used elsewhere.
- The existing rafters were boarded over and a weather resistant reinforced polyethylene air-vapour barrier was placed on the boarded surface, making the dwelling weather tight.
- FSC certified timber I-beams and minimal timber noggings were used on top of the original rafters, to provide a depth for 400mm of mineral fibre insulation.

Figure 30: Insulation batts are installed between the I beams

Figure 31: The impact of thermal bridging around rooflights is shown by melting snow

Lessons learnt

The project team felt that this was a successful solution which allowed the creation of a good sized 'room in a roof', whilst giving excellent insulation levels and airtightness. If the decision had been taken to insulate at loft level it would have been much more difficult to achieve reduced thermal bridging and airtightness, and an opportunity to affordably increase living space would have been missed.

The finished roof construction was airtight and thermally efficient with the only issue identified being some thermal bridging around the rooflight, which had been difficult to design out – although the builders did take the opportunity to add some insulation within the reveal linings over the face of the window frame to reduce heat losses through the frame.

8. Windows

- The dwelling's existing windows were single glazed to the rear, with replacement UPVC double glazing to the front of the property.
- Initially the project team were considering keeping the existing double glazing and simply returning the external insulation over the frames, to reduce thermal bridging losses – a viable option as the windows were sliding sash style, rather than outward opening.
- However it was decided that a more consistent thermal upgrade was preferred to ensure high comfort levels throughout (e.g. when sitting near windows in very cold weather), and as a result advanced triple glazing was specified.
- To further reduce energy requirements, and in line with Passivhaus practice, the wall insulation was designed to cover an area of window frame to further reduce heat loss, and also guard against interstitial condensation risks around the window frame/wall junction. The effect of this is discussed further in section 17.

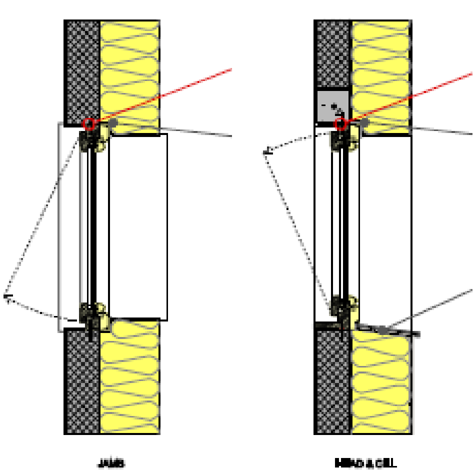


Figure 32: External insulation is returned on all four external faces of the window frame to reduce heat-loss

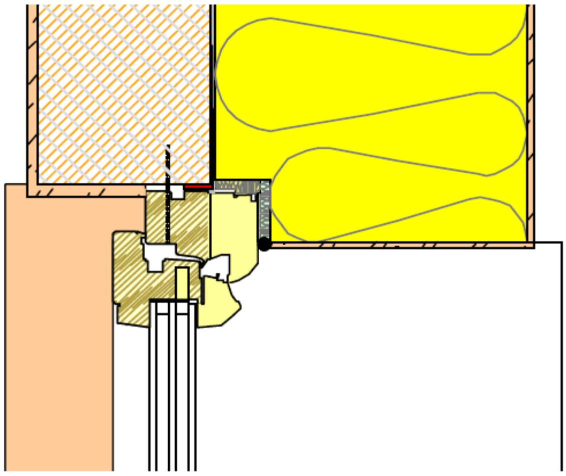


Figure 33: lintel insulation detail showing insulation return

Lessons learnt

In future, a vapour variable membrane (rather than polyethylene) will be used around windows to ensure a low risk of interstitial condensation associated with the wall to frame junction during different seasonal conditions – particularly for timber windows.

Also the use of steel straps would be advised to hold windows rather than, as here, frame fixings through the frame into the outer edge of the brickwork – again to ensure long term robustness of window fixing.

9. Thermal bridging

One of the central aims of the project was the adoption of 'thermal bridge free' construction (as defined by the Passivhaus Institute) for the new extension and for refurbishment works wherever possible. Both the Passivhaus Institute and the AECB's CarbonLite guidance were referred to, with CarbonLite insulation details being adopted for newly constructed areas and adjusted for some of the refurbished elements.

The Energy Saving Trust recently carried out full thermal modelling on an existing solid walled property, both pre and post refurbishment. This indicated that levels of thermal bridging heat losses actually increase proportionally in highly insulated refurbished dwellings, making it even more important to address these losses in a project such as Grove Cottage.

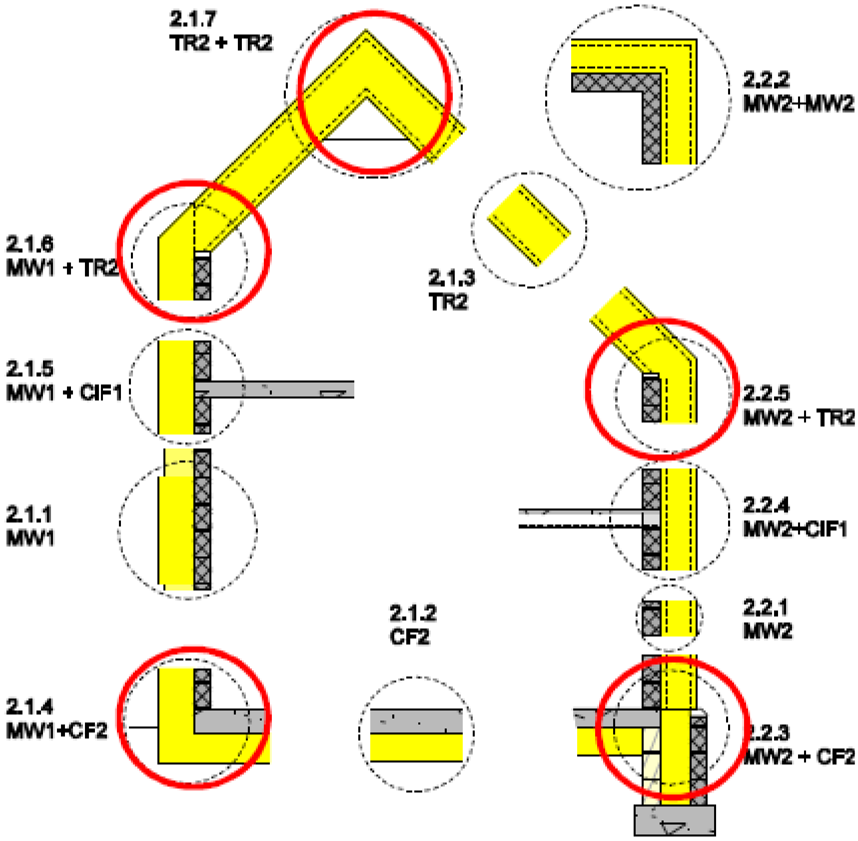


Figure 34: ClimateLite construction details

- The 'wrap around' strategy of external insulation provided a good starting point and offered enhanced control over thermal bridging losses.
- Simple rules of thumb were used to produce the initial design for each area, before thermal bridge modelling was used to estimate actual performance. Figures 35 to 38 show this design and modelling process.

