CASE STUDY

CAMDEN PASSIVHAUS

Building Performance Evaluation

Credit: Tim Crocker

The project reported here is part of the Technology Strategy Board's Building Performance Evaluation programme and acknowledgement is made of the financial support provided by that programme. Specific results and their interpretation remain the responsibility of the project team.

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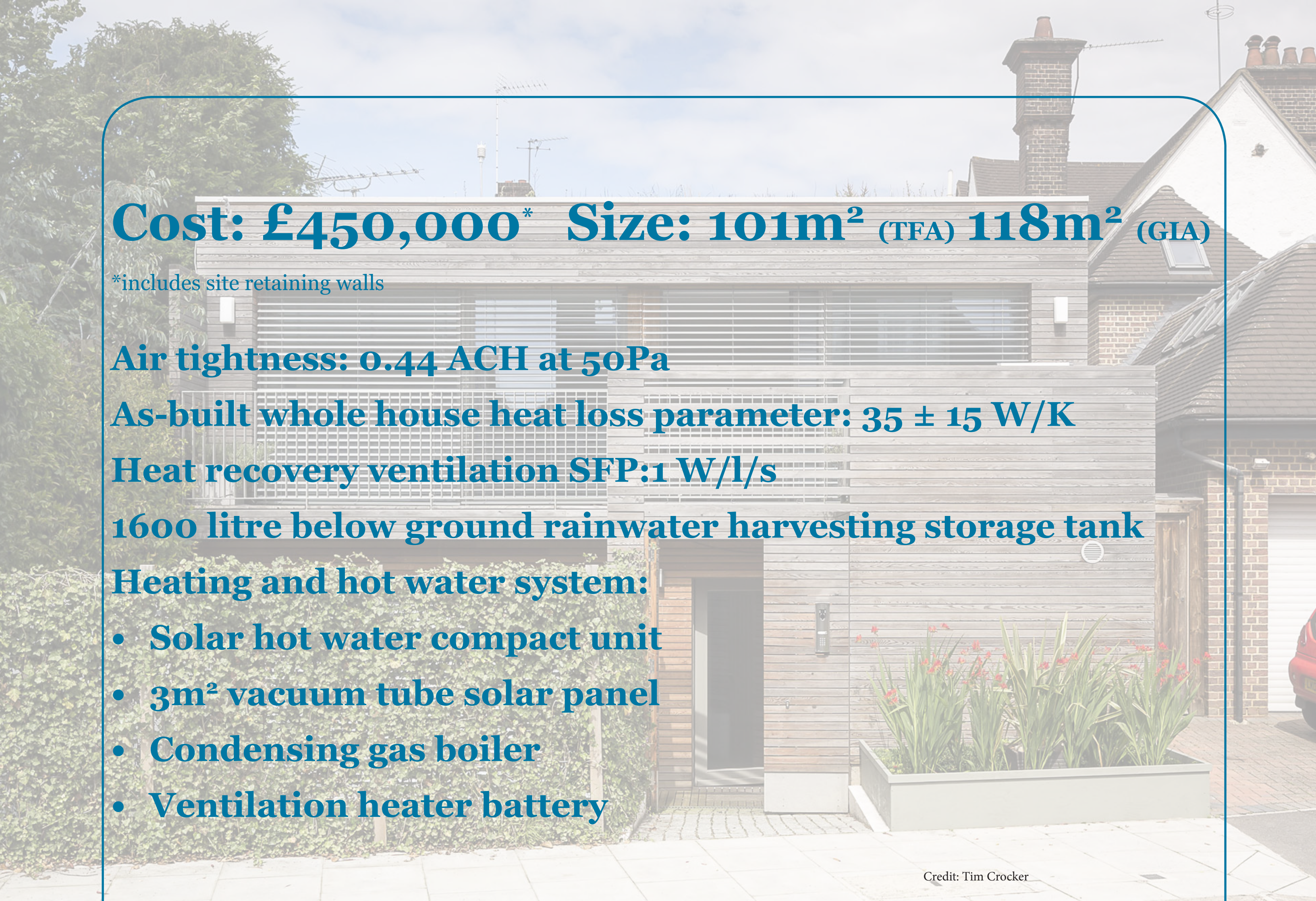


