# Building Performance Evaluation
# Final report

## Camden Passive House

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Technology Strategy Board
Driving Innovation

# Building Performance Evaluation

# Final report

## Domestic Buildings

## Phase 1: Post construction and early occupation

Camden Passivhaus

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| **Technology Strategy Board BPE ref no:** | 4638-31202 |
| **Project title:** | Camden Passivhaus |
| **Lead organisation name:** | Bere Architects |
| **Number of properties part of BPE:** | 1 |
| **BPE project type (phase 1 or 2)** | Phase 1 |

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| **Prepared for:** | Bere Architects |
| **Prepared by:** | Jason Palmer |

# Contents

# 1 Introduction and overview

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| **Technology Strategy Board guidance on section requirements:** | This section of the report should be an introduction to the scope of the BPE project and will include a summary of the key facts, figures and findings. Give an introduction to the project covering the project team and a broad overview of the energy strategy and design strategy rationale. Only the basic facts etc. should be included here - more detailed information should be given in the relevant sections in this document and added to the data storage system as appropriate. |

This two-storey dwelling in Camden, north London, was completed at the end of 2010, with the owner moving in at Christmas. It is a two-storey detached house of 101m$^2$ Treated floor area[1]. It was designed to meet Passivhaus standards (the first in London), and underwent considerable testing and monitoring during the Building Performance Evaluation.

Like other passivhaus homes, it has mechanical ventilation with heat recovery, extremely good insulation and airtightness, high performance glazing, and (apart from two heated towel rails) only air-side heating.

The house is built using a prefabricated timber frame, with the ground floor wrapped in a concrete retaining wall – supporting high earth at the back and sides of the house. Walls have timber cladding and the roof is constructed from timber panels.

The house has a measured heat loss coefficient of 35 ± 15 W/K for both ventilation and fabric losses and 33.4 ± 12 W/K for fabric losses alone. It achieved an air tightness test result of 0.53 m$^3$/m$^2$/hour at 50 Pa.

*The house is a modern, timber-clad design with exceptionally low heat loss and excellent air tightness*

[1] TFA based on the German floor area ordinance Wohnflachenverordnung, which roughly translates as 'residential regulation'.

## Design rationale

The primary objective of this project was to achieve a comfortable and healthy home for the client's daughter, her boyfriend and small pet dog, while minimising energy use. Architect Bere Architects discussed the possibility of designing the house to Passivhaus standards with the client at an early stage – the client was supportive of this approach partly as it was expected to improve the prospects of getting planning consent. The dwelling would eschew a conventional heating system in favour of maintaining warm and comfortable interior temperatures (at standard occupancy and 20C in winter), while using less than 15kWh/$m^2$/y for heating.

Bere Architects discussed the improved air quality experienced in Passivhauses due to the fine (F8) filters used in the heat recovery ventilation unit, which filter out harmful particulates and pollen. Passivhauses supply filtered fresh air to habitable rooms 24hrs a day, maintaining healthy levels of $C0_2$ and efficiently removing odours. As well as the prospect of low heating bills, the client was excited by the idea of healthy indoor air quality, as his daughter suffers from asthma. Based on both the low energy and air quality advantages of the Passivhaus model, he agreed to embrace the standard and build London's first Passivhaus.

# 2 About the building: design, specification, construction and delivery

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| **Technology Strategy Board guidance on section requirements:** | This section should summarise the building type, form, materials, surrounding environment and orientation, as well as related dwellings in the development (which may or may not be part of the BPE project). Other amenities, such as transport links, cycling facilities, etc. should also be outlined where relevant. Also provide comments on the design intent, construction process and the product delivered. If the original specification is available, describe how closely the final design meets it, what the discrepancies are and why these occurred. Indicate whether the explanation comes from the design team or from evaluator judgement. Identify any discrepancies between the design and SAP and whether the design accurately reflected in the SAP calculations and describe where these discrepancies lie. Does the SAP performance match the specified performance and was this informed through measured or calculated data. As far as possible provide an explanation of the rationale behind the design and any changes that occurred. In particular, it will be helpful to understand the basis for making key decisions on the choice of measures and technologies. These may have been chosen to suit the particular property or a physical situation, or they may have been chosen to test an innovative material or a new product.<br>Complete this section with conclusions and recommendations. |

## Design and specification – the building

The house is on a residential street in Camden, north London. The street has mainly large, detached homes built conventionally using weight-bearing masonry. The street and houses along it are well-maintained, and most of the homes have established, well-kept gardens.

It is not well-served by public transport, although there is a bus route with buses to Kings Cross.

The client for the house owned a garage and a garden in Camden and decided to build a new house, originally as an investment. It is difficult to obtain planning permission to build in green spaces in London and Bere Architects felt that building London's first certified Passivhaus house with green roofs would improve the prospects of getting planning consent. (The planners were also wary of establishing a precedent for houses to be built in gardens.)

Part-way through design, the client decided that his daughter would live in the house. This changed the brief, and introduced a series of late changes to the design – in particular, linked to the interior design.

The structure of the house consists of larch and spruce prefabricated elements made in Austria. It has 280mm of Rockwool Flexi insulation in floor and walls, with 380-

400mm of insulation in the roof, and an airtightness membrane stapled and taped throughout. Calculated u-values for roof, floor and walls vary from 0.07 to 0.14 $W/m^2K$.

Passive House Planning Package was used as a design tool to determine the U-Values required to meet the Passivhaus standard on this site. It is sometimes difficult to accommodate the thick insulation needed to meet Passivhaus standards – especially in the UK where timber frames are usually a maximum of 215mm. However, for this project Kaufmann Zimmerei sourced all of the timber for the house in Austria, where larger timbers are readily available.

Bere have since worked on Passivhaus projects in the UK using UK timber, which required different detailing to account for the smaller timber sections available. According to the Welsh School of Architecture, the house exceeds the minimum requirements of current Building Regulations by 70% and would meet the carbon compliance limit for 2016 zero carbon homes.[2]

The detailed design of the superstructure was carried out by Bere with expert input from Matthias Kaufmann, Austrian technician in the practice, who had knowledge about the design of prefabricated timber construction and about Passivhaus. In addition, Matthias's family owns a timber factory in Austria (Kaufmann Zimmerei). Matthias Kaufmann was involved in working on the details in London and in the shop drawings when he returned to Austria at the end of his 18month placement at Bere. Therefore he functioned both as designer and contractor for the superstructure. He was responsible for all the detailing and supervision of the manufacturing of the structure in Austria, working with Kaufmann Zimmerei's own timber engineers, and the construction on site in London.

The house's main contractor was from the United Kingdom. The Structural Engineers responsible for the substructure were Rodrigues Associates. The concrete substructure placed the house in the landscape, with the walls of the ground floor being partly retaining walls. After the substructure was in place, the Austrian team built the super structure over two weeks. The mechanical and electrical installations were then installed by a local team. Bere found the sub-contractors reluctant to employ new techniques. Extra time was required on site from the architects to compensate for this, and make sure that the Passivhaus standard was met. Bere provided guidance for the local team regarding insulating pipe work and working with the air tightness membranes and tapes, although Bere said the advice was not always followed, which resulted in some abortive work. The Austrian team returned for two more weeks to

[2] Design Review Passivhaus Project: Camden, Welsh School of Architecture Cardiff University, report prepared by Olivia Guerra-Santin and Chris Tweed, October 2011.

finish the internal walls, external decking and the gate. The UK team finished the internal works.

The house consists of two bedrooms with private bathrooms, plus a WC on the ground floor. The open-plan kitchen, dining room and living room are on the first floor. Large windows are a key feature of the passive solar heating strategy. As a result, privacy became an important issue in the design of the house. The layout maximises the natural light in the first floor where less privacy is needed.

The owner was willing to implement as many low carbon technologies as possible within his budget. Bere steered the client towards low carbon technologies and the client was interested in the options available and embraced a number of these technologies. The low carbon technologies used in the house are:

- A solar collector to provide hot water;
- Green roofing; and
- Mechanical ventilation with heat recovery (MVHR).

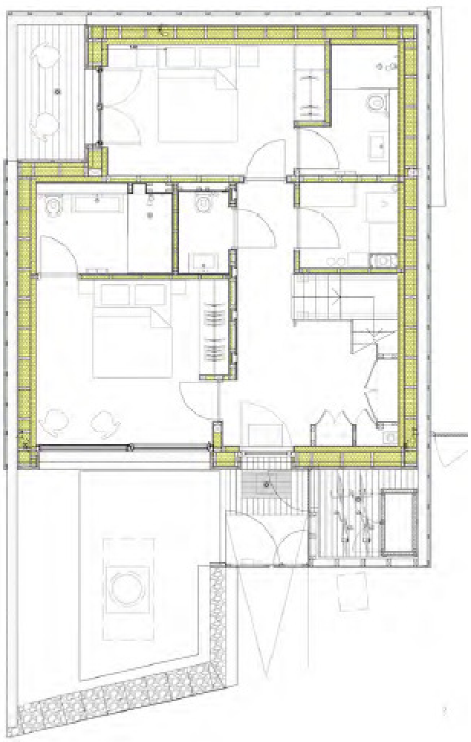
The design and sizing of the MVHR system was carried out by the Green Building Store and by the services advisor, Alan Clarke, who also designed the rest of the services.

There was close collaboration between the architects' team and the client during the construction of the project. However, the client's daughter and her partner – who now live in the house, were not involved until the final stages on site. They made some late changes, mainly to internal works. They also decided to have a wooden fence instead of the gabion wall around the front garden, which resulted in less privacy to the main bedroom. To help the new occupants understand the Passivhaus, the architects provided a user guide with information about how to use and manage the building. (Refer to appendices on page 56 for the user guide).

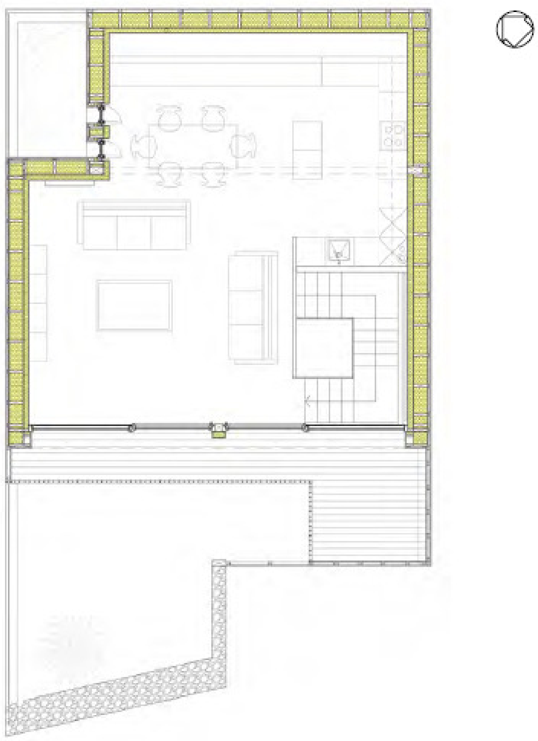
Passivhaus Planning Package (PHPP) was used to work out the optimum position of the house and the best orientation. Initially Bere had considered positioning the house at the front of the site with a small private north facing garden, through working closely with the PHPP the strategy changed to positioning the house at the rear of the site. By locating the house in this alterative position, the shadowing from the houses across the street was reduced, the occupants gained a good sized south-facing garden and terrace, and this approach was more amenable to planners and therefore more likely to obtain planning permission.  Biodiversity was also important in the overall concept design, and there are two wild flower green roofs, a planted garden and an ivy-covered stone wall. Installing the green roofs was a condition of the planning permission, as was the general landscaping around the house. The architects worked with Dusty Gedge, a leading green roof expert, on the specification of the plants for the two green roofs.

The Planning Package was used iteratively to refine design, estimating energy use in different configurations. This showed that the initial design (with the north facing garden) achieved a low heat energy demand of 21.2 $kWh/m^2/y$, but this was not low enough to meet the Passivhaus standard, and would require a conventional heating system to meet peak demand. By analysing the data in the PHPP, Bere established that the initial design had too much north glazing for a small house. The ratio of building envelope to volume was also too high, resulting in excessive heat loss.

After estimating energy use for 14 different configurations, Bere settled on one that did achieve the 15 $kWh/m^2/y$ stipulated to achieve Passivhaus. A number of the iterations met the Passivhaus heat energy demand, but this configuration was chosen as it had the garden to the south-west and a small courtyard accessed from a bedroom in the northern corner of the site, see plans below. The design also had a relatively simple envelope form, which worked well for the heat energy demand but also for the project budget.

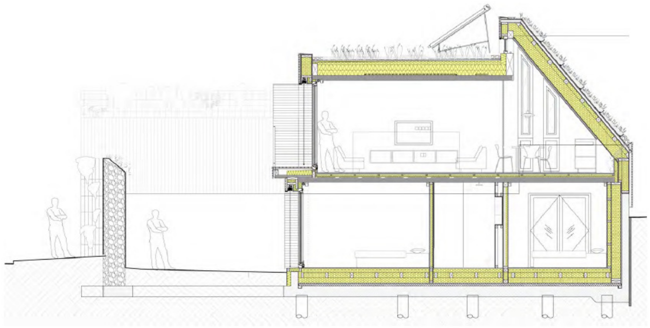


Ground floor Plan



First floor Plan

*There is a heavyweight concrete wall around the back (north-east) and sides of the house, with the main glazed elevation facing south-west.*



*The house is open plan on the first floor, with the main living areas, and sub-divided into bedrooms on the ground floor.*

One significant constraint on the design was a height restriction – the house could not go higher than the existing neighbouring garage. Thus, the building was sunk into the ground. This restricted the floor heights (ground floor has lower ceiling height, while heights were maximized for the living space on the first floor). Due to the height restrictions Bere designed the roof to have 400mm of high performing rigid insulation, with a thermal conductivity of 0.026W/(mK), to maximise the thermal performance while minimising the build-up, The U-value of the roof is 0.067W/(m$^2$K). This insulation also works well with the green roof build-up.