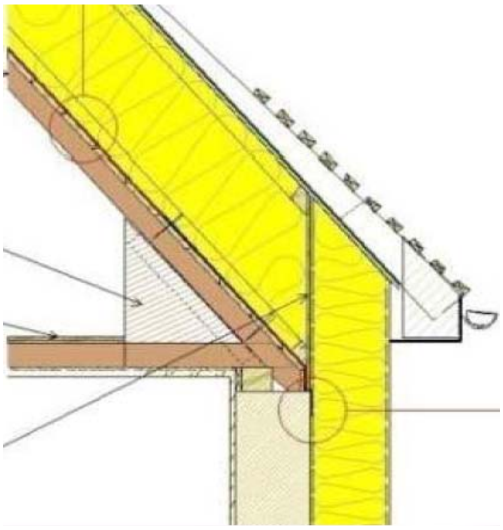


Figure 35: Roof/wall junction insulation detail

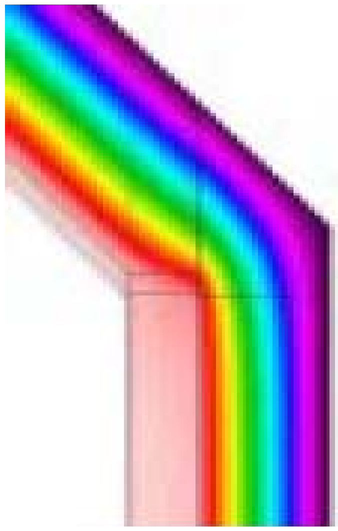


Figure 36: Roof/wall junction thermal model.

The coloured lines show the temperature gradient across the construction (red=warm, blue=cold).

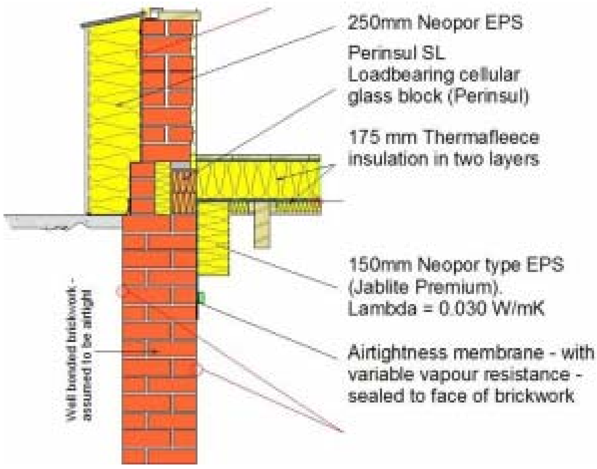


Figure 37: Ground floor/wall junction insulation detail

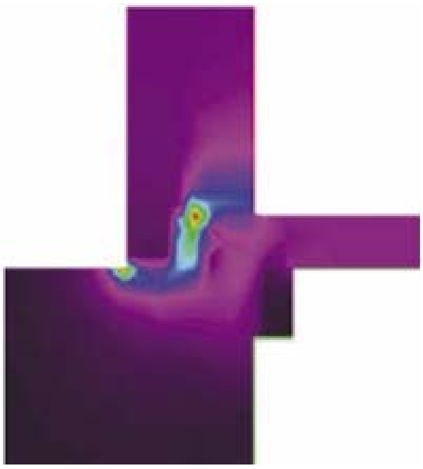


Figure 38: Ground floor/wall junction

- Thermal modelling is an area that few refurbishment projects fully embrace, often due to concerns of high cost and limited scope for improvement.
- In the case of Grove Cottage the data provided by thermal modelling was shown to actually reduce costs overall.
- Figure 37 shows proposed remedial work to an area of damaged wall, which is also intended to dramatically improve thermal performance in line with Passivhaus requirements.
- By thermally modelling this design the specific psi value (-0.019W/mK – a negative figure due to the use of German measurement conventions, in line with the Passivhaus standard), could be appraised, thus demonstrating that a relatively low cost intervention would be effective in reducing heat loss to the required level.
- Without the use of modelling, the project team would have chosen the more traditional approach of digging an external trench adjacent to the brick wall and installing 250mm thick EPS insulation against the brickwork down to approximately 1200mm below ground. The cost savings achieved here meant that overall refurbishment costs were reduced by several hundred pounds.
- The design team did not carry out full thermal modelling of the few remaining thermal bridges, but due to the project's extensive use of thermal bridge free detailing, an overall y-value of 0.04 $W/m^2.K$ (UK measurement conventions) was assumed by Energy Saving Trust for its post-refurbishment assessment.

Lessons learnt

It was found that once the design team had gone through the process of designing several thermal bridge free details it became increasingly straightforward to detail in this way. On site the builder also embraced the challenge and became very focused on achieving thermal integrity (no gaps) and also ensuring that unnecessary thermal bridges (e.g. excessive noggings between rafters) were not incorporated.

Consistent attention needed to be paid to ensure that unexpected junctions were carefully considered, and close contact was maintained between the builder, the architect and the owner, which greatly aided this process.

As we worked through the build we were aware that the property would undergo a thermographic survey which would highlight any flaws in its detailing, and this certainly helped to focus everyone's minds.

10. Airtightness

Achieving excellent levels of airtightness is essential to the Passivhaus standard, and so the aim for this project was the Passivhaus Standard's 0.6$m^3/m^2/h$, with a more realistic ambition not to exceed 1$m^3/m^2/h$, a highly challenging target for a refurbishment project.

The various areas of the dwelling were addressed as follows:

10.1 Walls

The external face of the existing brickwork was parged with a cement slurry to provide an airtight layer. New timber framed Larsen truss sections included an air/vapour membrane (see figure 39). The gable wall 25mm away from Grove Cottage's neighbour (see figures 41-43) was filled with polyurethane foam to prevent air movement. By placing both the airtightness layer and the insulation outside the brick walls it became easier to achieve the advanced levels of airtightness required to ensure high comfort levels, efficient operation of the MVHR system and to reduce the risks of interstitial condensation in the whole construction.

10.2 Roof

An air/vapour membrane was installed as part of the re-roofing.

10.3 Floor

An air/vapour membrane was installed beneath the insulated timber floor. The existing solid floor was assumed fairly airtight, only being improved by a sand / cement slurry brushed along the base of the walls where they met the existing concrete floor.

10.4 Windows and doors

An airtight barrier was sealed to the perimeters of the window and door frames and then after frames were installed this was sealed to the brickwork (which was primed to receive the 'polymer modified bitumen tape' used for this purpose). The external parge coat over the brickwork was taken right up to the taped joint to provide a robust parging/tape seal (see figure 40). If the weather was cold the bitument tape was rolled using a small roller and hot air gun to ensure it fully bonded to the primed brickwork.