Cost: £450,000* Size: 101m^2 (TFA) 118m^2 (GIA)

*includes site retaining walls

Air tightness: 0.44 ACH at 50Pa

As-built whole house heat loss parameter: 35 ± 15 W/K

Heat recovery ventilation SFP:1 W/l/s

1600 litre below ground rainwater harvesting storage tank

Heating and hot water system:

- **Solar hot water compact unit**
- **3m^2 vacuum tube solar panel**
- **Condensing gas boiler**
- **Ventilation heater battery**

Credit: Tim Crocker

Delivery Team

Bere:Architects (Architect)
Alan Clarke (Building Services advisor)
Rodrigues Associates (Substructure)
Green Building Store (Ventilation advisor)
Kaufmann Zimmerei (Timber frame suppliers and engineers)
Visco (main contractor) with Dominic Danner (Air-tightness champion)

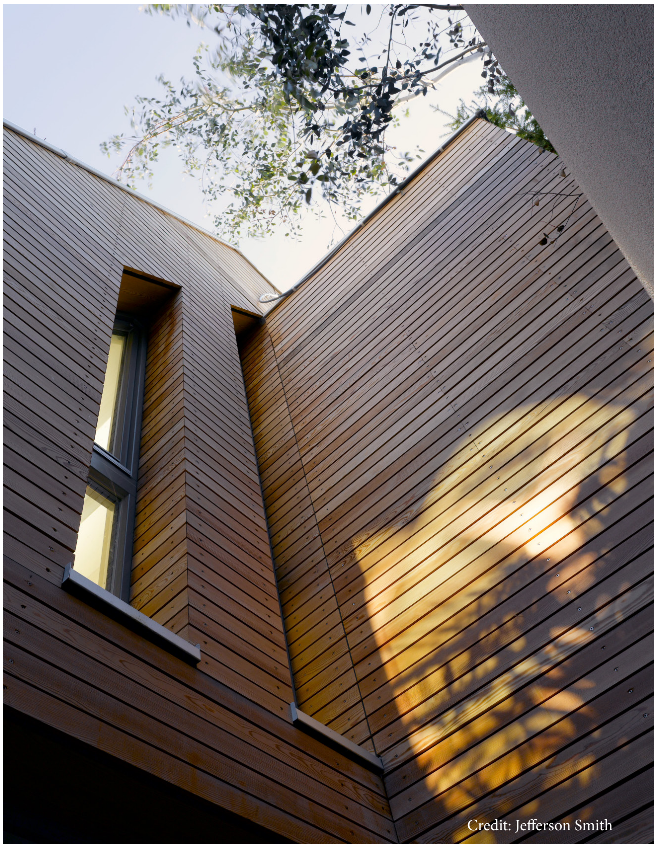
Evaluation Team

University College London
Jason Palmer
Bere:Architects
Good Homes Alliance

Credit: Tim Crocker

Introduction

London's first certified Passivhaus dwelling, this 101 m^2 (TFA) two-storey detached house in Camden, north London was completed in the spring of 2010, with the occupants moving in at the end of 2010. Camden Passivhaus incorporates heat recovery ventilation (HRV, or MVHR), extremely good insulation and air-tightness, and high performance glazing to create comfortable and healthy conditions, and minimise energy requirements.



Camden Passivhaus

Built on the site of a garage and garden on a residential street with predominately larger detached homes, construction started in September 2009 and the house was certified to the Passivhaus standard in April 2010. The occupants moved in during the following Christmas holidays. Following the Soft Landings process, Bere Architects maintained frequent contact with the client through all stages of the build process, and still retain regular contact both with the client and occupant.