The ground floor was insulated with 400mm of natural wood fibre insulation, with a thermal conductivity of 0.035W/(mK), giving a total U-value of 0.103 W/(m$^2$K). The roof area is larger, so has a greater impact on the heat demand, and is exposed to external conditions, while the ground slab is located partially below ground level, which reduces the heat lost through this element. The final design showed as-designed transmission heat losses (calculated in PHPP) for the roof elements of 535kWh/a, while the losses through the floor slab are 278kWh/a.

The Passivhaus standard requires thermal bridges of less than 0.01W/mK, and all bridges greater than 0.01W/mK must be calculated and fed into PHPP to assess their impact on the overall energy use. Bere Architects used HEAT2 software to analyse all junction details – because it was the practice's first Passivhaus project. The sum of all thermal bridges in PHPP was negative, showing that the building details performed very well and would not have an adverse impact on the peak heat load. (Bere now understand which junctions are vulnerable to missing the 0.01W/mK limit, which reduces the number of bridges that have to be calculated.)  A table of the thermal bridges is included as an appendix to this document.

The joinery was imported, high specification, with low u-values and very good draught-seals. Triple-glazed, passivhaus-certified windows achieve Uw-values of 0.6

$W/m^2K$ (throughout, excluding the frames). The overall window u-values were around 0.8 $W/m^2K$ – exceptionally low heat loss for windows in the UK.

Automatic blinds were fitted to the large south-west facing windows – to reduce summer overheating and to provide more privacy.

## Design and specification – the services

Building services were designed by Alan Clarke with MVHR design by the Green Building Store, both in conjunction with Bere Architects.

*Ventilation*

Regarding passive ventilation strategies, large south-facing glazing in the bedroom and living room are secure when tilted. The main living space also has two smaller windows on the opposite side, which are turn only but are narrow and only accessible through the private courtyard, so Bere says they do not present a security risk. This allows cross and stack ventilation strategies in the living room and bedroom, as well as purge ventilation at night if necessary.

Regarding active ventilation, the heat recovery ventilation system provides supply and extract ventilation. It also provides space heating. According to manufacturers, the heat recovery equipment is 92% efficient. The efficiency of the system will be measured as part of next Phase of the TSB study. The system uses a Paul Thermos 200 MVHR unit located in an insulated enclosure in the bike shed attached to the building.

Originally the MVHR air handling unit was due to be located under the stairs. However, it emerged during design that this would make it very hard to get access to change the filters. So the air handling unit was moved to the cycle store outside the dwelling, within an insulated box (see sections below). The ductwork connecting the MVHR to the house is as short as possible – reducing thermal losses.

Supply air from the MVHR is ducted to a heater battery located under the stairs. The heater is supplied with hot water from the central heating boiler at nominal flow temperature of 60C. The target air temperature in the duct is 50-53C. The supply of heat to the heater battery is under control of the ventilation controls. More details of the heating aspect are covered in heating section below.

Heated air is carried in insulated ductwork to the two bedrooms and the living room. Air is extracted from the two en-suite bathrooms, the WC, the utility room, and the kitchen area. Extract air returns to the MVHR. Terminals are Lindab steel terminals and extract valves, plus a filtered kitchen extract grille, with flow rates adjustable at the terminal.

Ductwork used is Lindab spiral wound galvanised metal ductwork. Insulation of heated ducts is mineral fibre and foil, insulation of ducts between MVHR and the interior of the house is Armaflex. Duct intake is from the garden side of the bike shed, at approx 2m above ground level, and exhaust is to the pavement side of the shed.

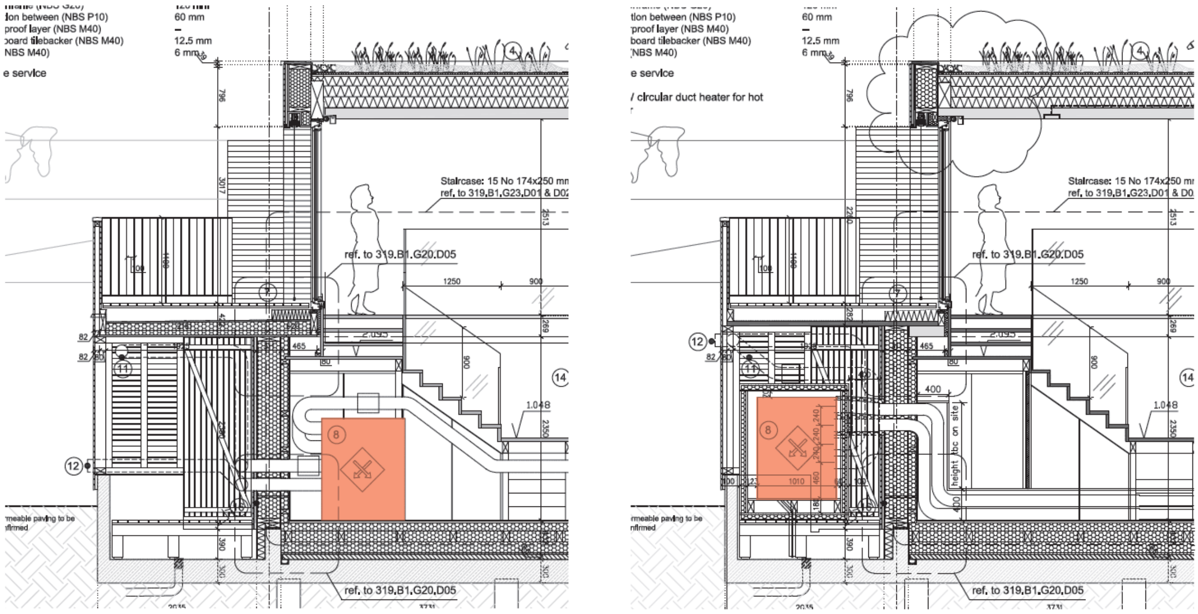
There is a boost button on the ventilation controls so that occupants can increase the air change rate (for 15mins only) when they need extra ventilation for a short period.

This is located outside the master ensuite bathroom, and is expected to be used when the shower is being used. There are separate controls for the MVHR speed, which have there are three settings: low, normal and party. These are located in the main living space, and intended to be used when the occupancy level changes for an extended period of a few hours or more. There is also a heat-recovery bypass for use in the summer when heat recovery is not needed. This saves fan energy.

MVHR power consumption was measured at 42 Watts at 130m$^3$/hr, 30 Watts at 99m$^3$/hr, 23 Watts at 72m$^3$/h. At around 0.3Wh/m$^3$ or 1W/l/s these figures are higher than the standard test figures (SAP appendix Q and PHI certificate) and probably reflect the higher pressure loss incurred by PTC (ceramic element) frost heater with pre-filter, F8 fine filter, and air heater battery, compared with standard testing. (Nevertheless, it still complies with the Building Regulations requirement of no higher than 1.5W/l/s.

According to Bere, when the house was designed and specified, the PAUL thermos 200 DC was the best performing unit on the market, although it was really intended for a building of greater volume than the Camden Passivhaus. The standing power of the control unit is higher than ideal, which influences the watts/l/s at the very low air flow rates it is being used for.

One lesson from this project is that wherever possible it is better to position the MVHR within the thermal envelope than outside it. Positioning outside adds considerably to the problems of insulation and managing condensation run off. In part, Bere's and the Green Building Store's concerns on the standing power consumption have lead to a new and improved control unit from PAUL, which has a standing power consumption of around 0.1 Watts. Though it is a complicated area to discuss in full, there are implications for designing ducting systems with extremely low pressure loss, and maintaining the desired air distribution around the building as temperature gradients change.




*These sections show how the air handling unit for the MVHR was moved from under the stairs (left) to the cycle store (right) to improve access to the filters.*

*Heating*

The heating system here is classic Passivhaus design, with heating via the ventilation air. There is also heat from two towel rails in the bathrooms. This is both to provide higher temperatures in these rooms for comfort, and to increase the maximum capacity of the heating system. At normal ventilation rate it is only just possible to meet the calculated heat demand via air heating, so the towel radiators provide a margin for error, and the ability to cope with extra cold weather. Viessmann (the boiler manufacturer) were quite negative about air heating, based on experience of Passivhaus buildings in Germany. Viessmann said they were concerned about lack of spare heating capacity to recover room temperature if it was allowed to drop.  The clients were also nervous about not having any radiators or underfloor heating, so pipework was also put in for a living room radiator in case it proved necessary to add one.

The occupants moved into the house in the winter and noted no problems with obtaining their optimum comfort temperatures and have confirmed they do not want a radiator installed.  The internal temperatures will also be monitored as part of the Phase 2 BPE.

At detail design it became apparent that the boiler would have trouble maintaining a steady temperature if supplying just the air heater battery, this has very low thermal capacity and output limited to about 1kW, whereas the minimum output of the boiler is around 5kW. At 50C flow temperature the efficiency is 96% at both min and max output, while at 90C flow the efficiency is 86% at min output, and 90% at max. - ie at

60C flow there should be no significant efficiency loss. Although the boiler and hot water are integrated into a single unit, it functions as a standard boiler + hot water cylinder arrangement, and there is no thermal buffering on the heating side.

The low thermal capacity of the system was addressed by including the towel radiators in parallel – so whenever the controls called for heat the towel rails would be heated along with the air heater, with towel rails limited by TRVs. This was a change from the previous arrangement of towel rails under user and timed control. Although this reduced the occupant control of the towel rails, the BUS has shown that occupants are happy with the heating systems and do not feel these need to be improved.

Run-back timers are provided to operate the towel rails in summer, giving the option of 30min, 1hr or 2hr operation. Each ensuite has a runback timer but for simplicity they both operate the two towel rails together. The towel rail runback timers call for heat from the boiler, via an additional switch input to the boiler controls. There are no zone valves on the towel rail circuit, so they are heated whenever the boiler provides heating. The duct heater has a zone valve controlled on room temperature (via a relay on the ventilation controls), and the end switch of this valve also calls the boiler via the same switch input as the towel rails.

The boiler does not have the standard weather compensation normally supplied with the Vitodens 343, but instead has simpler controls since the air-heating system requires a constant heating temperature. The constant water temperature is the boiler flow temperature ie using the boiler's own internal thermostat. This limits the maximum air temperature, and there is a band of around 5C between boiler set point and the maximum flow temperature. Room temperature control is by the ventilation control unit, which is located in the dining area and includes a room temperature sensor and user thermostat.

The room temperature is controlled by the ventilation controls as these also control the summer bypass to provide cooling, based on internal temperature. To avoid simultaneous heating and free-cooling, the ventilation controller only enables the summer bypass when the heating is set to "off". If boiler controls controlled the heating, then occupants could increase the heating set point above the summer cooling set point. This would mean the MVHR would bypass the heat recovery on hot days, bringing cool air into the house. This may just increase heating energy consumption but if the heater battery is unable to raise the supply temperature enough then room temperature would also fall.

It is recommended in Passivhaus design to limit air temperatures in the duct to around 52C to avoid "hot" smells in the supply air. Control of the heater battery on duct temperature was not used so as to avoid extra complication and potential for controls conflicts. Instead the boiler flow temperature was adjusted to give the correct air temperature – the heater battery selection software indicated that the air temperature would only vary by 1-2 degrees for the various airflows used, and that water flow temperature needed to be approx 10C higher than desired air temperature. Boiler temperature was initially set at 65C then reduced to 60C on seeing that it tended to run above the set point. This is now being monitored as part of the Phase 2BPE.

## Procurement, Construction and Delivery

Construction started in September 2009 and was completed slightly later than expected. The house was certified to Passivhaus standards in April 2010, but was still not finished internally, as the client wished to carry out parts of the interior design. The occupants finally moved in during Christmas holidays.

The procurement route for this project was traditional with selective tendering. When analysing the project in terms of the risk, cost, time and quality, the overriding factor in this job was the quality aspect or, put more precisely, 'control'. Cost was important to the client, but the key issues were that this was a unique building. It was crucial that full control over the design was retained once on site, particularly because of the airtightness and thermal performance of the building as required for Passivhaus certification. A number of variations to the procurement route were investigated between January and July 2009. This protracted pre-contract period was due to the client experiencing funding problems, which allowed Bere Architects to spend time establishing the most appropriate route for the project. This is a pioneering project for the UK and there were no precedents or experienced contractors within the UK. This meant that a contractor had to be selected who without previous Passivhaus experience, which resulted in additional supervision time on site for Bere.

The contract Bere recommended for the project and used was the ICD05. This gave adequate control to the architects as contract administrators and was able to deal with the issues likely to arise on site. Another reason for using ICD05 was that in this contract there was provision (unlike in Minor Works or Standard forms) under clause 3.7 and Schedule 2 for work to be carried out by a named sub-contractor, using the 'Intermediate Named Sub-Contract Tender' and 'Agreement ICSub/NAM'. Under these provisions, Bere could name the sub-contractors, Kaufmann Zimmerei (KZ), for the main prefabricated structure using Procedure One. This meant naming them in the specification prior to the Contractor(s) costing the works and giving a full description of the work to be carried out by KZ. The Invitation to Tender was completed by Bere, and gave the particulars of the Main and Sub-Contract Works, together with details of the sub-contract programme. The tendering contractors were all very interested in working on a Passivhaus project and keen to learn from KZ. None had any concerns with the KZ programme.