10.6 Pipework and cabling penetrations

Phone cables were run through a plastic duct at an appropriate point (door threshold) and foamed for airtightness. Waste pipes were also foamed to the brickwork (from outside). Power cables out were also run in ducts through the brickwork that was sealed for airtightness in the same way. Service penetrations through the membrane were sealed by using airtight self-adhesive grommets for cables and pipes.

10.7 Intersections

Roof/wall **-** the airtight barrier was lapped down from the timber roof deck over the brickwork. The immediate area of brickwork was sealed using a bitumen primer. The barrier was then sealed to the brickwork using the bitumen tape. Subsequently the sealed barrier was parged up to.

Window/wall **-** the same method was used, with the airtight barrier being lapped out around the window frame, as shown in figure 40.

Timber floor/wall - again the same method was used here, with the barrier being sealed to the basement walls, however using a butyl strip behind the membrane, and the whole joint trapped using a treated timber batten fixed through to the basement wall brickwork. This batten was also used to support the EPS down stand insulation along this area of the basement wall.

10.8 Pressure tests

The dwelling was pressure tested after refurbishment and achieved an airtightness of $0.97 m^3/m^2/h$ – an outstanding achievement for a refurbishment project. The dwelling was re-tested after one year of occupation, in its fully finished state, and achieved an improved airtightness of $0.82 m^3/m^2/h$.

Figure 39: Breather membrane installation, second layer of defence behind timber cladding for weathering protection, and also to reduce heat losses from 'wind washing' of insulation via any gaps in prime sheathing board.

Figure 40: Barrier sealed to perimeter of window frame, folded to outer face of brickwork ready for taping (note bitumen to brickwork

Figure 41: Insulation installed between the two gable ends

Figure 42: Cement used to consolidate top of gable wall, ready to receive air-vapour barrier

Figure 43: Sealing the roof air-vapour barrier to the top of the gable wall, using bitumen tape

Lessons learnt

The strategy of designating the outer face of the solid wall as the airtightness zone appears to have been a robust design decision, and was simple and straightforward to apply on site – although behind the scenes, the design team had to give careful consideration to all the situations where this strategy might be compromised and plan accordingly.

Some unexpected work was nevertheless required; for example, the repair / rebuilding of the top of the gable wall (shown in figures 41 – 43), which was mainly prompted by the need to create a structurally sound gable end for the airtightness membrane to work to, in order to ensure a robust and durable result.

This area associated with the junction between houses was one of the most complex and expensive area of the project.

11. Ventilation

Given the demanding airtightness target, ensuring good ventilation was a key consideration at Grove Cottage. In accordance with the requirements of the Passivhaus standard, MVHR was used as the dwelling's ventilation strategy.

- MVHR is a whole-house system which extracts stale, moist air from wet rooms (kitchen and bathrooms) and transfers its heat to incoming fresh air.
- The filtered, pre-warmed air is then delivered to living areas and bedrooms.
- A system of ductwork is used to move the air through the dwelling.
- The system provides a consistent ventilation rate throughout the year, and incoming air is filtered to remove particulate pollution.
- Figure 44 shows a typical MVHR layout, along with the system of supply and extract ducts.

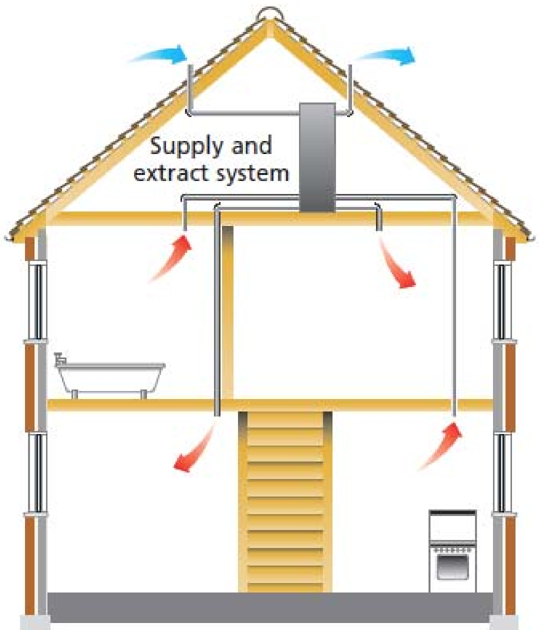


Figure 44: A typical MVHR system layout

11.1 Locating the central unit

There are a number of considerations when choosing where to site the main MVHR unit:

- The unit needs to be placed for easy access, because the system's filters will need to be maintained from time to time (typically once every 3-6 months).
- It should also be sited away from quiet spaces, to minimise any potential noise issues.
- The location must allow for a condensate drain to the outside, and also provide suitable positions for intake and exhaust ducts through external walls.
- Having taken these factors into consideration, the MVHR unit was housed where the original ground floor WC had been. This location was suitable because it provided easy access to an external wall, and also kept the low-level noise from the MVHR unit's operation away from the main living and sleeping areas.
- The air intake was positioned in an area (edge of first floor bathroom roof) where it was felt that air would be generally cleanest (away from neighbours' kitchen/boiler terminals, and to avoid downdraughts from neighbours chimney stacks).

11.2 Design and integration of ductwork

- When planning to install an MVHR system in an existing dwelling, careful consideration must be given to simplicity of layout and minimisation of duct runs, to ensure ductwork routes can be easily accommodated. This necessitates careful planning before deciding on the final internal MVHR layout.
- Where ductwork can be well integrated into an existing space, the only visible sign of the MVHR system is an inlet or outlet rose set into the wall or ceiling.
- Where this is not possible, some boxing in may be required, or alternatively ductwork may be left exposed or painted to blend in with its surroundings.

In Grove Cottage, a number of strategies were used to ensure ductwork was as inconspicuous as possible:

- Integration within false floor
- Integration within false ceiling above stairwell
- Integration within voids to the side of attic room (see figure 45)
- Integration within boiler cupboard
- The use of 'air throw' valves in walls also reduced the need to carry ducts further into some rooms.

Figure 45: MVHR ductwork housed in void to side of attic room

In Grove cottage the ductwork was therefore almost all hidden. In a couple of places the galvanised steel ducting has been left visible and is considered aesthetically acceptable by the occupants. Figure 46 below shows how the ductwork was integrated in Grove Cottage.