This evaluation was conducted under the Technology Strategy Board's Building Performance Evaluation programme. The purpose of this programme is to assemble data from different new buildings so that conclusions about the effectiveness of different design types and construction and operational practices can be drawn, with the aim of disseminating knowledge to the wider house building sector.

To determine the effectiveness of the design and delivery strategy in Camden Passivhaus, real fabric performance indicators were tested to compare these results with anticipated performance. The project team followed the Technology Strategy Board protocols for fabric and services testing (Phase 1), conducting the following tests:

- Thermographic survey
- In-situ U-value tests
- Air-tightness tests
- Coheating test
- Services commissioning checks

The delivery process and occupant perceptions were also analysed.

Following on from this phase of fabric and service testing, Camden Passivhaus underwent a 2 year programme (Phase 2) of in-use evaluation, examining energy consumption and building services systems' performance over time. This study was completed in October 2013.

The results from the Phase 1 programme are positive. The building fabric has exceptionally low heat loss in line with design predictions and the occupants are very happy with their house.

Design Targets

The following design targets in Table 1 were set to in order to achieve overarching Passivhaus requirements.

Annual space heating	13 kWh/(m²a)
Primary energy	99 kWh/(m²a)
Whole house heat loss	63.6 W/K (PHPP)
Air permeability	≤0.6 ACH at 50Pa
U-value: roof	Flat roof 0.067 W/m²K, Sloping roof 0.116W/m²K Terrace 0.139W/m²K
U-value: walls	Lower 0.125W/m²K, Upper 0.116W/m²K
U-value: ground floor	0.103 W/m²K
U-value: windows	0.76 W/m²K
U-value: doors	0.78 W/m²K
MVHR: electrical efficiency	0.36 Wh/m³
MVHR: heat exchanger efficiency	92%
Boiler efficiency (SEDBUK)	89.4%

Table 1. Design Targets

Kaufmann Zimmerei factory

Construction

The house is built using a prefabricated timber frame, with the ground floor set within a concrete retaining wall, supporting earth at the back and sides of the house. Walls are timber framed and clad in Austrian untreated Larch. The roof and first floor structural decks are constructed from interlocking planks of cross-laminated timber in order to limit noise transmission between the floors.

The concrete substructure, including the retaining walls, was cast on site while the larch and spruce wooden superstructure and façade cladding was prefabricated in Austria. Bere used prefabricated systems because of the associated benefits of “fine tolerances, reduced construction times and minimised waste”, and they employed an Austrian technician well versed in both Passivhaus design and prefabricated timber buildings to help design and build the superstructure.

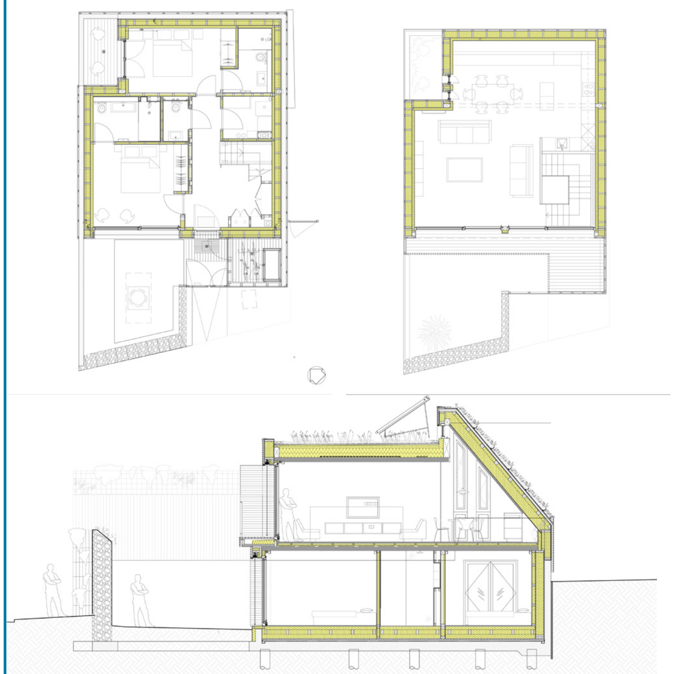
Passivhaus certified windows in living room