The service installations required for the house required specialist knowledge and the architects had built up a good team of sub-contractors that they wanted to write into the contract for these elements. ICD05 allowed them to do this.

*Tendering*

Bere first sent superstructure drawings to Austria for pricing by KZ in January 2009. The price came back at £250,000 excluding services, which was more than the client could apportion to this part of the project as a good portion of the total budget would be used for enabling works and services. As a result, KZ was asked to re-tender for the project excluding the finishes. This brought the price within the budget at £190,000. This tender price was received by Bere in February 2009.

Bere also approached a prefabrication company with a base in England, in April 2009, and in May 2009 a German company, with a base in Ireland, to get a price for the prefabricated superstructure. Using a UK-based company could have provided a cost saving given the Euro exchange rate at the time. The English company's price excluded many of the key elements of the airtightness envelope, making Bere nervous of their ability to deliver to Passivhaus standards.

Bere discussed these budget prices with the client, along with the concerns over the English company's ability to deliver the Passivhaus standards. The German company's costs were comparable with the costs from KZ. However, the client said he would be happier using KZ, as Bere already had a working relationship with them. This was strengthened by that fact that the project could benefit from the unique position that Matthias Kaufmann, an employee of KZ, had and the expertise he could bring to the development of the scheme.

In addition, Matthias was able to work with Bere in their offices for 18 months while they prepared the drawing package, after which he transferred back to Austria to work on the shop drawings. This resulted in an excellent knowledge transfer, which was further enhanced when MK also came back to the UK as part of the site team installing the prefabricated structure. KZ were also named in the contract so their price formed part of the tender returned from the main contractors.

Bere interviewed three UK main contractors for the project. After initial discussions, the architects sent drawing packs and specifications out for budget costing to the three companies, which included a company called Visco.b:a had not worked with Visco previously but had been introduced to them at a Passivhaus Conference.

The prices from all of the contractors were comparable. Visco were interested in branching out into Passivhaus projects and had hired a project manager who had recently completed the Passivhaus Designer 1 course in Germany. This project provided a great opportunity for Visco, who proposed running the project for the full duration of the site works, including the substructure, full house construction, services and finishes. Visco's price was within the project budget, so it was agreed that the project would be progressed with Visco as main contractors and KZ named as the sub-contractor for the prefabricated elements.

*Summary of design changes*

The Welsh School of Architecture analysed variations between the original design and the as-constructed house, and summarised what they found in the table over leaf.

| Variation | Reason | Consequence(s) |
|---|---|---|
| Ivy fence instead of the gabion wall in front garden (Figure 4) | Occupant asked for it | Less privacy in main bedroom or less light and sunshine if blinds are down |
| High window in kitchen does not open (Figure 5) | The geometry of the house, with the steeply sloping roof at the rear of the property, restricted the amount of air movement which would be possible through the high level windows. It was therefore decided to have fixed windows which also provided a cost saving. | No consequences, as cross and stack ventilation are still achieved through the vertical windows in the dining area. |
| Plaster on ceiling instead of exposed Austrian silver spruce ceiling | Occupant asked for it | Special detailing was needed around the sprinklers |
| Overflows for the roof (see [2]) | Typical Austrian detail was not included in original construction drawings | Contingency if the Sarna membrane was pierced providing a route for the water to escape without overloading the roof |
| Kingspan TR27 insulation was used instead of Bauder PIR Styropor in the roof area under the high level windows | Not enough material was ordered due to miscalculation | Since the substitute has the same U-value (0.025-0.027 w/mk) as the original (0.026 w/mk), this change has no effect on the calculations. |
| Detailing of the front of the roof terrace | The flat roof was collecting water. The design had been for a flat roof, as it was considered that having the roof slope to the outlets was not necessary. However, on site this detail did not work as the roof was falling away from the outlets. | Additional tapered insulation boards had to be installed to create falls to the outlets and remove the problem (water ponds under the decking) |
| Location of MVHR unit (unit had to be relocated to the bike shed) (Figure 6) | Positioning of the unit did not work with the specification of the unit (ducts were on the wrong side of the unit) | The unit had to be located in the bike shed. |
| Installation error with the solar panel. | Caused when the panel was laid flat to avoid stagnation of the fluid inside the tubes (Figure 7). | According to contractor, no consequence, but the design team took specialist advice on this and found that it was necessary to amend the orientation to maximise the potential of the panel. |

Corrections to this table:
Item 5 column 3 should read thermal conductivity not U-value.
Item 6 column 3 Clarification that this change improved the thermal specification

WSA summarised differences between the original design and as-built construction (Source: WSA 2011)

*Problems encountered on site*

Some problems were encountered on site – an inevitable result of working in new ways and learning-by-doing. The contractor, Visco, felt that more of the detailed design work should have been finalised before work started on site. This relates to difficulties with M&E design work being part of the 'contractor's design portion' under the form of contract used. The contractor under-estimated how much the M&E design would cost, and as a result, this work was delayed. The contractor's design portion included completing the design of the electrical and drainage installations.

The programme of work required the unusual (in the UK) step of laying the screed early, so the building was watertight before the timber frame was erected. Heavy rain meant that this filled with water, creating a 'swimming pool' (in the contractors' words), and this lengthened the drying time and caused delays. In future projects, they would use a temporary roof structure to prevent a screed floor from filling with water.

In general, the contractor observed that: 'Passivhaus Construction is much more exact and requires a much higher quality of works and tradesmen than we envisaged. It was a very steep learning curve. We made mistakes, which I hope and believe that we have learned from.'

One of the learning points for the contractor was that they should have been tougher with operatives and trades that did not perform, and in particular that they should have recognised that not everyone will buy into the passivhaus way of working. A second was the need to stay up to date with paperwork and photos.

Visco also noted that changes to design – variations – are particularly expensive with passivhaus. In their view it is even more important than usual to keep variations to a minimum, even if this means starting work on site later.

One of the variations was a response to water collecting on the balcony/terrace. Although there was no risk of penetration or flooding, this may have attracted flies, so the gradient of the terrace was re-designed to allow water to run off. This was identified post-contract by the client and was redesigned by Bere with the roofing contractor.

The main contractor went on to say that site management and office-based staff did not always appreciate the complexities of Passivhaus Construction. They recognised that people managing site work need to buy into the concept of passivhaus construction, and accept that more work is needed – both additional paperwork and numerous site photographs.

Moving the MVHR unit from inside to outside the building, in the cycle store, happened at a late stage. This meant that openings required for ducting had not been designed into the timber frame. Fortunately the timber frame contractor Kaufmann completed this work at no extra cost, but otherwise there could have been problems.

Other complications came from protracted negotiations between the architect and client about the design of the staircase, and some uncertainty about Party Wall Agreements with the neighbours.

There were also difficulties on site when the client employed his own trades to carry out work alongside the main contractors.

*Heating*

Operation of heating was checked at the on-site review. The heater battery was turned on using the ventilation controls. Air temperature in the duct after the heater battery was in range 51-54C, for a boiler flow temperature of 60-64C and return of 51-54C.

The boiler flow temperature rises gradually above the setpoint of 60C since the heat output of towel rails and air heater is slightly below the minimum boiler output, but the rise is controlled and takes several minutes. Then the boiler stops firing, but the pump continues to run until flow temperature drops below 60C. This was seen to maintain air temperature at a suitably high level despite the boiler cycling on and off.

The ventilation controls do include a limiting cut out for high air temperature in the duct. This is set at 55C with 5 degree hysteresis, so will not cut the duct heating till air temperature reaches 60C. This was not seen happening. If it did, it is expected that the boiler heat would be dissipated via the pump run on through the towel rails and the air temperature would drop fairly quickly to 50C as the duct heater zone valve would be closed, and then the boiler would fire again.

Heating balance is a little complicated with air heating, and although in this house it worked out well there may be an element of beginner's luck. As air is carrying the heat, the more air you get the more heat you get. This conflicts with a desire to get high airflow into bedrooms and yet keep the living area warmer than the bedrooms. In this case the airflow was adjusted to be 50:50 to each floor. Unlike with radiators there is no option to reduce heat output in particular rooms.

Bere say they would use this system again as it proved to work well in this house and provides significant cost savings – by not requiring a wet heating system to be installed. Since completing this project they have used air heating in other UK Passivhaus projects, where they say it is also working well.

It seems that the upside down arrangement of the house (with bedrooms downstairs) helped, since buoyancy circulation tends to keep the upstairs at least as warm as downstairs. Upstairs has the higher solar gain. The addition of towel radiators downstairs doesn't seem to have upset the temperature distribution.

One factor not anticipated in the heating design was the high heat loss from the ducts and the reduced air supply temperature. Supply air temperature is around 15C lower than off-heater temperature in bedrooms and 5C lower in the living room. The reason for the difference is unknown, probably down to relative duct length, but is better for heat distribution.

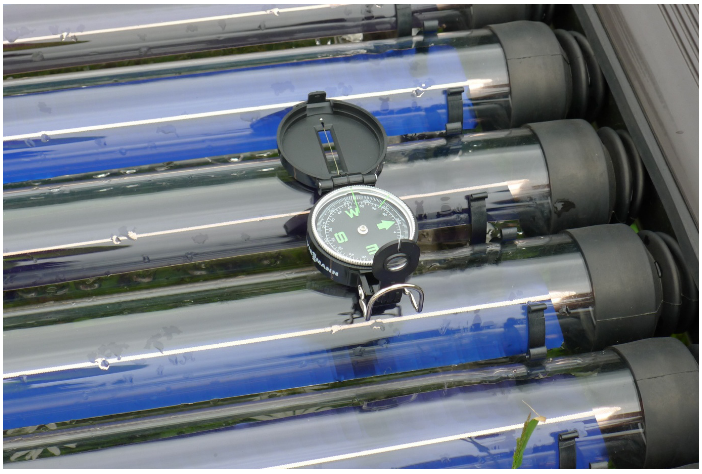
The supply ducts are insulated in most areas but, due to the reduced internal ceiling heights on the ground floor, the ducts are not insulated where they cross the ground floor corridor en route to the bedrooms. Designers thought at the time that as any heat loss would be into the house, the effect of reduced insulation would not cause any significant problems. In future projects, more careful planning of the duct runs and insulation levels would help to prevent this issue.

*Solar thermal*

Sensors showed that the Viessmann solar thermal system was not generating as much thermal energy as expected. Examining the roof showed that the installation was incorrect. The original design was for the panel to be mounted on an A-frame, facing south; this was shown on the tender and construction drawings. After work had started on site, though, the suppliers for the system recommended that the panel should instead be installed flat with tubes running East-West, and each tube rotated approx 30 degrees so the collector surface in each tube in angled towards the sun. They recommended this change due to problems of stagnating water in previous installations.

No new drawings were issued with this instruction, with the contractor confirming that they would enact this variation. However, when inspected on site the panel was actually installed with tubes running North-South. In addition about a third of the tubes were upside down, which inevitably cuts output significantly. They had effectively installed the panel to match the orientation of the original A-frame design but in the flat position. Viessmann attended site to commission the system, their commissioning report was issued to the main contractor but a copy was not sent to Bere or the client. This report has now been circulated and showed that these Viessmann highlighted the problem with the orientation and noted this must be corrected. This clearly did not happen.

To prevent a repeat of this situation, it is important that clear drawings are issued with instructions relating to any changes from the construction drawings – especially with regards to the orientation of specialist equipment. In addition, a copy of the commissioning report should be provided to the design team for review.



*Solar thermal tubes were installed north-south instead of east-west, and a third of them were installed upside-down.*

## SAP Assessment

The project team used NHER Plan Assessor for SAP 2005 calculations. This is much simpler than the PHPP version 1.0, and SAP is probably less well suited to assessing low energy homes like the Camden Passivhaus than the PHPP.

PHPP estimates a much lower air change rate – consistent with the passivhaus goal of very high airtightness.

A summary of the SAP and PHPP estimates of annual energy use is shown below.

| | SAP | PHPP |
|---|---|---|
| Space heating | 1572 | 1348 |
| Water heating | 3708 | 2218 |
| Auxiliary energy | 1411 | 594 |
| Lighting | 1464 | 1822* |
| Renewable | 0 | 1127 |

Table 1Energy requirements in kWh/a
(*) Including appliances

Source: WSA (2011) Design Review Passivhaus Project: Camden

The overall SAP Rating for the house was 88, or a 'B' rating. This is very surprising given the exceptionally good insulation, airtightness, MVHR and other low energy aspects of the house. The relatively low rating probably reflects a weakness of SAP in assessing very low energy homes rather than any flaws in design or construction methods.

Without carrying out a full and detailed analysis of the differences between SAP and PHPP, it is difficult to quantify exactly where the differences are. We know the SAP calculation method does not take as much benefit from solar gains. In addition a small issue is that as this house has very simple heating controls: the Passivhaus design does not require complex heating systems such as weather compensation etc. However, there is a SAP credit for these, so the Passivhaus loses out. Another impact on the differences is that the standard weather data in SAP is for Sheffield, so insolation (affecting solar gain) may be quite different from the more specific regional data in the PHPP. This would need to be looked at more carefully to comment more fully.