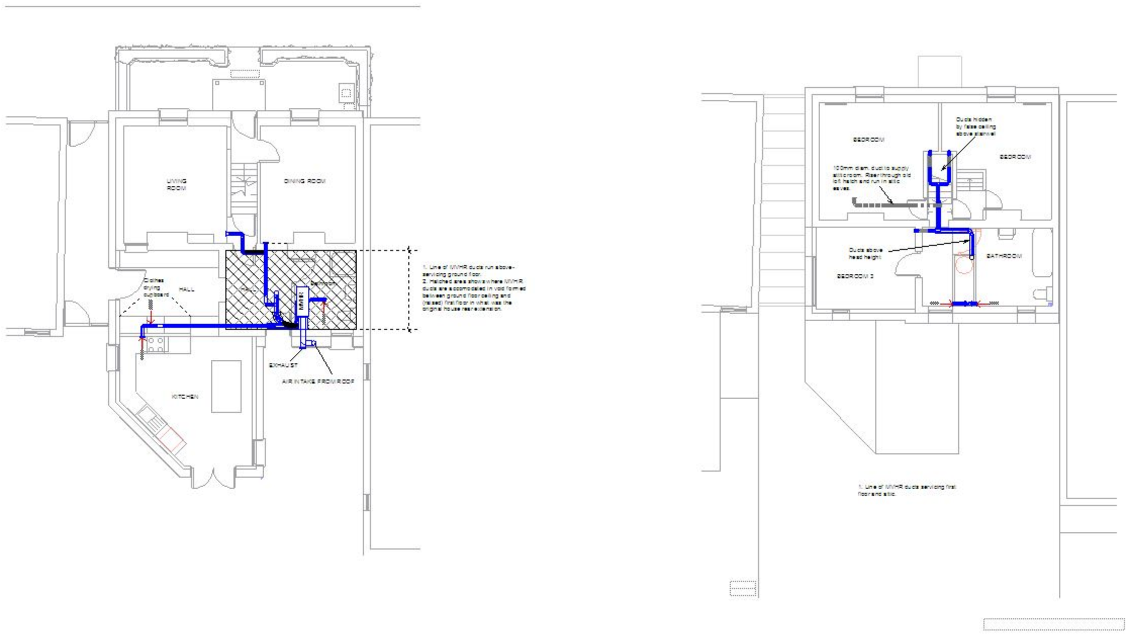


Figure 46: MVHR ductwork layout

11.3 Efficiency

- The MVHR system in Grove Cottage runs at a theoretical efficiency of 90%.
- To ensure that this level of performance is not compromised, it is important to maximise the use of rigid ductwork, and minimise the use of flexible ductwork. Flexible ductwork has an uneven internal surface, which creates drag and therefore increases the amount of energy needed to convey air through the system.
- To further increase system efficiency, the idea of tempering incoming air temperature by passing it through earth tubes was considered. This technique reduces fluctuations in incoming air temperature by passing it through subterranean ducts, which reduce higher summer temperatures, and increase lower winter air temperatures. This idea was subsequently abandoned as it was felt the increase in efficiency would be too small to justify the substantial cost and work involved in creating such a system. There were also potential problems relating to the incorporation of a condensation drainage sump on the flat site.

11.4 MVHR drying room

- An unusual feature of Grove Cottage is the integration of an MVHR serviced drying cupboard, designed to remove the need for a tumble dryer during the heating season and generally to reduce the inconvenience of drying clothes outside in inclement weather.
- The room is served by an additional wet room extract, which removes moisture from damp clothes.
- The potential effects on energy consumption (from the latent heat of evaporation of water from damp clothes) will be interesting to note as monitored data becomes available.

Lessons learnt

The MVHR system was the most complex services element in terms of design, with ductwork runs needing careful consideration, although installation was relatively straightforward. Working in communication with the suppliers, the owner was able to fit the MVHR system himself, having developed enough understanding to make subtle alterations to the ductwork layout without compromising performance.

Air quality in the house has been excellent, with the MVHR running on two settings, 'normal' (some of the day) and 'minimum' (some of the day and night time) - with the system left on 24 hours a day, 365 days a year. The unit is fitted with a summer bypass mode, which allows for air supply and extract with no heat recovery. The power consumption of the MVHR fans on the 'normal' setting appear to be about 20 - 25W, and approximately half as much when set to 'minimum'. It is intended to separately monitor the MVHR's energy consumption at a future date.

Occupation has shown that the MVHR alone is enough to keep the dwelling at 20°C for most of the year, by re-circulating heat gains from occupants, appliances and cooking. As a consequence the heating season at Grove Cottage is comparatively short; in 2009 the heating system was not required until late November.

The occupants have also experimented with various techniques for maximising dwelling 'coolth' in the summer months, both with and without the use of the MVHR system. A short trial during summer 2009, with the MVHR system turned off, showed that the opening of windows on the ground floor and on the first and attic floors produce good natural ventilation for the whole house with the right weather conditions (weather being a factor in all passive ventilation strategies).

However it was generally found more effective during hot spells to conserve the coolth built up during several nights by keeping windows shut during the day and relying on the continuous operation of the MVHR (on heat bypass mode) for ventilation. The automatic summer bypass mechanism appears to works well for night time background cooling when the internal temperature goes above 22°C during hot weather.

For more dramatic night time cooling (from a greater rate flow of air) the use of open windows (in 'hopper' position) at night have proved very effective. The drying cupboard has proved very successful in all weathers, and the tumble dryer has duly been retired.

12. Space and water heating

- Because the heat load in a new build Passivhaus is so low, it can be air-heated via small electrical heating coils housed within the MVHR ductwork, meaning that a traditional central heating system is not required.
- However, for Grove Cottage the decision was taken against air heating. Primarily this was because the design team knew that in a refurbishment project, achieving the Passivhaus requirement in practice would be highly challenging.
- In addition, if air heating were adopted the ductwork would need to be insulated, making it thicker and therefore more difficult to integrate within the existing dwelling.
- Radically reduced use of very clean burning natural gas was considered to be both cost effective and the responsible choice in a built up area due to its relatively clean burn (low particulate emissions when compared with biomass), and also its lower carbon emissions as compared to electricity. Therefore the decision was taken to retain a traditional gas boiler and the existing radiators.
- A new A-rated boiler was installed and linked to the cottage's existing radiators. Because the heat load was predicted to be so low, the boiler was sized on the basis of domestic hot water demand.
- A number of supplementary design features were added to increase the system's efficiency, including an energy efficient external pump, and a weather compensator. This system uses an external sensor to read weather conditions, and prevents the boiler from firing unnecessarily, thus saving energy.
- All water pipes, both hot and cold, were insulated. This prevents space heat from being absorbed into the cold water in winter, and also prevents unwanted heat from hot water radiating into the dwelling in summer.
- Pipework 'dead legs' were minimised to reduce heat up time for hot water, saving both energy and wasted water.
- For increased water efficiency, low flush toilets were installed.
- As discussed in the ventilation section, the combination of super insulation and heat recovery has shortened the heating season, meaning that supplementary heating from the gas boiler has so far only being required from late November onwards.
- The project team's energy consultant advised that it would be most efficient to lower the water temperature in the radiator system, in order to make the boiler operate more efficiently, and to set the heating controls to continuous heating rather than a timed programme.