The house has two layers of insulation in the walls: 240-280mm of Rockwool Flexi between the timber studs, plus 100mm of natural wood fibre insulation inside the vapour control layer It has 400mm of PIR insulation on the roof and 400mm wood fibre insulation on the floor slab, and an airtightness membrane stapled and taped throughout, designed to achieve an air permeability of 0.6 ACH (at 50Pa). Calculated U-values for the roof, floor and walls vary between 0.07 to 0.14 W/m²K.

Triple-glazed, Passivhaus-certified windows were imported, designed to achieve U-values of 0.6 W/m²K (centre-pane) and 0.76 W/m²K overall (including frame). External automatic blinds were fitted to the large south-west facing windows to reduce the incidence of summer overheating and to provide more privacy.

Biodiversity was key in the overall concept design. There are two wild flower green roofs, a planted garden and, as designed, an ivycovered stone wall. Installing the green roofs was a planning condition, as was the general landscaping around the house.

The general layout is not traditional for homes in the UK. The ground floor consists of two bedrooms with private bathrooms, plus an additional WC, while an open-plan kitchen, din-



Ground and first floor layouts, elevation

ing room and living room are on the first floor. Large windows are essential to the passive solar heating strategy. As a result of the bedrooms being on the ground floor, and the large windows in the first floor living room, privacy became an important issue in the design of the house. The layout tries to maximise natural light on the first floor, where less privacy is needed.

Building fabric design

Passive House Planning Package (PHPP) was used to iteratively refine the design, estimating energy use in many different spatial configurations. U-values required to meet the Passivhaus standard were determined using this tool. PHPP was also used to work out the optimum position of the house and the best orientation for solar gains in the winter, but prevent overheating in the summer.

The initial sketch design achieved a low heat demand of 21.2 kWh/(m^{2}a) not low enough to meet the Passivhaus standard. Bere determined that this design had too much north glazing for a house this size, and the surface area to volume ratio was also too high, resulting in too much heat loss. After estimating energy use in the building in 14 different configurations, Bere selected one that did achieve the calculated 15 kWh/(m^{2}a), necessary to achieve Passivhaus certification, while still providing windows at the back of the house.

Due to the height restrictions coming from planning, Bere lowered the building up to 3 metres below the neighbouring gardens and designed the roof to have 400mm of insulation using high performing rigid foam with a thermal

Prefabricated frame placed in-situ

conductivity of 0.026 W/mK. This maximised thermal performance while limiting the build-up, yielding a calculated U-value for the roof of 0.067 W/m^{2}K. The ground floor was insulated with 400mm of natural wood fibre insulation with a thermal conductivity of 0.035 W/mK, resulting in a calculated U-value of 0.103 W/m^{2}K. The final design in PHPP predicted transmission heat losses for the roof elements to be 535 kWh/annum, while the losses through the floor slab were 278 kWh/annum.

The Passivhaus standard requires thermal bridges to be less than 0.01 W/mK, and any bridges unavoidably greater than 0.01 W/mK must be calculated and fed into PHPP to assess their impact on the overall energy use. Bere Architects used HEAT2 software to analyse and improve all junction details; the thermal bridging then inputted into PHPP was a negative sum. By using HEAT2 for all junctions in Camden Passivhaus, Bere now have a good understanding of the type of junctions which are the most difficult to hit the 0.01 W/mK limit.

To meet the stringent air tightness target, the contractor employed an “airtightness champion” to supervise on-site, to make sure the installation of the membrane was provided with a sufficient seal and that all details were constructed as they were designed. The airtightness champion also briefed workers from the construction team about the importance of airtightness.