SAP 2009 uses regional weather data for cooling loads and version proposed for 2013 uses regional weather data for heat load too. DHW also differs, and EST's paper on SAP and DHW calculations found[3] that SAP is very accurate on DHW use but only for standard users with standard appliances, and it is not reliable for good or best practice with low flow appliances. Lastly, the Psi value calculations were not taken into account in the SAP but a y-value applied instead. Negative average psi values in the Camden Passivhaus means this is another area where PHPP diverges from SAP.

## Handover

Bere now adopt the Soft Landings protocol for their projects, and this was one of the first projects they used this protocol on. By following the Soft Landings methodology Bere say they will stay engaged with the occupants through the first 2-3 years of occupation.

When the house was complete and handed over to the client, the architects provided a user guide with information about how to manage the building, see Appendix 1. The handover process involved Bere visiting the house after the occupant moved in to discuss the operation of the various systems. During the handover it was clear that the boost switch for the ventilation required additional text explaining what it did. Bere designed a simple text box which was fixed to the switch on site. The architects report that the handover went well, and they do not feel that anything significant needs to be changed with the process. However, feedback from the occupant on the user guide has resulted in some changes for future projects. These changes relate to information on the exchange of filters.

The occupant says she is satisfied with the handover process and finds the user manual inside the utility room easy to understand and very useful.

[3] Energy Saving Trust (2008) Measurement of Domestic Hot Water Consumption in Dwellings. London: EST/DEFRA.

## Conclusions and key findings for this section

1. There is generally a tension in setting air change rates in mechanical ventilation: between air quality and over-dry air. Higher air volumes improve air quality, but may also lead to over dry air in winter (as well as, inevitably, higher fan and heating energy use). In a Passivhaus the aim is to keep $CO_2$ levels below 1000ppm. Generally in the Camden Passihaus, Bere says humidity levels have remained in the ideal range of 40-60% at 20-21deg.

2. The filters for the MVHR were visibly dirty after six months' use, and needed to be replaced. The intake louvre for the MVHR was also dirty, and needed to be cleaned.

3. Fine F8 filters raise fan energy needed in homes with MVHR.

4. The heat meter fitted as standard in Veissmann solar thermal systems assumes a default flow-rate, so kWh figures from the meter should not be trusted.

5. Designers should not assume that solar thermal systems will be installed as designed, and should check orientation and rotation on site post-completion.

6. Balancing the heating is more difficult in a home with MVHR, since heat is normally provided along with fresh air. There is a conflict in trying to provide a higher living room temperature compared with bedroom temperatures and maintaining high air quality in bedrooms.

7. There can be complications when the contract chosen requires the main contractor to carry out M&E design – especially when the contractor has limited experience of passivhaus work. In particular, this can lead contractors to under-price M&E design work, which inevitably has knock-on effects.

## Conclusions and key findings for other projects

1. SAP and PHPP give very different estimates of heat loss, infiltration and energy use. PHPP is probably better suited to low energy homes, and especially passivhauses.

2. Be very careful to select designers and contractors with sufficient experience of passivhaus work. Site work requires meticulous detailing and execution, and greater site supervision than usual.

3. M&E design costs can be higher for passivhaus work than conventional homes.

4. Avoid late changes to design wherever possible, and where changes are unavoidable, consider how they affect related aspects of the design.

5. Contractors wishing to work on passivhaus projects must accept that greater management and supervision of operatives is needed to meet the demanding standards of airtightness and insulation. These projects usually demand more paperwork and photos to document work too.

6. Trades and site operatives must accept that working on passivhaus projects requires a different attitude on site. Realistically, not all staff will accept this, and those managing site work need to be tough on those who are reluctant to meet extra demands.

7. Traditional procurement with selective tendering was chosen as the most appropriate way to procure this house. Bere used the ICD05 contract, which gave adequate control on site, and the ability to use a named, trusted, sub-contractor for highly specialist tasks (in this case building the timber frame).

8. SAP is not well suited to assessing very low energy homes. The Passivhaus Planning Package is a more reliable way to assess passivhaus designs.

9. It is essential to provide a straightforward manual for occupants – especially when installed ventilation and heating systems diverge from traditional UK systems.

10. It is better to keep the MVHR air handling unit inside the insulated envelope – especially for condensation reasons.

11. Any late changes to specialist equipment (e.g. solar collectors) should be issued with drawings to show the revisions. And commissioning reports for such equipment should be sent to the design team as well as contractors.

# 3 Fabric and services testing

| | |
|---|---|
| **Technology Strategy Board guidance on section requirements:** | This section should provide a summary of the fabric and services testing undertaken as part of the mandatory elements of the BPE programme, plus any other discretionary elements that have been undertaken.<br>Ensure that information on u-value measurements; thermography, air-tightness, any testing on party wall bypasses and any co-heating tests are covered.<br>Give an overview of the testing process including conditions for the test any deviations in testing methodology and any measures taken to address deficiencies. Confirm whether any deviations highlighted have been rectified.<br>As some tests (particularly the thermographic survey) are essentially qualitative it is important that the interpretation is informed by knowledge of the construction of the elements being looked at.<br>Complete this section with conclusions and recommendations for future projects. |

## Overview

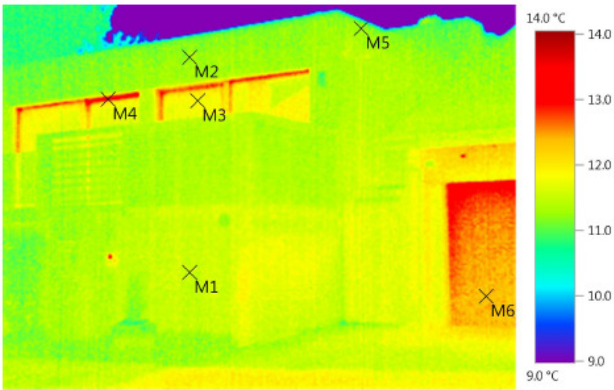
The project team followed the TSB protocols for fabric and services testing. The Building Performance Evaluation team carried out:

- a thermographic survey
- a heat flux study
- an airtightness test
- a co-heating test, and
- services tests.

Taken together, these tests built up a consistent and positive story about the way the house was constructed. The building fabric has exceptionally low heat loss, and the services are performing as expected.

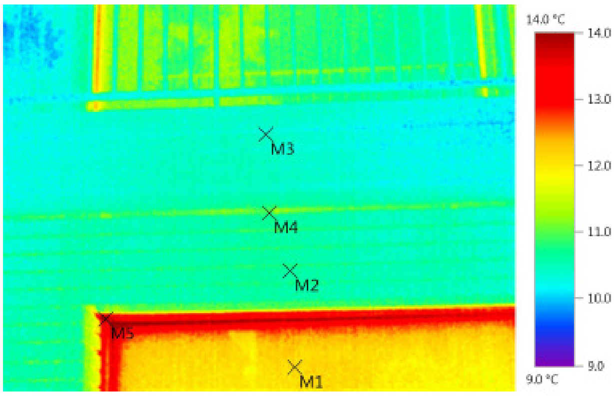
## Thermographic Survey

Bere Architects carried out a thermographic survey on the 1st April 2011. They followed the BS standard for such studies. The house was measured at 25°C internally (much warmer than usual – it was the last day of the co-heating test), while it was 11-12°C outside: a healthy temperature difference.




*There is minimal heat loss through the walls – although surface temperatures are very low because of the air gap behind cladding*

The survey showed surface temperatures for the walls as almost exactly the same as ambient temperature, but this was at least partly due to the air gap between timber cladding and the insulation behind. Windows had a slightly higher surface temperature – 13℃ (1.4℃ higher than the surrounding wall elements) – showing that even triple glazing does not completely prevent heat loss through glass. (Some caution is needed when comparing surface temperatures of glass and timber because of different emissivity and absorption of moisture.)




*The only significant area of heat loss is the perimeter of windows – the frames and window reveals were 14℃. This is low heat loss compared to standard construction details and double glazed units.*

The study showed that the edges of windows have unavoidable heat loss compared to the very high performance wall. Neverthless the psi values are 0.010-0.020W/(mK), which are very low. Even here, though, the surface temperature was only two or three degrees above ambient temperature.

The study also showed that there is some thermal bridge heat loss above one of the ground floor windows, which could be due to incomplete insulation around the window. There is also some thermal bridging around the beam supporting the sloping roof in the kitchen. The psi value of this junction was calculated at the design stage and taken into account in the PHPP.

## Heat Flux Study

UCL used heat flux meters to look in detail at the thermal performance of the wall and floor insulation. They found that both out-performed the design intentions (just).

For the floor slab, Bere had intended to achieve 0.103 $W/m^2K$. The post-construction test of the slab found a measured u-value of 0.099 +/-0.013 $W/m^2K$.

The measured wall insulation value (at a single point) was 0.097 +/-0.020 $W/m^2K$, against a design value of 0.122+/-0.020 $W/m^2K$. Again, this is an excellent result.

## Airtightness Test

BRE did an airtightness test on 7th September 2011. It was already occupied, and all air inlets and extracts were temporarily sealed. BRE followed the ATTMA and BS protocols for air permeability tests, and used fans in the main entrance to the dwelling to pressurise and depressurise.

The test revealed an excellent result of 0.53 $m^3/m^2$/hour at 50 Pa – around a twentieth of the leakage of the minimum required in current Building Regulations. This was even better than the design target of 0.6 $m^3/m^2$/hour. Yet this is slightly higher than the original test, undertaken on completion. Air leakage tests identified a small area of leakage around the front of the house, where a new services cable had been installed. Bere had designed an extra services conduit into the house, filled with insulation and sealed for future use, and the occupant had used this conduit. However, they did not correctly seal around the new cable, although this would be easy to rectify. BRE noted that the previous test was not carried out by them, with their equipment, so they advise caution in comparing the two results. Further tests will be undertaken as part of the Phase 2BPE.

## Co-heating Test

A co-heating test was carried out at the Camden Passivhaus for 13 days between the 20th March and 1st April 2011. The purpose of the test was to assess the total heat loss coefficient of the building, to be compared with its designed value calculated in the Passivhaus package PHPP.

We identified a total heat loss of 35 ± 15 W/K for both ventilation and fabric losses and 33.4 ± 12 W/K for fabric losses alone. This compared with the designed value of 63.6

W/K in the Passivhaus design package (PHPP) and suggests the building is performing within its designed thermal heat loss.

The large error in the stated test value comes from problems with the test, namely the large amounts of warm and sunny weather during the test. The effects of high and varying temperatures on the result are discussed in detail in the Co-Heating report. Corrections for thermal mass contributions, which improved the mathematical accuracy of result, gave a similar final result.

However, subject to funding and availability of the house for testing, we recommended that the house be retested. Homes with such high design performance need the weather to be as cold and dull as possible, so that findings are not distorted by solar gain. Preferably this would be between November and February and be of at least two weeks – which would be very difficult if the house is occupied. We also recommended that any re-test should use better equipment, including more accurate external temperature sensors and a full weather station to measure wind speed. Air permeability tests should also be conducted directly before and after the co-heating test.

Additionally a $CO_2$ decay test was carried out to determine the air infiltration rate during the test period. The calculated value of 0.38 ± 0.08/hour compares to the previous pressurization result of ACH50 = 0.44/hour, again indicating the building is meeting its performance criteria.

## Conclusions and key findings about this house

1. Fabric testing including a co-heating test, air permeability test and thermographic survey, suggest that the fabric of the house is meeting design specifications.

2. The design and detailing have achieved excellent air tightness and heat loss results – dramatically better than current or proposed Building Regulations standards.

3. Heating and ventilation systems appear to be working correctly.

## Conclusions and key findings for other projects

1. Sometimes internal thermographic photos are more complicated to interpret in mechnically-ventilated homes. Cold patches may be due to problems in distributing heat evenly as well as areas of heat loss.

2. Co-heating tests should be carried out between November and February to be more confident of a large enough temperature difference and to minimise the effects of solar gain.

3. It is desirable to have a full weather station on site when the co-heating test is carried out – including accurate external temperature sensors (shielded from solar gain), an anemometer to measure wind speed and a pyranometer to measure solar flux.

4. It is also desirable to do an air permeability test directly before and after co-heating.

# 4 Review of building services and energy systems

| | |
|---|---|
| **Technology Strategy Board guidance on section requirements:** | Explain what commissioning was carried out, what problems were discovered and how these were addressed.<br>Discuss as to whether the initial installation and commissioning was found to be correct and any remedial actions taken.<br>Comment on whether the original operational strategy for lighting, heating/cooling, ventilation, and domestic hot water has been achieved. Compare original specification with equipment installed, referring to SAP calculations if appropriate. Give an explanation and rationale for the selection and sizing (specification) of system elements.<br>Use this section to discuss the itemised list of services and equipment given in the associated Excel document titled "BPE characteristics data capture form (v4.0)". For each system comment on the quality of the installation of the system and its relation to other building elements (e.g. installation of MVHR has necessitated removal of insulation in some areas of roof).<br>Describe the commissioning process Describe any deviation from expected operational characteristics and whether the relevant guidance (Approved Documents, MCS etc.) was followed. Explanation of deviations to any expected process must be commented in this section. An explanation of remedial actions must also be given.<br>Describe the operational settings for the systems and how these are set.<br>Comment on lessons learned, conclusions and recommendations for future homes covering design/selection, commissioning and set up of systems. Also consider future maintenance, upgrade and repair – ease, skills required, etc. |

## Services Testing

Alan Clarke tested the heating and ventilation systems on 31 January 2011. Room temperature was found to be 19-20°C with heating off initially, and an external temperature of 7.5°C. Alan found that the systems and controls were functioning correctly, although the towel rail needed bleeding and there was missing insulation on a duct heater and some pipework.