Lessons learnt

- During the cold winter of 2009/10 the house stayed comfortable at an average of 21°C downstairs. All radiators were found to function well, with the exception of two on the first floor (perhaps as a result of worn out existing thermostatic valves). This led to slightly lower temperatures being logged at first floor level and attic. Although not intended, this temperature differential in the house is actually preferred as it leads to warmer living rooms and cooler bedrooms. As a result the non-functioning radiators may even be removed at some point in the future.

- Due to the 'always on' heating regime, radiator temperatures are low (luke warm) and it was not generally noticed whether the heating system was firing or not during cold weather.

- Due to the insulated pipe work hot water now retains its temperature within the pipework, and as a result warm water arrives much faster to taps and showers. A personal anecdote is that the owner is now happy to use cold water for hand washing, a change in habit he attributes to the increased level of thermal comfort throughout the house.

13. Renewables

- To facilitate the planned future addition of $4m^2$ solar thermal panels for water heating, a dual coil hot water cylinder has been installed (with additional site-applied supplementary insulation)
- A high level platform angled at 45°C has been constructed to receive the panels.
- A clear route for pre-insulated pipework has been built in to connect the two, to avoid future damage to the insulation, weatherproofing or air barrier.

Figure 47: Solar ready HWC before additional insulation added. DHW pipes (not radiator pipework) were later insulated

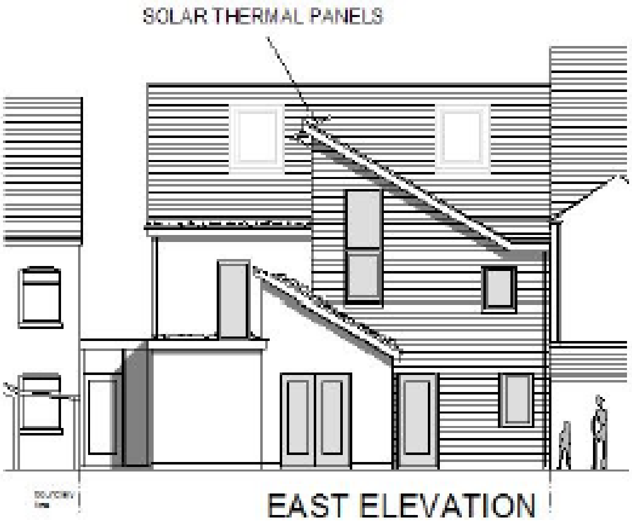


Figure 48: A platform for solar thermal panels has been mounted to the rear of the property

Lessons learnt

The design team chose a 'fabric first' strategy, and prioritised demand reduction and increases in thermal comfort, as opposed to any kind of renewable power. However, given the ambitious scale and success of the demand reduction measures, there is little potential to reduce CO_2 emissions any further without the installation of renewable energy in some form.

Therefore when financially possible it is still a firm intention to install solar thermal panels for domestic hot water to reduce CO_2 emission from a whole house prediction of $22kg/m^2.yr$ to a predicted $15\ kg/m^2.yr$. This will reduce gas consumption, and fuel bills, even further.

14. Other areas

14.1 Improved solar gain

- The new build Passivhaus standard typically requires that dwelling passive solar heat gains be maximised, in order to meet a proportion of the overall heating requirement.
- In general terms, maximising solar gains can be more difficult in refurbishment, due to constrictions created by existing windows, overshading by neighbouring existing and future buildings as well as restrictions related to the overall dwelling layout.
- Grove Cottage is orientated with the majority of its windows facing east (garden) – west (street), meaning that it has less potential for significant useful solar gain than a dwelling facing north-south.
- In order to overcome this, the design team designed large high level south facing windows into the new extension, thereby avoiding overshading from neighbours.
- Two new south facing windows were also incorporated into the existing building.
- This combined approach provides high levels of daylight (maximised by painting the internal spaces off-white) and views out with useful winter solar gains.

Figure 49: Improved solar gains and daylighting

14.2 Protection against overheating

- Guarding against potential summer time overheating was also an important consideration. The external insulation helps to mitigate against overheating, and allowed existing thermal mass from the solid brick walls to be retained within the insulated envelope, along with the concrete floor and the dense concrete blockwork of the new extension.
- The position of windows within the thickness of the walls affects daylight levels and solar gains: the windows were recessed to a position that aimed to strike a balance between reduced daylight and the shading effect required for summertime overheating protection.
- Integral blinds, for both privacy and solar control (using Internorm's '2+1' windows) were considered for all windows, but discounted due to the additional costs and reduced thermal performance.
- No overheating of the house has been experienced, with the occasional exception of the attic room, as a result of localised and slightly excessive solar gain through the east and west facing rooflights. A solar control blind will be fitted to each roof light to mitigate this problem.

14.3 Reduced noise pollution

- The combination of thicker walls with reduced air leakage and triple glazed windows means that external noise is now much less noticeable within the dwelling.
- In addition the ventilation system means that during summer time windows can be left closed if desired, meaning that any passing noise from the street is no longer a problem.

14.4 Improved quality of living spaces

- Alongside the energy and water saving benefits of the refurbishment, the works have also helped to create a healthier and more comfortable space to live for occupants.
- In addition to the reduced noise pollution and better light levels throughout, the refurbishment has also improved indoor air quality. The MVHR system provides constant ventilation and filtered, pre-warmed fresh air, as well as inhibiting dust mite infestation.
- The highly insulated building fabric means that internal wall and window surfaces are warmer, leading to greater thermal comfort for occupants.
- Cold spots have been effectively eliminated, radically reducing the likelihood of mould or condensation issues.

14.5 Environmentally friendly materials

- The project team wished to maximise the use of natural and lower-impact materials as far as possible; sheep's wool, timber windows, and a mixture of re-used, locally sourced and FSC construction timber were used to reduce the project's environmental impact.

14.6 Recycling and reuse

- Purlins from the original roof structure were reused to create frames for the new windows and deepen the floor beams in the basement;
- Other recoverable timbers were also used around the refurbished property, as were the original radiators and roof slates.

15. Costs

- The total cost of improvements, including the new extension, creation of an attic room-in-the-roof and structural repairs to ground floor / basement walls was approximately £125,000.
- Various discounts on materials and products were provided; the approximate total cost was £15,000.
- No grants were available.
- A 'C-Change' mortgage was arranged with the Ecology Building Society, discounted by 1% as a result of the project working to CarbonLite Step 2 / Passivhaus.