Building services design

A Paul Thermos 200 heat recovery ventilation unit provides supply and extract ventilation, and according to the manufacturers, the heat recovery equipment is 92% efficient. This efficiency will be measured as part of next phase of the Technology Strategy Board study. Fine (F8) filters in the unit help filter out particulates and pollen to improve the air quality in the house – a main driver for the Passivhaus approach for the client whose daughter suffers from asthma.

The unit is housed in an insulated enclosure in the bike shed, which is attached to the building, but outside its thermal envelope. Originally the HRV unit was due to be located under the stairs. When it became apparent during design that more storage space was needed inside the house, it was moved to the cycle store. The ductwork connecting the HRV to the house is as short as possible to minimise thermal losses.

User controls for HRV speed are located in the main living space, and have three settings: low, normal and party. Summer by-pass is an additional option on the control panel. Controls are available to be used to reflect changes in occupancy, sustained for a few hours or more. Timed boost, manually selected by a button-press, is also provided in the bathrooms. Automatic heat-recovery bypass for use in the summer is also installed.

In addition to the ventilation provided by the HRV, openable windows in the bedroom and living space provide cross and stack ventilation for summer use, and enable the occupants to purge warmer air at night, in the summer months.

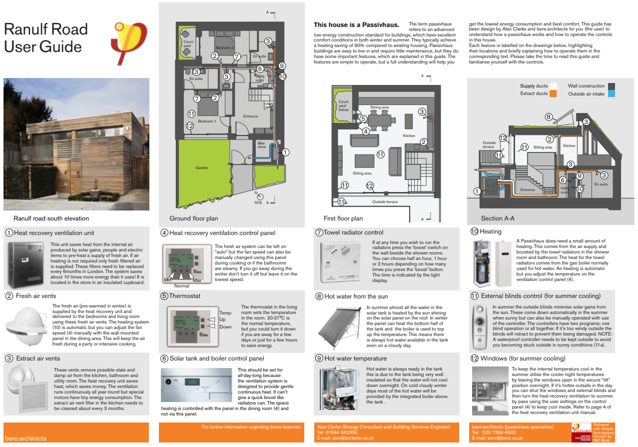
The heating system is classic Passivhaus, with the heat requirement provided through the air flow of the ventilation system. Supply air from the HRV is ducted to a heater battery located under the stairs, which is supplied with heat from a compact solar hot water unit, which has a small integral backup gas boiler.

In addition to the heat provided in the ventilation air, the boiler and solar combination also supplies heat to two towel rails in the bathrooms. This functions to enable higher temperatures in these rooms for comfort, but importantly also to increase the capacity of the heating distribution system. At ‘normal’ ventilation rate it is only just possible to meet the calculated peak heating load through the fresh air, so the towel radiators provide extra heating - a margin for error, and the ability to deal with extreme cold weather.

Hot water is provided from a cylinder which is an integral part of the Viessmann Vitodens boiler and solar panel system, located in the ground floor utility room. Heat to the cylinder is supplied by indirect heat inputs from the solar thermal system and topped up by the small integral gas boiler on the coldest days. An electric immersion heating element is also included in the unit for periodic pasteurisation.

Rainwater harvesting has also been installed, providing irrigation to the south garden and sloping green roof.

The occupants were provided with O&M manuals for the house by the main contractor. Additionally an A1 wall-mounted, pictorial User Guide was provided by the architects, as part of the Soft Landings process. In addition to descriptions of the mechanical systems, the User Guide has information about using blinds and summer night purge ventilation.



A1 User Guide

Delivery

As well as the prospect of low heating bills, the client was interested in good indoor air quality, as his daughter suffers from asthma. Based on both the low energy and good air quality advantages of the Passivhaus model, he agreed to embrace the standard and build London's first certified Passivhaus house.

The owner was also willing to implement as many low carbon technologies as possible, within his budget, and decided to incorporate a solar thermal panel, LED lights and rainwater harvesting into the building.

Part-way through design, the client changed the brief, announcing that his daughter would live in the house. The client's daughter and her partner, who both live in the house, did not become involved in the design until the final construction stages, and made some late changes, mainly to the interior design.