## Commissioning

Andrew Farr commissioned the ventilation system using two different anemometers, the second more accurate than the first. The first time he commissioned the system, before the occupant moved in, he did not own the more accurate anemometer. The more accurate anemometer was used for the BPE re-commissioning. He made minor adjustments to the ventilation balancing on both occasions.

Andrew also upgraded the filter on the air intake to 'F8' (a finer mesh than the original filter) – in line with new Passivhaus recommendations.

## Conclusions and key findings for this section

1. The original objectives for building services were achieved successfully: the MVHR is providing fresh air and sufficient heating, and there is no intrusive noise from fans; lighting and daylight are satisfactory; and although there were some problems with shading and the first-floor doors to the balcony, these have been largely resolved. The occupant mainly chooses not to use the shading on the first floor, enjoying the warmer temperatures she can obtain with the blind left up.

# 5 Monitoring methods and findings

| | |
|---|---|
| **Technology Strategy Board guidance on section requirements:** | This section provides a summary breakdown of where the energy is being consumed, based around the first 6 months of metering results and other test results. Where possible, provide a simple breakdown of all major energy uses/producers (such as renewables) and the predicted CO2 emissions. Explain how findings are affected by the building design, construction and use. This section should provide a review of any initial discoveries in initial performance in-use (e.g. after fine-tuning). If early stage interventions or adjustments were made post handover, these should be explained here and any savings (or increases) highlighted.<br>Does the energy and water consumption of the dwelling meet the original expectations? If not, explain any ideas you have on how it can be improved.<br>Summarise with conclusions and key findings. |

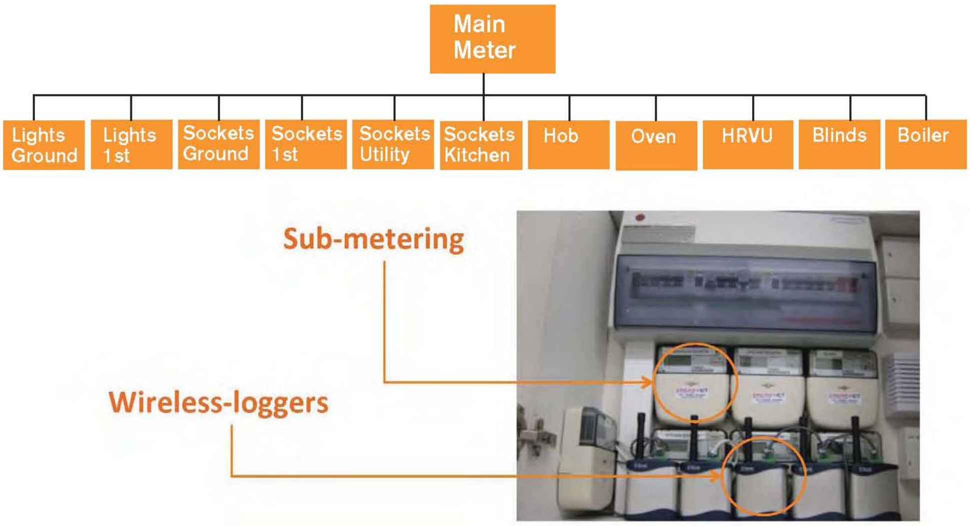
## Monitoring methods

The monitoring system at the Camden Passivhaus was designed specified and overseen by Dr Ian Ridley, at University College London. The installation was overseen by Bere Architects using electricians and plumbers familiar with the site. The Data logging equipment was supplied, installed and tested by Eltek Limited.

Data is being downloaded remotely via modem by UCL on a weekly basis. The data is checked for sensor dropouts and to identify general maintenance and reliability issues. Monthly summary reports are being provided by UCL to Bere Architects. Detailed monitoring reports will be produced on a quarterly basis, giving a forensic analysis of building performance.

Monitoring equipment manufacturer Eltek installed a very comprehensive range of monitoring devices, refer to monitoring guide in Appendix 3, including:

- 11 electrical sub-meters as shown below




- 14 temperature meters (5 with relative humidity sensors, and 2 with CO2 sensors)

- a total water use meter

- an external weather station

- 2 kWh heat meters (one on the towel rails, one on the duct heater), and

- a total gas meter.

Data retrieval is carried out using Darca Plus software. This program was used to set up the system transmitters and the logger's channels. It also monitors and graphs the data on screen in real time, and stores the data for analysis and printout. Data is logged at five-minute intervals

Data is also exported to a spreadsheet for analysis and archiving.

Individual ventilation outlets have temperature sensors upstairs and downstairs, along with a sensor on the heating coil and hot water temperature. This should shed light on the relationship between air temperature, water temperature and the airflow.

Electrical sub-meters were fitted with wireless transmitters to connect them to Eltek's datalogger.

## Early Monitoring Results

So far gas consumption has been reasonably in line with expectations, and detailed monitoring will work out the split between heating and hot water.

Initial (total) electricity use is marginally above average for UK homes but this has recently been found to be largely due to a replacement Viessmann control panel which had not been specifically programmed for the solar combination unit. This resulted in solar and boiler pumps running continuously, 24 hours a day. Specialist programming of the replacement controller has now been undertaken and Bere says the electricity consumption in-use is matching the design.

The preliminary tables below suggest that about a third of electricity is being used for appliances, a surprising amount (two-fifths) is being used for the boiler/towel rail (due to the above control fault). About a sixth is being used for lights, and a small proportion – only 5% to power the MVHR. The sub-metering will allow more detailed analysis in the future to explore how electricity is being used.

Temporary monitoring of the electricity use by the MVHR air handling unit indicated that it uses 30 Watts in normal mode, 10.5 Watts with fans off and rising to 42 Watts when fans are in booster mode.

According to the Welsh School of Architecture, the PHPP calculations estimated total annual energy use of 97 kWh/m$^2$/y (compared to 120 kWh/m$^2$/y required to achieve passivhaus certification). WSA say the calculation indicates that 46 kWh/m$^2$/y is needed for 'regulated' energy – space heating, hot water and auxiliary loads.

| Electricity Consumption | % of Total | kWh |
|---|---|---|
| Lights | 23.7 | 89.556 |
| Sockets | 32.2 | 121.437 |
| Cooking | 0.6 | 2.152 |
| Blinds | 0.4 | 1.669 |
| Boiler/Towel | 38.5 | 145.07 |
| MVHR | 5.4 | 20.519 |
| Total | 100 | 380.4 |
| | | |
| | | |
| | | kWh |
| Gas | | 23.1 |
| DHW | | 78 |
| Solar Input | | 167 |

Preliminary energy data – August 2011

| Electricity Consumption | %of Total | kWh |
|---|---|---|
| Lights | 16.2 | 58.791 |
| Sockets | 32.1 | 116.602 |
| Cooking | 0.7 | 2.438 |
| Blinds | 0.0 | 0 |
| Boiler/Towel | 45.2 | 164.203 |
| MVHR | 6.4 | 23.289 |
| Total | 100.5 | 365.3 |
| | | |

| | | |
|---|---|---|
| | | |
| | | kWh |
| Gas | | 63.6 |
| DHW | | 73 |
| Solar | | 149 |

Preliminary energy data – September 2011

*Source: Ian Ridley/UCL, 2011*

## Conclusions and key findings for this section

1. There is a comprehensive set of monitoring instruments installed in the house, recording gas and electricity use, internal temperature, humidity, water use, air quality and weather.

2. The instruments allow data collection from a distance, and there is a system in place for recording the data.

3. Electricity use so far is a little above the UK average of around 4,000 kWh/year, due largely to a controls fault on the solar water and boiler pumps.

4. The MVHR system uses minimal electricity – only about 5% of the monthly electricity use so far.

5. A surprising amount of electricity is currently being used to run the boiler and towel rail. This has been traced to a problem with the solar water controls, and now resolved.

# 6 Key findings from the occupant walkthroughs and Building Use Survey

| | |
|---|---|
| **Technology Strategy Board guidance on section requirements:** | This section should reveal the main findings learnt from the early stage BPE process and in particular with cross reference to the occupant handover process, training and operating manuals, aftercare, BUS survey, interviews and discussions.<br>Note where the dwelling is being used as intended and where it is not; what they like / dislike about the home; what is easy or awkward; what they worry about.<br>Are there any issues relating to the dwelling's operation? This would include: programmers; timing systems and controls; lights; ventilation systems; temperature settings; motorised or manual openings / vents.<br>Do the developer / manufacturer produced user manuals help or hinder the correct use of the dwelling?<br>Have there been any issues relating to maintenance, reliability and breakdowns of systems within the dwelling? Do breakdowns affect building use and operation? Does the occupant have easy access to a help service? Does the occupant log issues in a record book or similar? Does the occupant have any particular issues with lighting within the dwelling (both artificial lighting and natural daylighting)? Add further explanatory information if necessary |

## Occupant Walkthroughs

The occupant semi-structured interview, combined with the walkthrough, was carried out on the 20th of July 2011, with one of the two occupants. Architect Sarah Lewis also participated in the walkthrough, sometimes also asking the occupant questions or giving suggestions as to how to use the house in a more efficient and user-friendly way.

The house is occupied by a working couple. They moved into the house during Christmas 2010 holidays. Both of them work during the day. They were generally satisfied with the handover process and find the user manual located inside the utility room to be easy to understand and very useful.

The occupant is likes the aesthetics of the house and its modern styling and stated that it is a nice place to live in. They are also happy with room sizes but would prefer more wardrobe space. The only potential issue regarding the size of the house is potential future expansion of the family with two children or more, in which case it may not be large enough.

Due to privacy issues of big glazed windows, they said external blinds are always down in the living room when the occupants are at home. In the bedroom this will not be necessary once the ivy grows to its full extent. Because the client decided to replace the original gabion wall with ivy, the bedroom has limited privacy, so the ground floor bedroom blinds are always left lowered. This significantly limits the winter solar gains on the ground floor. Conversely, the first floor windows were locked in the up position all summer so the house didn't benefit from shading. However, the clients appear to like the higher summer indoor temperatures.

The extra bedroom, currently used as a study or guest bedroom, has north-west orientation and thus generally has lower temperatures, which is convenient for the summer and does not cause a problem during winter as it is little used.

On controls, the occupant noted that in the utility room all controls are automatic – nothing is controlled by the occupant. However, they observed that they cannot clearly see if solar water heating is working.

The occupant considers the house to be easy to maintain.

*Heating and ventilation*

The occupant is satisfied with the MVHR, noting that it is responsive and easy to use. They prefer the Passivhaus concept of heating through heat recovery to a conventional system as the house is always warm: "warmer than my parents' house", she said. During winter, temperatures are considered to be stable and always sufficiently high, and are usually kept in the 20-22C range.

(The architect's response to this was that the occupant was used to much higher air temperatures in her parents' house – 24-25C – but believes her house to be warmer because of higher surface temperatures and less radiant heat loss from her skin to walls, floor and ceiling. The architect is disappointed that the occupant runs her house warmer than the 20C anticipated in design calculations of energy use, due to the high temperatures she has been brought up with. However, they are still confident that the design is robust enough to achieve this without significantly compromising energy performance, and this was borne out by testing higher internal temperatures in the PHPP.)

The occupant understands the principles of the MVHR and the importance of minimising natural ventilation in winter (i.e keeping the windows closed), and as a result the windows are barely opened in winter.

Mechanical ventilation is only adjusted by using the boost ventilation control in bathroom, only occasionally after showers. There are no reported problems with humidity. Otherwise the ventilation rate is never adjusted, even when the number of people increases. The occupant instead prefers to open a window to get additional fresh air.