16. Dwelling performance pre and post-refurbishment

	SAP analysis			PHPP analysis		
	Pre	Post	Saving	Pre	Post	Saving
Electricity consumption (kWh pa) *Does not include appliances and cooking*	1046	1121	Increase of 75 kWh due to MVHR	-	-	-
Gas consumption (kWh pa)	42,395	2,108 (annual heat demand only) 7,950 (total)	81%	-	2898 (annual heat demand only)	-
Space heating requirement (kWh/m².yr)	246	14	94%	-	21	-
Primary energy demand (kWh/m².yr)	534	90	83%	-	97.2-	-
Heating load (W/m²)	-	-	-	-	10	-
Fuel bills (£ pa)	£1,540	£481	£1059	-	-	-
CO_2 emissions (tonnes pa)	8.7	2.0	77%	-	2.7	-
EPC band	F (SAP 35)	B (SAP 85)	+SAP 50	-	-	-

Notes

- SAP and PHPP have differing assessment conventions, which will lead to variance between results. A complete description of each methodology is beyond the scope of this guide; for further details see bre.co.uk/SAP2005 and passivhaus.org.uk
- The PHPP analysis modelled the house using an internal temperature of 21°C rather than the 20°C used as default for PH certified projects. This was to make the modelling consistent with the TSB's Retrofit for the Future competition methodology.

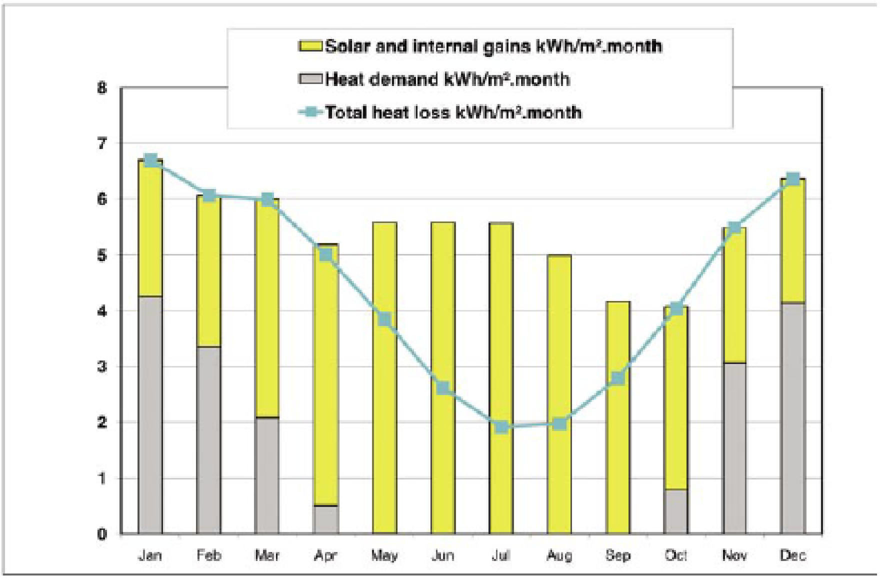


Figure 50: Gains, heat demand and heat loss projected by PHPP

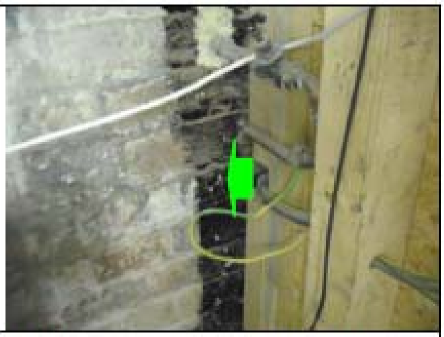
17. Post-completion testing

After refurbishment works were completed, both pressure testing and thermographic imaging were carried out to interrogate construction quality. Monitoring of internal temperatures and relative humidity is ongoing.

17.1 Pressure testing – test one

- The first post refurbishment pressure test was carried out prior to occupation, and showed that the dwelling had achieved an airtightness level of 0.97 $m^3/m^2/h$.
- This level of airtightness is very rarely achieved, even in new build construction, and was a testament to the excellent work carried out by the project team in both the design and construction phases.
- Nevertheless, a few areas of air leakage were discovered, which are documented below.

Putty patches to holes through membrane at base of access stairs to basement.



Leakage in basement in places between timber framing and brick front wall, also around service penetration.

Expanded foam last minute sealing around waste pipe from kitchen – to be cut back and mastic over-sealed for a neat & airtight finish.

Some leakage across head of rear double door – to be adjusted.

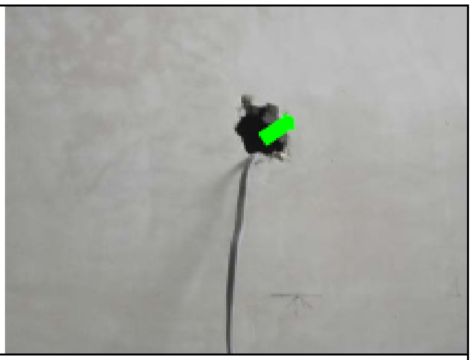
Air leakage through lock, even with key in place!

Leakage along bottom of skirting on party wall, connecting to unfilled cavity between dwellings – to be further reduced.

Leakage through gaps behind plasterboard beside entrance door.

Leakage between foam and lintel where plastering above door not yet done.

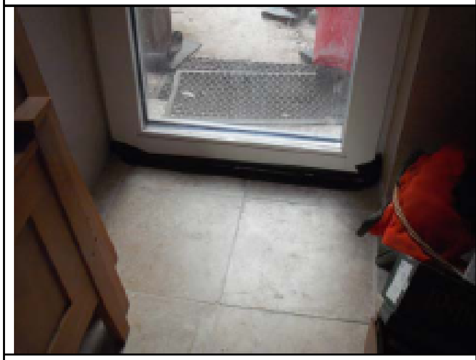
Minor leakage at wall/ ceiling corner in upper bathroom, at complex junction of internal and external air barriers.



Minor leakage through service void entering dwelling around cable.

Minor leakage at joint in window frame.

Leakage in corner of high level window.



Temporary seal across bottom of single door during final test.

Temporary seal across bottom of double door during final test.

17.2 Pressure testing – test two

- The second post refurbishment pressure test was carried out after the property had been occupied for one year.
- The reasons for re-testing at this point were to better understand how the drying-out process might have affected airtightness, and whether or not the sealing measures had remained effective, alongside the various other impacts that occupation might have had on measured performance.
- The underlying assumption was that the airtightness value would in all likelihood be slightly worse than that shown by the original test. However, the re-test showed that the dwelling now achieves an airtightness level of $0.82m^3/m^2/h$; proportionally, a significant improvement over the initial test.
- Some of this is will be the result of easing and adjusting the four doors to the property, particularly the double doors to the rear kitchen, which was carried out subsequently to that test.
- However such a significant improvement suggests that there was also some substantial unidentified leakage at the time of the test. This might have been through the area where sealing works were incomplete – the party wall to the adjacent house – or perhaps some temporary sealing, most likely in the basement, had come partially away during the testing.
- Some minor leakage was identified beneath doors and at the corners of window frames, and also in the basement stairwell and above the front door where the foam sealing has not yet been finished off.
- No leakage could be found along the party wall, or around the service penetrations associated with the heat recovery ventilation.
- A slight concentration of leakage was identified around the cable hole to the ceiling rose in the upstairs bedroom in the newbuild extension.
- Some leakage was also identified in the rear upstairs bathroom wall, where there had been some residual leakage at the time of the acceptance testing.
- The similarity of the results between the pressurisation and depressurisation tests suggests that there are no significant problems with the membranes in the walls or roof, since this would tend to be substantially worse under one or other of the two different pressure regimes.
- Overall Grove Cottage meets the draft airtightness target (1.0 ACH @ 50 Pa) set by the Passivhaus Institute in the forthcoming Enerphit standard for refurbished Passivhaus dwellings.