The procurement route was traditional, with selective tendering. Bere felt it was important that full control over the design was retained once construction began to ensure the airtightness and thermal performance of the building would meet Passivhaus certification standards.

The detailed design of the superstructure was done by Bere Architects, with input from Kaufmann Zimmerei, the Austrian timber supplier, who has experience delivering Passivhaus projects. For Camden Passivhaus they served as both structural engineer and contractor for the superstructure.

The house's main contractor, Visco, was from the United Kingdom. The Structural Engineers responsible for the substructure were Rodrigues Associates. After the substructure was in place, Kaufmann Zimmerei constructed the superstructure 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. This meant that Bere had to spend extra time on site to make sure that the Passivhaus standard was met.

Frustrations arose between the onsite 'airtightness champion' and some of the other members of the contracting team (mainly the building owner's own M&E contractors), when extra care for tasks was not understood. Despite this, the delivery team felt that it worked well for an airtightness champion to be employed by the main contractor.

Bere now adopt the Soft Landings process in all of their projects, and this was one of the first projects where they followed this protocol. Bere say they will stay in touch with the occupants through the first 2-3 years of occupation, beyond the timeline of the Technology Strategy Board study.

When the house was complete and handed over to the client, the architects provided the occupants with a bespoke designed User Guide with information about how to manage the building. This was permanently mounted behind the door to the utility room. Bere also visited the house after the occupants had moved in and discussed the M&E design philosophy, explained the controls and demonstrated how to change the ventilation filters.

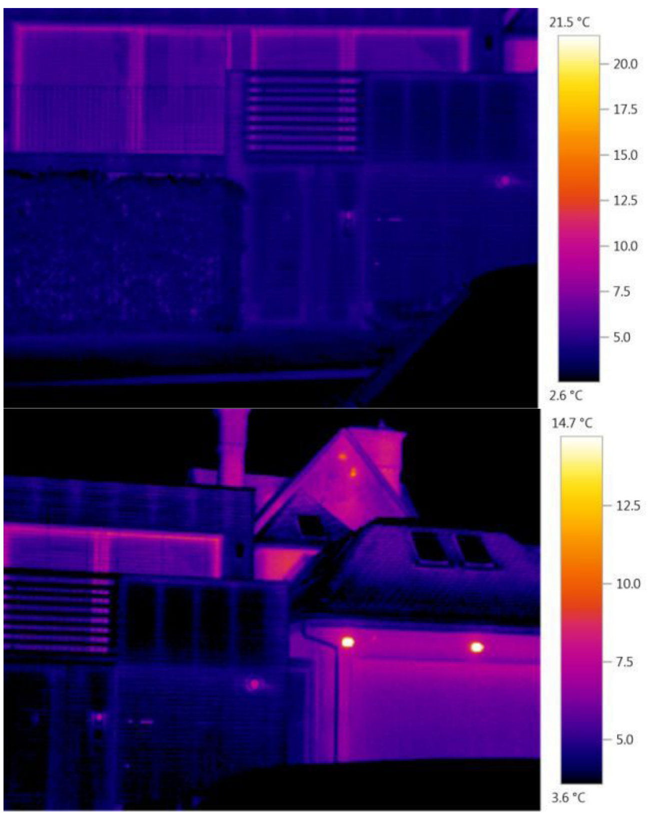
Real performance

	Predicted	Real
Whole house heat loss coefficient	63.6 W/K (calculated in PHPP)	35 ± 15 W/K for both ventilation and fabric losses
Air permeability	0.6 ACH @50pa	0.40 $m^3/(m^2h)$ and 0.44 ACH at 50 Pa
Ground floor slab	0.103 W/m^2K	0.099 +/-0.013 W/m^2K
Lower Wall	0.125 W/m^2K	0.097 +/-0.020 W/m^2K
Roof	0.067 W/m^2K	Not tested to avoid damaging ceiling finishes

Table 2. Closing the Performance Gap.