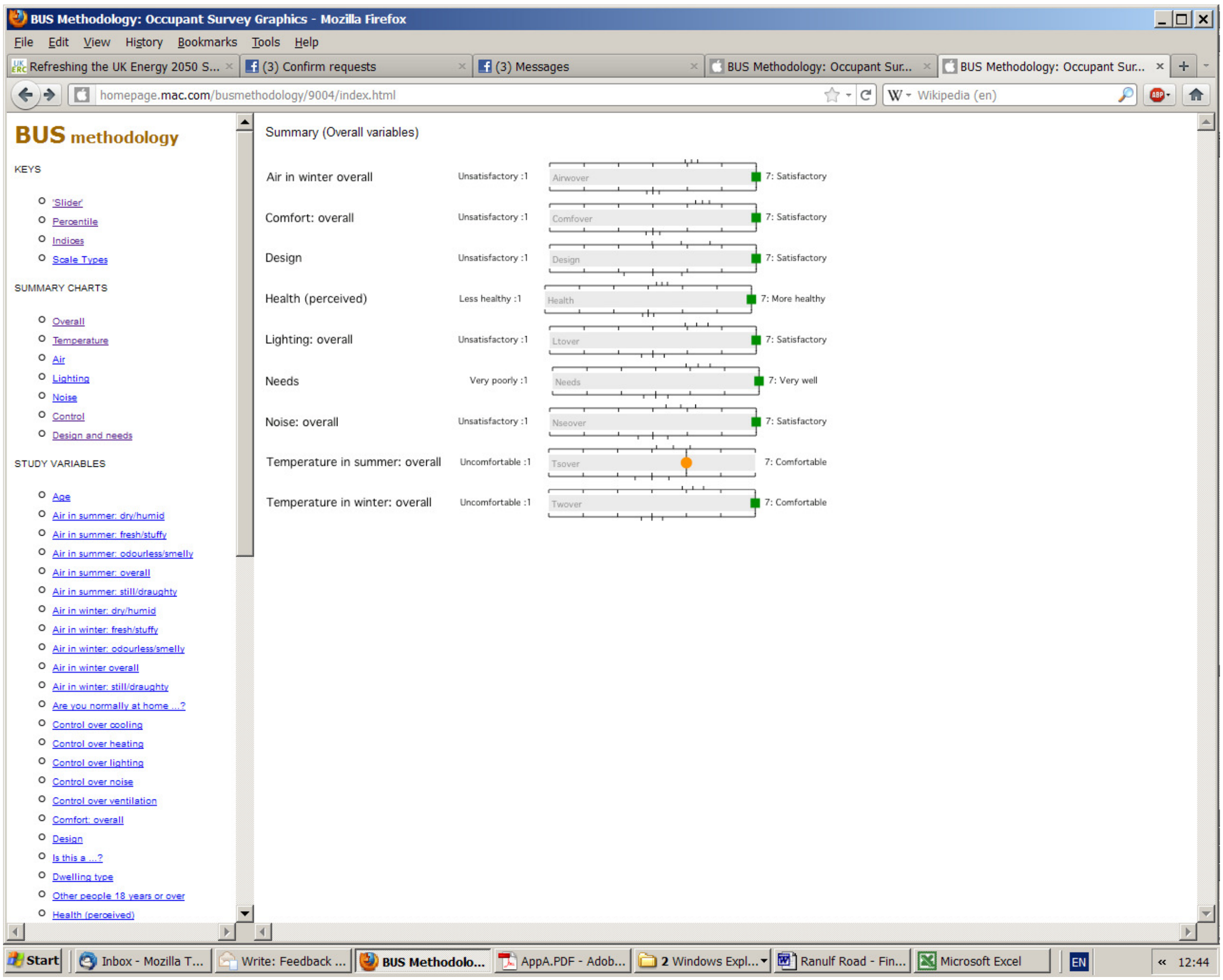
According to the architect, mechanical ventilation is used during the summer but the heat recovery unit is by-passed. This is reportedly easy to do using the control panel in the living room. Windows are opened for additional cooling if necessary only during the day. During the night the occupant uses a fan. The architects suggested opening the window instead, but the occupant prefers not to because they do not feel safe with the bedroom on the ground floor, even though the windows are secured when tilted. The occupant once tried to leave small windows in the living room open but this resulted in overcooling according to the BUS. As a result the occupant does not use night purge ventilation as often as expected as she enjoys the warmer temperatures.

The mechanical ventilation is quiet and there are no complaints from the occupant. Fine filter (F8) is used because of the occupants' asthma. She has not had the opportunity to test the effect of air quality on her asthma because she is unable to come off her medication.

The occupant is aware that the filters in the MHVR unit need to be changed regularly, but seemed not to be aware of the fact that the water filters are also supposed to be changed.

## BUS Study

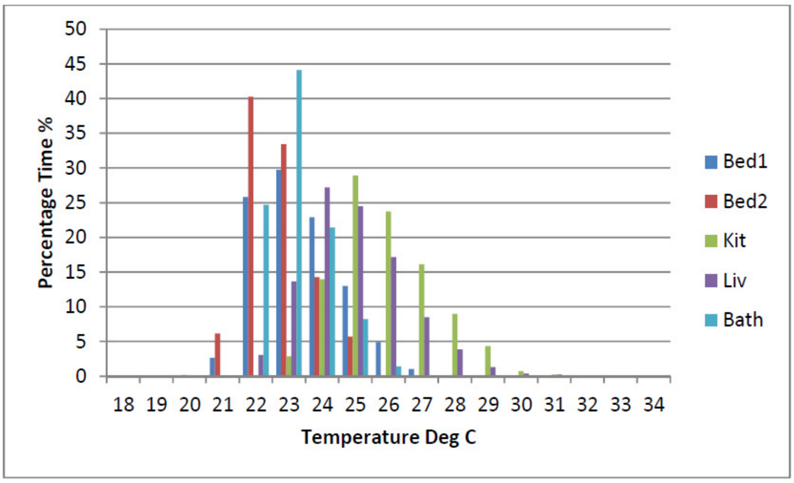
The Camden Passivhaus scored extremely well in the Building Use Survey, although results are different from most BUS studies because only one person completed the survey. The owner appears to be happy with nearly all aspects of thermal comfort, with the only significant blot on the scorecard some concern about summer temperature, see graph below.  The occupants live-in partner chose not to take part in the survey, we understand this was due to a busy work schedule.




Regarding summer comfort, the respondent said: "Gets too hot at night - can leave window open but then no control of temperature so may get too cold."

The PHPP estimates of summer overheating suggested that leaving one window open for a quarter of the day, and leaving the solar blinds closed for half the day, would completely eliminate overheating (defined as hours above 25C). However, the PHPP estimates also suggested that if occupants do not open windows, then internal temperature will rise above 25C for 7.6% of the time (WSA, 2011). It seems as if the occupants are not using the solar blinds at all in summer (they are over-riding the automatic controls), and it is unclear how much they leave windows open. The BUS may suggest that occupants prefer higher temperatures, and it is possible that they intentionally override the external blinds to make it warmer. As part of the Phase 2 study the team will be monitoring the use of blinds and windows – particularly during autumn and spring periods.

UCL's record of internal temperatures in August and September in the house (below) show that internal temperature does indeed rise above 25C on the first floor – for around half the time in the kitchen, and about a third of the time in the living room. It also reached very high temperatures (above 28C) for a few hours on the first floor, but as previously mentioned the external blinds have not been used this summer and the house was probably unoccupied during these periods of very high internal temperature. The occupants were unable to remember if they were in the house over this period but the data from the CO2 sensors suggest that the house was unoccupied.




*UCL's temperature records for August and September 2011 show that the bedrooms stayed below 25C nearly all the time, although first floor temperatures rose higher.*

The occupant appears to be somewhat concerned about gaps beneath the internal doors. In relation to noise, they said: "Gaps under doors so if someone was staying in other room would be able to hear them." This can partly be attributed to the choice of wooden floors as opposed to the carpeted floors Victoria has been used to. A 10mm gap has to be maintained under the door for cross flow ventilation.

While it is hard to compare this with the BUS scoring archive because there is just a single respondent, superficially the house appears to compare very favourably with other homes.

## Conclusions and key findings for this section

1. The occupant likes the aesthetics and modern styling of their home. They are also content with room sizes.

2. However, there are some concerns about privacy because of the large windows in the living room, and as a result they said internal blinds are always down when they are at home. The architects intend to teach Victoria how to use the external blinds correctly but the worry would then be that she disables the blinds in the ‘down’ position when solar gains are needed in the winter.

3. The occupant likes automatic controls on heating and ventilation, although they dislike not knowing whether the solar water heating is working. The design team are looking into displays for future projects with information on the effectiveness of the solar water heating.

4. They are happy with internal temperatures – especially winter temperature – although the BUS revealed some concern about high night-time temperature in summer.

5. Although the BUS survey was a tiny sample size of one person, the results were very positive.

6. Actual temperature monitoring in August and September found high temperatures (above 25C) for some of the time on the first floor due to the client’s disabling of the automatic solar blinds and (probably) leaving the house for a few days.

# 7 Key findings from the design and delivery team walkthrough

| | |
|---|---|
| **Technology Strategy Board guidance on section requirements:** | This section should reveal the main findings learnt from the early stage BPE process and in particular with cross reference to the walkthrough with the design and delivery team. Explore the degree to which the design intent has been followed through in terms of delivery and subsequent adoption by the occupant(s). Focus on what constraints or problems they had to accept or address in delivering the project.<br>Have there been any issues relating to maintenance, reliability and reporting of breakdowns of systems within the dwelling? Do breakdowns affect building use and operation? Have issues been logged in a record book or similar? Add further explanatory information if necessary.<br>Explain any other items not covered above that may be relevant to a building performance study.<br>If action was taken to remedy matters, improve support or feed occupant preferences into future design cycles this should be explained.<br>Graphs, images and test results could be included in this section where it supports a developing view of how well or otherwise the design intent has been delivered during the pre and post completion phases. |

## Observations from the design and delivery team

In considering whether the outcome of the work met the original project objectives, the design team was generally positive. The architects said: “The rigorous and detailed design requirements needed for Passivhaus certification are easily fulfilled by an experienced architect. The spatial requirements requested by the occupant (two bedrooms with ensuite bathrooms, and living space) were also fulfilled.”

However, they also noted: “The front garden was originally intended to have gabion wall facing the street. The occupant decided to change it and have an ivy planted fence, which significantly reduced the levels of privacy. Consequently it is thought that the garden space will not be used as much as was originally intended and the internal spaces will be shaded from useful solar gains as the blinds will be lowered for privacy.”

The client also departed from the original design in covering the timber ceilings with plaster board, which resulted in a more complicated design to allow for the sprinkler system.

The architects reported a positive experience of using the Passivhaus Planning Package, and they now use PHPP even in projects that do not require Passivhaus certification – they consider it to be a useful design tool which helps to optimize their low energy design. Design decisions are therefore not arbitrary, but based on accurately estimated energy demands, which are considered to be important parameters.

Regarding the construction process, the concrete substructure was cast on site and the wooden superstructure, including façade cladding, was prefabricated and completed in Austria. The architects have used prefabricated structures again, using UK timber suppliers, because of the associated benefits of “high tolerances, reduced construction times and minimised waste”. It was also important in this case to speed up the construction process due to disturbance caused to neighbours.

The contractor employed Dominic Danner, an “airtightness champion”, who supervised on-site works, ensuring correct installation of the membrane to provide a sufficient air-tight seal and making sure that all details were carried out as designed. He was also key in briefing all workers on the construction team about the aims of the project and importance of airtightness. It worked well on site for Dominic to be a direct employee of the main contractor’s although at points frustrations arose between the main contractor and Dominic, when the extra care and skill required was not appreciated.

Dominic experienced difficulties with some sub-contractors, noting that they quickly fell back into old habits if not constantly monitored. Dominic has a German background and introduced the team to a new role which could be used for future projects. This role is a ‘Process Technologist’ a person who is responsible for all of the integration of the M&E through design and into construction. Alan Clarke provided this service for Camden in design but if his role had been extended to be more active on site this would be helpful.

*Occupant comfort*

Initial temperature monitoring and gas meter readings for January and February 2011 showed that the house performed as predicted by PHPP. However, the project team is aware that a longer monitoring period is needed to draw more certain conclusions.

According to the architect, feedback from the occupant indicates that the house is easy to live in and that the temperatures are satisfactory. This is the first project by Bere Architects which has no conventional back-up heating, instead when heating is required it is supplied through the air supply, with towel rails also automatically switched on at the same time.

The clients initially expressed concern about this, however there have been no complaints of low temperatures since completion. As a precautionary measure pipe work connections were installed to the living room to allow for a radiator to be fitted if necessary in the future. The architect said that the occupant occasionally uses fans during the night in summer, because the client doesn’t like doing night purge cooling and reportedly enjoys higher temperatures.

*Other comments*

The project team made a series of other comments about what could have been improved on the project. They said:

1. Due to a problem with Visco providing M&E subcontractors anywhere near the provisional sum allowance in the contract, the client decided to bring in his own direct labour and a large portion of the M&E was removed from the contract. With the M&E under partial client control quality was harder to manage.

2. Although Visco were concentrating on the Passivhaus certification, both their and the client's sub-contractors showed disregard for the PH standards and quickly fell back into old habits if not constantly monitored (see item 4 below for an example).

3. Visco did not appreciate the extra care and skill required on the M&E side so frustrations arose between Visco and Dominic Danner, who was monitoring quality on site. While Visco were keen to obtain the PH standard they were less willing to adapt their construction methods.

4. Pipe insulation provides a good example of where traditional methods did not meet the PH specification. The plumber installed copper pipes at standard centres, which did not accommodate the insulation. The client refused to allow the plumber to correct the piping due to cost constraints. Additional time was required from Dominic to propose a suitable method for insulating the pipes without repositioning and then additional inspection was required to make sure the insulation was installed as agreed.

5. Where PH goes beyond Building Regs it was difficult on this project to get sub-contractors to understand why the PH should be adopted.

The project team also made suggestions about how to resolve problems in the future:

1. More control is needed on site than usual – without client supplying labour, and keeping the line of responsibility with the main contractor.

2. Collectively, the construction industry needs to improve skills to achieve the demands of Passivhaus construction. This includes increased provision (cost budgeted) for inspection.

3. Main contractors and/or designers need to get sub-contractors on board.

4. More firms should purchase their own air testing equipment and get the full team involved in the airtightness tests.

5. In Germany there is a 'Process Technologist' role: a person who is responsible for integrating the M&E through design and into construction. Alan Clarke provided this service for Camden in design but if his role had been extended to be more active on

site this would be helpful. However, on this project the client would not have been happy to pay for this additional service.

## Conclusions and key findings for this section

1. Passivhaus requires additional insulation on pipework, so the pipework must be installed with wider spacing than usual.

2. Passivhaus sometimes conflicts with UK Building Regulations, but the standard is usually superior and should take precedence over Building Regulations.

3. Better skills and coordination are needed in the construction supply chain – including building more experience of air tightness testing, Passivhaus standards, and the true M&E costs of Passivhaus.