17.3 Thermographic imaging

Thermographic imaging showed that overall fabric thermal performance was excellent, with significantly reduced heat losses compared to neighbouring properties.

Figure 51: Thermographic image of Grove Cottage (centre)

The thermographic imaging also proved useful in identifying several minor areas of concern.

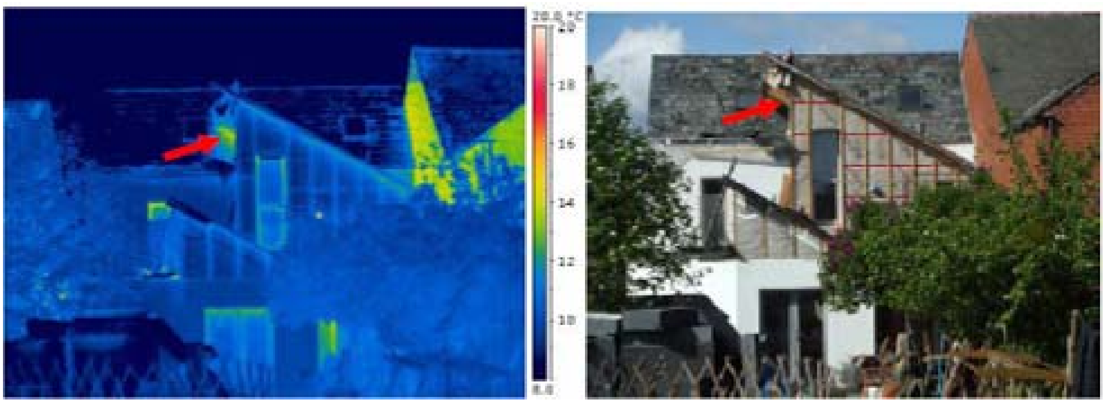


Figure 52: Thermographic image showing rear of Grove Cottage

Figure 52 shows elevated temperatures (indicated by the arrow) under the eave of the extension roof at the junction where it meets the main cottage roof. This was investigated and found to be caused by a glazed unit that had not been fully sealed to its frame. The unit was subsequently sealed as specified.

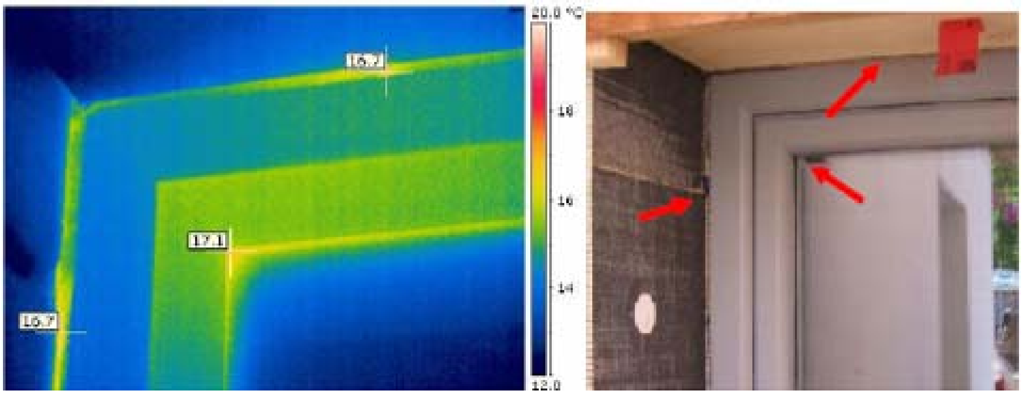


Figure 53: Back door, next to WC

The temperature gradients identified around the door frame were felt to be excessive and in need of further investigation. As similar effect was identified around the WC window (see figure 54). It was established that at the time of the test, the final layer of insulation had not yet been fitted to the windows and doors in the 'Larsen Truss' area of the wall. The final detail will include a 50mm foam board which overlaps the frame by 40mm, to be applied to all soffits and jambs of windows in the trussed walls; this should reduce such heat loss significantly.

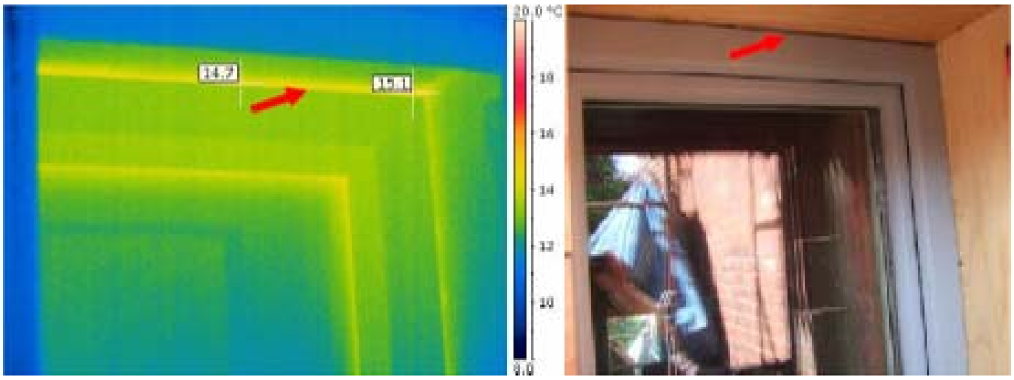


Figure 54: WC window

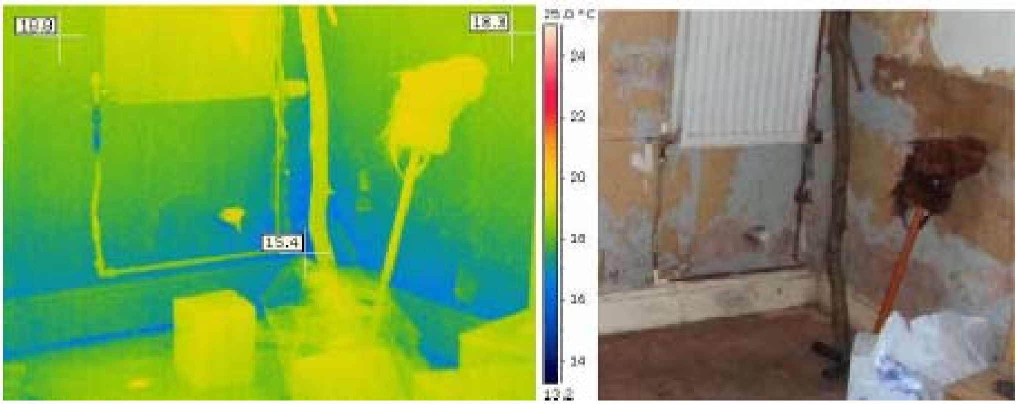


Figure 55: Cold corner at junction of front and North ('party') walls.