Building Fabric

Bere Architects carried out a thermographic survey on the 1st April 2011 during the Co-heating test when the indoor spaces were heated to an elevated temperature of 25°C, in order to accentuate cold bridging and make any easier to find. The study revealed at most only a few very minor thermal bridges. Any bridges that were found were expected from design psi calculations.



Thermal images

University College London performed the main fabric testing. They used heat flux meters to look in detail at the thermal performance of the lower walls and floor insulation. They found that both marginally out-performed the design intentions (see Table 2 above).

Paul Jennings, air leakage specialist at GAIA Aldas, conducted a final airtightness test on completion of the building contract as part of the certification process on 24th March 2010. The test revealed a result of 0.40 m^3/m^2hr at 50 Pa (0.44 ACH at 50 Pa). This value is around a twenty-fifth of the leakage of the minimum required in Building Regulations.

BRE did an airtightness test (both pressurisation and depressurisation) on 7th September 2011 as part of the Technology Strategy Board programme. It had already been occupied, and all air inlets and extracts were temporarily sealed. This test yielded a result of 0.53 m^3/m^2h at 50 Pa (0.59 ACH at 50 Pa).

This bettered the design target of 0.6 ACH, but was slightly higher than the Passivhaus certification test undertaken just after completion. Smoke tests identified a small area of leakage around the front of the house, where a new services cable had been installed. The design team had included a special sealed conduit for new services, however when the cable was installed the installer had not re-sealed the conduit - this repair was subsequently carried out.

A Coheating test was carried out at the Camden Passivhaus for 13 days between the 20th March and 1st April 2011. The purpose of the test is to assess the total heat loss coefficient of the building, to be compared with its designed value calculated in PHPP. A whole house heat loss of 35 ± 15 W/K (ventilation and fabric losses) and 33 ± 12 W/K for fabric losses alone was found. This compares favourably with the designed value of 65.4 W/K (whole house heat loss) and the value of 63.6 W/K for fabric losses alone in the Passivhaus design package (PHPP) and suggests the building is performing within its designed thermal heat loss. The large error in the tested values stems from problems conducting the test, namely the large amounts of warm and sunny weather during late March 2011. It should be noted that there may be additional systematic errors that create further bias in this result.

Building Services

The ventilation unit's Specific Fan Power (SFP) was measured at around 1W/l/s. At a measured 1 W/l/s this exceeds the SAP Appendix Q figure for this particular unit of 0.6 W/l/s but translated to the Passivhaus units of measurement (the testing methods differ as

Ventilation system testing

well), the in-use figure of 0.3 Wh/m3 is slightly better than the Passivhaus Institute's tested figure of 0.36 Wh/m3, which was the figure used in the design.

Alan Clarke tested the heating and ventilation systems on 31 January 2011. Room temperature was found to be 19-20°C and an external temperature of 7.5°C; the heating was not on, demonstrating good heat retention. Testing the mechanical systems, Alan found they were functioning correctly, although the towel rail needed bleeding and there was missing insulation on a duct heater and some pipework.

Operation of heating was also checked at the on-site systems review. The heater battery was turned on using the ventilation controls. On the whole, the heating and ventilation systems were operating according to design.

Designing and commissioning heat delivery with ventilation air can be fairly complicated, requiring highly skilled design and commissioning engineers. As fresh air is carrying the heat, the more air delivered the more heat you get. However, if there is a desire to keep the living area warmer than the bedrooms this can be difficult to achieve. Unlike with a radiator system and TRVs, there is no option to reduce heating supplied to particular rooms where heat is supplied through the air.

In Camden Passivhaus the fresh air provision was commissioned to supply 50% each on the ground and first floors. Despite equal air distribution, the 'upside down' arrangement of the house (with bedrooms downstairs) could help with buoyancy in potentially keeping the upstairs living room warmer than the downstairs bedrooms. Ambient temperature monitoring in the Phase 2 study will test this hypothesis.