# 8 Key messages for the client, owner and occupier

| | |
|---|---|
| **Technology Strategy Board guidance on section requirements:** | This section should investigate the main findings and draw out the key messages for communication to the client / developer and the building owner / occupier. There may also be messages for designers and supply chain members to improve their future approaches to this kind of development. Drawing from the findings of the rest of the report, specifically required are: a summary of points raised in discussion with team members; recommendations for improving pre and post handover processes; a summary of lessons learned: things to do, things to avoid, and things requiring further attention/study. Try to use layman's terms where possible so that the messages are understood correctly and so are more likely to be acted upon. |

## Messages for the client, owner and occupier

On the positive side, good early support of the Passivhaus approach meant that the project team was clear about aspirations for the house from the start. The client was always supportive of achieving certification even if his reasons were partly commercial rather than environmentally-motivated. He appreciated the wider benefits of certification – increased value, a guarantee of (most) of the workmanship, improved longevity of the building as a result of improved airtightness – quite apart from the benefits in getting planning approval.

Unsurprisingly, there were also some things that could have been improved in the project. Changes in the brief created difficulties in design and construction. In particular, changing from a speculative development to a home for the client's daughter mid-way through the design process forced a series of changes on the project team. In addition, a clearer brief at the start would have avoided issues with selecting ceiling finishes etc. Bere Architects would also have taken a more detailed approach to interiors if the fee from the start had reflected the type of project it would become.

There were also issues to do with a culture-clash between the client's small-scale developer's approach (getting a group of trades on site and managing them individually) versus the traditional contract approach with a main contractor coordinating all work on site. The latter requires clearer lines of communication, with formal instructions and improved documenting of work. Neither is necessarily better but mixing the two was problematic.

Where energy monitoring is needed, getting clear buy-in from clients for the process is essential. Although the client was on board, the occupant (his daughter) was reticent at first. Of course, she was more directly affected by monitoring, and this could have been handled better. She has generally been very supportive of the inevitable intrusions on her home.

One of the key messages for the client is that energy consumption can be higher than the design estimates because of the way the house is used – over heating, high appliances use, lights left on, etc.

At the Camden Passivhaus it appears the occupants are not using the blinds to avoid summer overheating. This is ultimately another message for the client – if shading devices are not used as intended then there is a much greater risk of the house becoming uncomfortable in summer. (Although in this case we understand that the occupant left the blinds up as they enjoyed the higher temperatures.) Arguably there is a need for another 'soft landings' type handover, with a graduated set of opportunities for the occupants to learn more about how to optimize use of their home – in different seasons, and providing information and feedback based on what they know already and how successful their home is in meeting their needs.

The occupants were provided with the O&M manuals for the house by the main contractor. An A1 format wall-mounted User Guide was also provided by the architects, as part of the initial occupancy Soft Landings process. This study has provided useful insights, which will be taken into account by the architects when they produce future User Guides – such as providing clear instructions for when and how to replace filters. The User Guide already has information about using blinds and summer night purge ventilation, so no changes are proposed to reflect the unexpected use of the blinds by these occupants.

## Conclusions and key findings for this section

1. Energy consumption can be higher than the design estimates because of the way the house is used – over heating, high appliances use, lights left on, etc.

2. If shading devices are not used as intended then there is a much greater risk of summer overheating.

3. There may be a need for another 'soft landings' type handover – with different levels of explanation of how to operate the house optimally according to how much experience they have and how the house is performing.

4. Try to avoid conflict on site by sticking to one form of management – either the formal approach of using a main contractor, or the less formal approach of employing trades people direct and giving individual instructions. It is a mistake to mix the two.

5. Explicit support from the client for achieving passivhaus standards, and particularly certification, is invaluable.

# 9 Wider Lessons

| | |
|---|---|
| **Technology Strategy Board guidance on section requirements:** | This section should summarise the wider lessons for the industry, clients / developers and the supply chain. These lessons need to be disseminated through trade bodies, professional Institutions, representation on standards bodies, best practice clubs etc. Provide a detailed insight in to the emerging lessons. What would you definitely do, not do, or do differently on a similar project. Include consideration of costs (what might you leave out and how would you make things cheaper); improvement of the design process (better informed design decisions, more professional input, etc.) and improvements of the construction process (reduce timescale, smooth operation, etc.). What lessons have been learned that will benefit the participants' businesses in terms of innovation, efficiency or increased opportunities. As far as possible these lessons should be put in layman's terms to ensure effective communication with a broad industry audience. |

## Learning points from the project

One conclusion from this project is that it is possible to build to very high construction standards in the UK – dramatically better insulation and airtightness than the minimum requirements of current Building Regulations. For the foreseeable future, this may not be possible without close scrutiny by architects or other suitably-qualified and experienced people. In projects where architects are involved (and empowered), it is up to them to make sure that contractors meet the standards – or to ensure someone else will do this.

The architect also feels that we need more specialist contractor training in the UK – possibly as an advanced extension to the CEPHUS (Passivhaus) training. While there is a large body of expertise in Passivhaus design and construction in Germany and Austria, it is possible to involve people and firms from these countries to help transfer knowledge here. There is also a growing community of Passivhaus contractors and specialists here in the UK.

Another major learning outcome is that occupants cannot be relied on to behave as designers and builders expect – notably with the use of shading devices, natural ventilation and lighting. Nevertheless, the architect points out that so far the Passivhaus design seems to be robust enough to provide warmer internal temperatures without unduly compromising energy performance.

The architect also learnt a lot about M&E services design and delivery. They said they learnt a lot through discussions with Alan Clarke about how to design services to minimise unregulated power consumption. The design team incorporated a number of novel ideas to minimise gas and electrical consumption. These ideas included introducing demand switches for bathroom towel radiators to avoid them being left on for longer than two hours at a time, and introducing a means by which the small gas boiler in the combined solar hot water system could in fact also supply the small specific heat demand of the house.

However, issues arose with the plumbing when the client's own plumbing subcontractor was reluctant to set out pipework to allow for insulation. The architect had difficulties getting the plumber to accept that small-bore pipework would be acceptable for the domestic hot water and towel radiators. The plumber tried to persuade the client to overrule the design but on the whole the plumbing design prevailed. The demand switches for the towel radiators were another bone of contention. The plumber persuaded the client to agree to installing a simple time switch instead of a demand switch and the architects ended up expending a lot of time and energy persuading the client to reinstate the original design.

Also, incorporating the detailed design of the electrical services within the Contractors Design Portion (CDP) did not work well on this project. This was not because the electrical services were complicated but because the specification of LED fittings was new to the contractor and the client's own electrical subcontractor – the latter seemed unable to take on new challenges.  Using LED lighting confused the electrical subcontractor, who wired the circuits for conventional lighting.

The wiring problem was only found at second fix, by which time the finishes were complete and the wiring was inaccessible. Normally rectifying this would have been the main contractor's responsibility but in this case the electrical subcontractor was employed by the client, who understandably did not want to pay to correct the mistake. The result is that downlights in the living room are too dim. This means the occupant seldom uses the downlights, relying on linear lighting to provide background light. (As an aside, the original lighting design only included four spots over the coffee table and staircase, but the client increased the number of downlights.)

## Messages for other designers

During the early design stages Bere worked closely with the PHPP (Passivhaus planning package). This was the first time they had done this and they found it essential in helping to achieve the Passivhaus standard.  They also worked closely with a two-dimensional static thermal modelling software, HEAT2, analysing all of the building details, which again helped to achieve the Passivhaus standard and in particular to understand the reality of 'thermal bridge free' construction.  There are a number of PHPP courses available in the UK.  The architects are self taught in using

HEAT2 and are not aware of specific training courses but note that these probably do exist in the UK.

During the design stage it is important to make the line of airtightness (air barrier) explicit and rational, and link this to the overall design strategy for the building. This was Bere's first Passivhaus project and they learned a lot about achieving airtight construction through prior research in Germany and Austria and by knowledge transfer from the Austrian timber frame company and German window manufacturer. For all future projects they intend to draw the air barrier in red so it is clear to all builders and subcontractors. They also learnt that it can be hard to maintain the high standards required for Passivhaus on site, so having a dedicated airtightness champion or a person with Passivhaus experience is important.

Making sure the contractors know what they are expected to do and having someone to show them how to achieve the standards and details required also emerged as fundamental to achieving passivhaus construction. It is important for the architect to take an active role on site and to transfer knowledge to the site team.

## Conclusions and key findings for this section

1. Pre-fabricated timber frame buildings can achieve exemplary heat loss: both fabric and infiltration heat losses are negligible in this house.

2. Occupants do not behave as you would expect – which has major implications for services design, and particularly overheating calculations based on 'rational' use of solar shading, night- and daytime ventilation.

3. Passivhaus design appears to be robust enough to achieve low energy consumption even if occupants deviate from expected behaviour.

4. Passivhaus specialists are available in Germany and Austria to support knowledge-transfer, and there is a small but growing community of suitable designers, contractors and specialist sub-contractors here in the UK.

5. It is important to show the air barrier on drawings and communicate the importance of the air barrier to all trades and site operatives.

6. Having a dedicated airtightness champion or someone with Passivhaus experience on site is important.

7. Similarly, having someone on site to show contractors how to achieve the standards and details required is critical.

8. The architect needs to take an active role on site and to transfer knowledge to the site team.

9. Designers should not assume that solar thermal systems will be installed as designed, and should check orientation and rotation on site post-completion.

10. Balancing the heating is more difficult in a home with MVHR, since heat is normally provided along with fresh air. There is a conflict in trying to provide higher living room temperature along with more fresh air in the bedroom.

11. It is essential to provide a straightforward manual for occupants – especially when installed ventilation and heating systems diverge from traditional UK systems.

12. Avoid allocating the design of electrical services in the Contractor's Design Portion – this limits scope for integrating electrical services with other aspects of design, and may jeopardise strategies for limiting electricity consumption.

# 10 Appendices

| **Technology Strategy Board guidance on section requirements:** | The appendices are likely to include the following documents:<br>• Initial energy consumption data and analysis (including demand profiles where available)<br>• Link to the BUS occupant survey and topline summary results<br>• Additional photographs, drawings, and relevant schematics<br>• Background relevant papers |
|---|---|

## Appendix 1: User Guide

# Appendix 2: Thermal Bridge Calculations

| Summary | | | | | | | |
|---|---|---|---|---|---|---|---|
| Group Nr. | Area Group | Temp Zone | Area | Unit | Comments | Building Element Overview | Average U-Value [W/(m²K)] |
| 1 | Treated Floor Area | | 99.02 | m² | Living area or useful area within the thermal envelope | | |
| 2 | North Windows | A | 0.00 | m² | Results are from the Windows worksheet. | North Windows | |
| 3 | East Windows | A | 0.00 | m² | | East Windows | |
| 4 | South Windows | A | 32.26 | m² | | South Windows | 0.744 |
| 5 | West Windows | A | 6.55 | m² | | West Windows | 0.850 |
| 6 | Horizontal Windows | A | 0.00 | m² | | Horizontal Windows | |
| 7 | Exterior Door | A | 0.00 | m² | *Please subtract area of door from respective building element* | Exterior Door | |
| 8 | Exterior Wall - Ambient | A | 120.55 | m² | *Window areas are subtracted from the individual areas specified in the "Windows" worksheet.* | Exterior Wall - Ambient | 0.110 |
| 9 | Exterior Wall - Ground | B | 60.75 | m² | *Temperature Zone "A" is ambient air.* | Exterior Wall - Ground | 0.122 |
| 10 | Roof/Ceiling - Ambient | A | 91.19 | m² | *Temperature zone "B" is the ground.* | Roof/Ceiling - Ambient | 0.089 |
| 11 | Floor Slab | B | 76.64 | m² | | Floor Slab | 0.103 |
| 12 | | | 0.00 | m² | *Temperature zones "A", "B","P" and "X" may be used. NOT "I"* | | |
| 13 | | | 0.00 | m² | *Temperature zones "A", "B","P" and "X" may be used. NOT "I"* Factor for X | | |
| 14 | | X | 0.00 | m² | *Temperature zone "X": Please provide user-defined reduction factor ( 0 < f, < 1):* 75% | | |
| | | | | | | Thermal Bridge Overview | Ψ [W/(mK)] |
| 15 | Thermal Bridges Ambient | A | 129.58 | m | *Units in m* | Thermal Bridges Ambient | -0.008 |
| 16 | Perimeter Thermal Bridges | P | 36.18 | m | *Units in m; temperature zone "P" is perimeter (see Ground worksheet).* | Perimeter Thermal Bridges | -0.072 |
| 17 | Thermal Bridges Floor Slab | B | 23.50 | m | *Units in m* | Thermal Bridges Floor Slab | 0.044 |
| 18 | Partition Wall to Neighbour | I | 0.00 | m² | *No heat losses, only considered for the heat load calculation.* | Partition Wall to Neighbour | |
| Total Thermal Envelope | | | 387.95 | m² | | Average Therm. Envelope | 0.164 |