Figure 55 shows a corner which is noticeably cooler than its surrounding wall. This was investigated and found to be due to an area of the 25mm cavity between dwellings that had not yet been filled with foam. The heat loss was exacerbated by a recessed telescopic air vent below the window (not visible in figure 55), that remained within the wall, effectively creating a void within the insulation.

Fortunately, despite this issue typical surface temperatures remain above the dew point, removing the risk of condensation. The remaining areas of unfilled cavity will be insulated, which should reduce heat loss significantly.

18. Monitoring

Since the dwelling underwent re-occupation it has been monitored for internal temperatures, as well as relative humidity. One key result so far indicates that the MVHR and thermally efficient fabric have significantly shortened the heating season, with the dwelling's main heating system only being required in late November.

Notes

- Measured consumption includes electricity use by the property's garden office.
- Loggers captured readings every hour and were located in the first floor bathroom, first floor bedroom and ground floor living room.
- The average relative humidity (RH) outdoors was 78.3 % with an indoor average RH of 48.9 %.
- The average temperature outdoors was 8°C with an average indoor temperature of 20.8°C.
- Further measured data will be available on the Architect's website: simmondsmills.com/

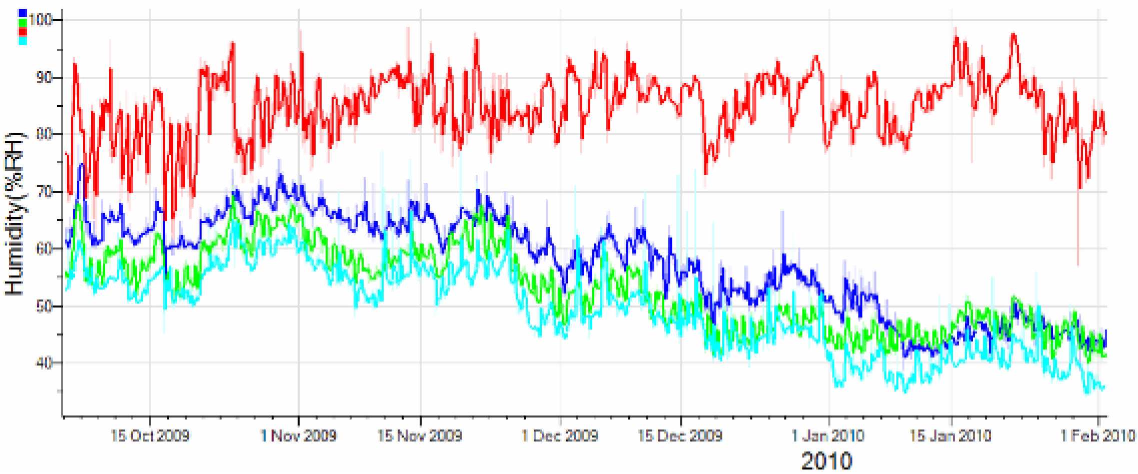


Figure 56: Dwelling relative humidity

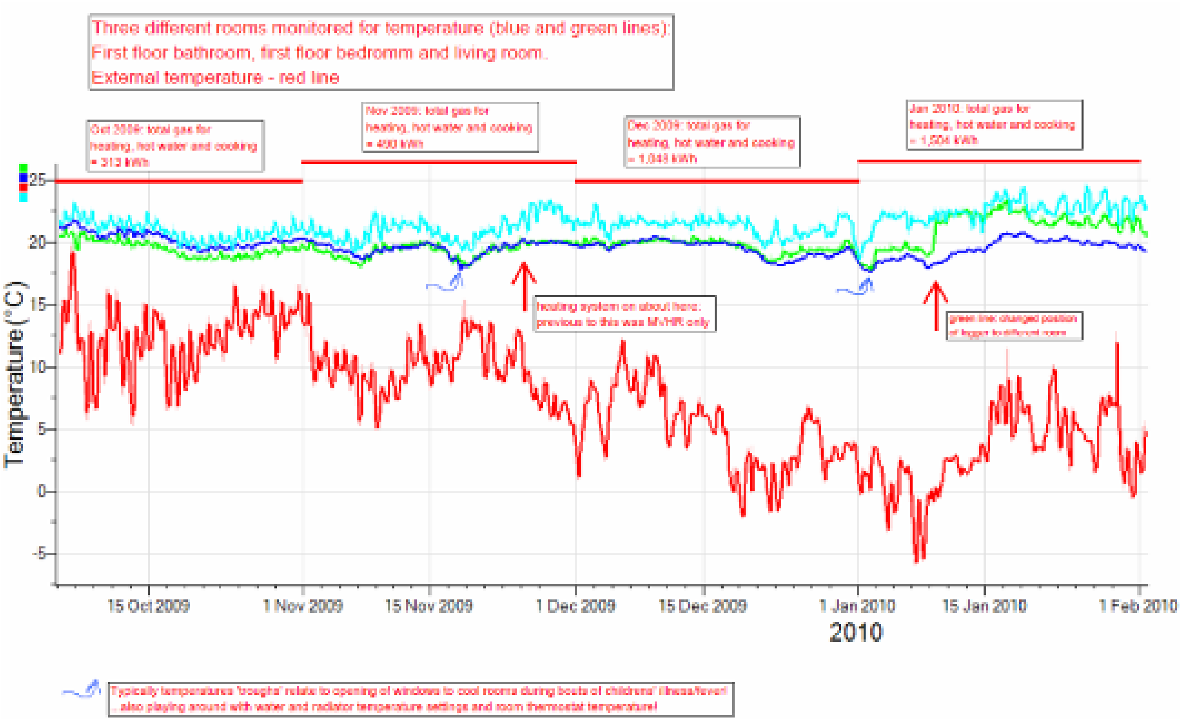


Figure 57: Dwelling internal temperatures

Notes

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Further information

The Energy Saving Trust works with the housing industry to provide technical guidance and solutions to help UK housing professionals design, build and refurbish to high levels of energy efficiency in domestic newbuild and renovation.

For more information visit energysavingtrust.org.uk/housing

Further reading

To download this, and to browse all available Energy Saving Trust publications, visit energysavingtrust.org.uk/housing/publications

- Sustainable refurbishment: towards an 80% reduction in CO_2 emissions (CE309)
- House type scenarios (CE330)
- Refurbishing high rise dwellings – a strategic guide for local authority managers (CE187)
- Making private rented housing energy efficient – the flagship home case study (CE192)
- Energy efficient historic homes – case studies (CE138)
- Post-construction testing – a professionals guide for testing housing for energy efficiency (CE128)
- External insulation systems for walls of dwellings (CE118)
- Internal wall insulation in existing housing (CE17)
- Insulation materials chart (CE71)

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