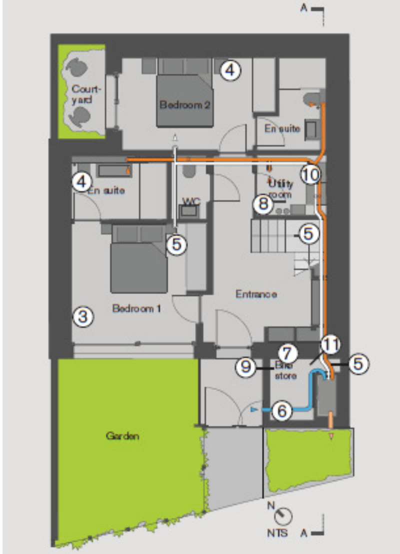
| Thermal Bridge Inputs | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nr. of Thermal Bridge | Thermal Bridge Description | Group Nr. | Assigned to Group | Quantity | x ( | User Determined Length [m] | - | Subtraction User-Determined Length [m] | )= | Length ℓ [m] | Input of Thermal Bridge Heat Loss Coefficient W/(mK) | Ψ W/(mK) |
| 1 | 1)flat roof-roof window | 15 | Thermal Bridges Ambient | 1 | x ( | 7.05 | - | | ) = | 7.05 | 1)flat roof-roof window | 0.043 |
| 2 | 14)slab upstand | 16 | Perimeter Thermal Bridges | 1 | x ( | 13.40 | - | | ) = | 13.40 | 14)slab upstand | -0.045 |
| 3 | 4)front roof beam-1f wall | 15 | Thermal Bridges Ambient | 1 | x ( | 7.90 | - | | ) = | 7.90 | 4)front roof beam-1f wall | -0.090 |
| 4 | 6)balcony:door-gf wall | 15 | Thermal Bridges Ambient | 1 | x ( | 3.84 | - | | ) = | 3.84 | 6)balcony:door-gf wall | -0.081 |
| 5 | | | | | x ( | | - | | ) = | | | |
| 6 | 13)balcony:doors both sides | 15 | Thermal Bridges Ambient | 1 | x ( | 3.68 | - | | ) = | 3.68 | 13)balcony:doors both sides | -0.153 |
| 7 | | | | | x ( | | - | | ) = | | | |
| 8 | 8)1floor-wall | 15 | Thermal Bridges Ambient | 1 | x ( | 22.00 | - | | ) = | 22.00 | 8)1floor-wall | 0.001 |
| 9 | 9)back beam-sloping roof | 15 | Thermal Bridges Ambient | 1 | x ( | 7.05 | - | | ) = | 7.05 | 9)back beam-sloping roof | 0.021 |
| 10 | 10)retaining wall-slab | 16 | Perimeter Thermal Bridges | 1 | x ( | 22.78 | - | | ) = | 22.78 | 10)retaining wall-slab | -0.088 |
| 11 | | | | | x ( | | - | | ) = | | | |
| 12 | 12)wall-roof detail | 15 | Thermal Bridges Ambient | 1 | x ( | 11.76 | - | | ) = | 11.76 | 12)wall-roof detail | -0.046 |
| 13 | | | | | x ( | | - | | ) = | | | |
| 14 | | | | | x ( | | - | | ) = | | | |
| 15 | 32)1f wall-flat roof | 15 | Thermal Bridges Ambient | 1 | x ( | 1.67 | - | | ) = | 1.67 | 32)1f wall-flat roof | -0.052 |
| 16 | 33)intermed floor courtyard wall | 15 | Thermal Bridges Ambient | 1 | x ( | 4.71 | - | | ) = | 4.71 | 33)intermed floor courtyard wall- | 0.044 |
| 17 | 34)1f-sloping roof sides | 15 | Thermal Bridges Ambient | 1 | x ( | 9.33 | - | | ) = | 9.33 | 34)1f-sloping roof sides | -0.026 |
| 18 | | | | | x ( | | - | | ) = | | | |
| 19 | 35)1f timber stud | 15 | Thermal Bridges Ambient | 1 | x ( | 2.41 | - | | ) = | 2.41 | 35)1f timber stud | -0.052 |
| 20 | | | | | x ( | | - | | ) = | | | |
| 21 | | | | | x ( | | - | | ) = | | | |
| 22 | | | | | x ( | | - | | ) = | | | |
| 23 | | | | | x ( | | - | | ) = | | | |
| 24 | 15)gf corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 2.84 | - | | ) = | 2.84 | 15)gf corner vertical | -0.004 |
| 25 | 16)gf corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 3.15 | - | | ) = | 3.15 | 16)gf corner vertical | 0.060 |
| 26 | 17)gf corber vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 2.84 | - | | ) = | 2.84 | 17)gf corber vertical | -0.023 |
| 27 | 18)gf corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 2.84 | - | | ) = | 2.84 | 18)gf corner vertical | 0.032 |
| 28 | 19)gf corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 2.84 | - | | ) = | 2.84 | 19)gf corner vertical | -0.006 |
| 29 | 20)gf corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 2.84 | - | | ) = | 2.84 | 20)gf corner vertical | 0.056 |
| 30 | 21)id.18 gf corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 2.84 | - | | ) = | 2.84 | 21)id.18 gf corner vertical | 0.032 |
| 31 | 22)gf corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 2.84 | - | | ) = | 2.84 | 22)gf corner vertical | -0.022 |
| 32 | 23)id.22 gf corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 2.84 | - | | ) = | 2.84 | 23)id.22 gf corner vertical | -0.022 |
| 33 | | | | | x ( | | - | | ) = | | | |
| 34 | 24)1f corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 3.79 | - | | ) = | 3.79 | 24)1f corner vertical | -0.014 |
| 35 | 25)1f corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 4.37 | - | | ) = | 4.37 | 25)1f corner vertical | 0.075 |
| 36 | 26)1f corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 1.12 | - | | ) = | 1.12 | 26)1f corner vertical | -0.016 |
| 37 | 27)1f corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 1.12 | - | | ) = | 1.12 | 27)1f corner vertical | -0.007 |
| 38 | 28)1f corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 4.37 | - | | ) = | 4.37 | 28)1f corner vertical | 0.055 |
| 39 | 29.2)1f corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 3.79 | - | | ) = | 3.79 | 29.2)1f corner vertical | 0.000 |
| 40 | 30)id.29.2 1f corner vertical | 15 | Thermal Bridges Ambient | 1 | x ( | 3.79 | - | | ) = | 3.79 | 30)id.29.2 1f corner vertical | 0.000 |
| 41 | | | | | x ( | | - | | ) = | | | |
| 42 | 11.1)gf internal 120mm-slab | 17 | Thermal Bridges Floor Slab | 1 | x ( | 6.12 | - | | ) = | 6.12 | 11.1)gf internal 120mm-slab | 0.037 |
| 43 | 11.2)gf internal 80mm-slab | 17 | Thermal Bridges Floor Slab | 1 | x ( | 7.33 | - | | ) = | 7.33 | 11.2)gf internal 80mm-slab | 0.035 |
| 44 | 11.3)gf internal 120mm-slab | 17 | Thermal Bridges Floor Slab | 1 | x ( | 4.59 | - | | ) = | 4.59 | 11.3)gf internal 120mm-slab | 0.055 |
| 45 | 11.8)gf internal 80mm-slab | 17 | Thermal Bridges Floor Slab | 1 | x ( | 5.46 | - | | ) = | 5.46 | 11.8)gf internal 80mm-slab | 0.056 |
| 46 | | | | | x ( | | - | | ) = | | | |
| 47 | | | | | x ( | | - | | ) = | | | |
| 48 | | | | | x ( | | - | | ) = | | | |
| 49 | | | | | x ( | | - | | ) = | | | |
| 50 | | | | | x ( | | - | | ) = | | | |
| TBend | | | | | | | | | | | | |

# Appendix 3: Monitoring Guide

## Technology Strategy Board
## Building Performance Evaluation

## Camden Passivhaus, London

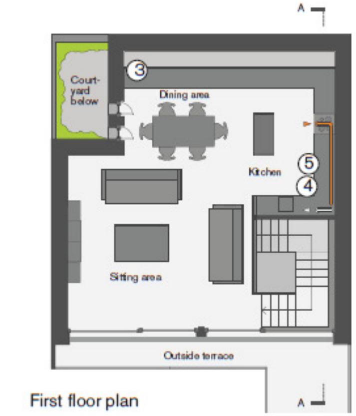

Camden Passivhaus south elevation



Ground floor plan

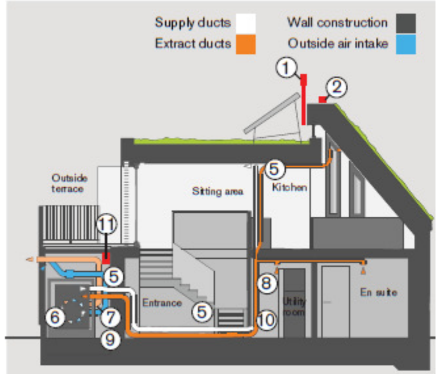
### Monitoring Guide

This guide locates the equipment which has been installed as part of the Technology Strategy Board's Building Performance Evaluation at the Camden Passivhaus. The Wireless Datalogging System was installed by Eltek (data logger specialists). Specialist heat flow meters were installed by a plumber and the electrical submeters were installed by an electrician.



First floor plan

Data can be viewed on the receiver logger's LCD display for instant system check or can be downloaded to a PC at UCL or bere:architects offices via a modem link. GSM communication is an ideal way of accessing the data in without disruption to the tenants. Data retrieval is carried out using Darca Plus software. This program is used to set up the system transmitters, the logger's channels, monitor and graph the data on screen in real time, and store the data for analysis and printout. Data is also exported to a spreadsheet for analysis and archiving.



Section A-A

### ① Weather

Vaisala weather station (WXT520), measuring the 6 most essential weather parameters; temp, rh, barometric pressure, wind speed/ direction & rainfall. The Vaisala is PV powered.

Mounted externally on a pole on the roof, fixed securely to the external cladding.

### ② Insolation

Kipp & Sonnen (CMP3) pyranometer monitoring solar radiation energy.

Positioned on the roof in an area where it will not be subject to shading from adjacent objects.

### ③ CO2, temperature & rh

Eltek wireless sensor (GD-47), requires an AC power supply. This sensor has built in rechargeable batteries for 100hr operation should AC supply fail.

Located in the living room and master bedroom.

### ④ Temperature & rh

Eltek wireless sensor (GC-10). No AC power supply required.

Located in the kitchen, master en-suite (with humidity protection) and second bedroom.

### ⑤ Temperature within ductwork

Eltek thermistor probes (ELCM-U-VS-03-0) for use with Eltek wireless temperature transmitter (GS-34).

Locatoions: HRV intake, supply, extract, and exhaust in bike store and duct heater under stairs, supply duct to master bedroom and supply duct to

### ⑥ kWh main electric meter

Elster electrical submeter (A100C) with 1Wh output. The output is pulsed to an Eltek wireless transmitter (GS-62) in the bike store.

Located within the electricity meter box in the bike store.

### ⑦ kWh Gas

G4-UGP secondary gas meter with 1inch bsp unions, 6m3/hr max, complete with pulse output. The output is pulsed to an Eltek wireless transmitter (GS-62) in the bike store.

Located in the bike store

### ⑧ kWh electric submeters

11 elster electric submeters (A100C) are used to meter; lights ground/ first, sockets ground/ first/ kitchen and utility, hob, oven, blinds and irrigation (plus one for the HRV located separately under the stair).

Located adjacent to the consumer unit within in the utility room. The outputs are pulsed to Eltek wireless transmitters (GS-62).

### ⑨ Total water use

Total water use is metered. The meter has a pulse output with the output pulsed to a wireless Eltek transmitter (GS-62) in the bike store.

Located on the incoming mains supply in the bike store.

### ⑩ Heat flow meters

ENER-G Ultrasonic heat meter (2WR6) with energy pulse output programmed to 0.1kWh. The output is pulsed to an Eltek wireless transmitter (GS-62) in the utility room.

Located on the following circuits within the utility room.; duct heater, towel radiator

### ⑪ Datalogger

Eltek receiver logger (RX250AL) with AC power supply, antenna and back up batteries. Records the monitoring data over time.

Located in the bike store, fixed securely to the wall.

### ⑫ Data logging receiver (GSM)

Eltek receiver (GSMPC) recieves monitoring data. This enables remote access to monitoring data using Vodaphone SIM cards.

These are located off site. One unit is located at bere:architects offices and the other at UCL.

For further information regarding these features:
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bere:architects (passivhaus specialists)
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E-mail: bere@bere.co.uk

Delivered with 'Details form passive Houses' by IBO Book

**References**

This report drew information from:

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BRE's (2011) Airtightness Testing Report

Alan Clarke's (2011) Review of Systems Design

Alan Clarke's (2011) Review of Monitoring Installation

Alan Clarke's (2011) Commissioning Report

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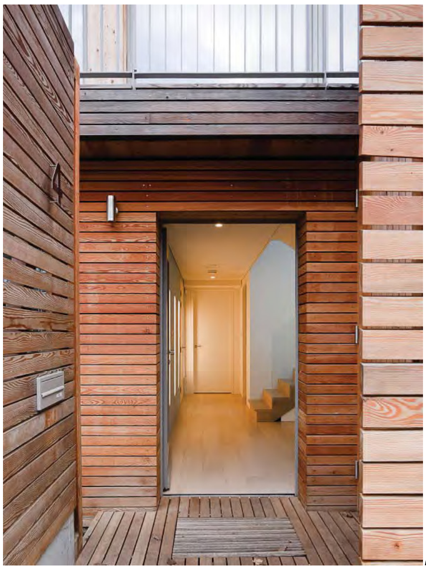
Ian Ridley/UCL (2011) Monitoring Report

Sam Stamp/UCL (2011) Monitoring of Camden Passivhaus

Welsh School of Architecture (2011) Design Review Passivhaus Project: Camden

## Photos

*North west courtyard, used to bring daylight into bedroom 2 and the dining area on the first floor*



*Main entrance showing the Austrian Larch cladding*

*First floor living and dining areas*

Photo: Tim Crocker


*South and east facades of the house*


*Master bedroom on ground floor, with external blinds down*

Photos: Tim Crocker