Bere say they would use this system again. They believe this system works effectively and can provide cost savings by eliminating the need for a wet heating system. Since completing Camden Passivhaus, they have used air heating in other domestic UK Passivhaus projects.

Sensors showed that the Viessmann solar thermal system was not generating as much useful heat as expected. Examining the installation on the roof revealed that the panel was facing the wrong direction. 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. However, after work had begun on site the suppliers recommended to the contractor that the panel should be installed horizontally instead. The revised arrangement would now have the evacuated tubes running East-West, with each tube rotated approximately 30 degrees to the South, so the collector surface in each tube in angled towards the sun. This was recommended to prevent stagnation, a problem the suppliers had encountered in previous installations of this particular wet tube system. No new drawings were issued showing this change – however the contractor had confirmed that this variation would be picked up.

When inspected on site by the architect and building services engineer it was found that the panel had been installed horizontally with tubes running North-South. About a third of the tubes were still upside down, in the pre-commissioning arrangement. After questioning the contractor, it was found that Viessmann had gone to site to commission the system, and had clearly highlighted this problem to the contractor. The commissioning report had been issued to the main contractor, but a copy was not sent to Bere or the client. The panel

Original solar panel orientation

installation was subsequently corrected.

Occupant Perceptions

The occupant semi-structured interview, combined with the walkthrough, was carried out on the 20th of July 2011, with one of the two occupants. Bere architect Sarah Lewis also participated in the walkthrough, asking the occupant questions and giving suggestions how the house can be used in a more efficient and user-friendly way.

The house is occupied by a working couple, who are gone during most of the day. They moved into the house during Christmas 2010 holidays. They were generally satisfied with the handover process and found the large pictorial user manual, located inside the utility room, to be easy to understand and very useful.

"It's absolutely beautifully warm in here and zero degrees outside. And it's always got that lovely sort of ambiance in here - it feels really warm and comfortable and fresh"

- Occupant

The occupants like the aesthetics of the house and are happy with room sizes, but stated that the house may not be large enough if in the future they were to have a family with two children or more.

The occupant considers the house to be easy to maintain. She understands the general principle of the ventilation system and is aware that the filters in the HRV unit need to be changed regularly.

She is satisfied with the HRV system, noting that it is responsive and easy to use. The ventilation is only occasionally increased by using the boost control in the bathroom after showers. There are no reported problems with humidity. The ventilation rate is never adjusted using the main controls, even when the number of people increases; they prefer to open a window to get additional fresh air when desired. The occupant did voice concern with sound travel underneath internal doors - these gaps are necessary for air distribution in the ventilation system.

The occupants appear to like higher summer indoor temperatures, and generally high indoor temperatures throughout the year. 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 20-22°C range. Bere believes that the occupant was acclimatised to much higher temperatures in her parents' house, kept at 24-25°C, but think she believes her house to be warmer because of higher surface temperatures. Although the house is kept higher than designed for, Bere are still confident that this design is robust enough to maintain these higher than usual internal temperatures and still achieve high energy performance. This was verified by testing higher internal temperatures in the PHPP. The heating demand increased very little.

According to the architect, mechanical ventilation is used during the summer with heat recovery bypassed. This is reportedly easy to do using the control panel in the living room. Windows are opened for cooling during the day, but at night the occupant prefers to keep the windows closed and uses a fan. The architects suggested tilting-open the window, but the occupant prefers not to because they do not feel safe with the window open in a bedroom on the ground floor, despite the windows being secure when tilted. The occupants said the external blinds on the large living room windows are always kept down while they are at home for privacy, at all times of the year.

Living room and kitchen, first floor

The Camden Passivhaus scored very well in the Building Use Survey (BUS), although results are different from most BUS studies because only one person (out of two living there) completed the survey. The occupant appears to be happy with nearly all aspects of thermal comfort, with only some concern about the summertime temperature. The respondent said: “Gets too hot at night - can leave window open but then no control of temperature so may get too cold.”

Process Review

Observations from the design and delivery team painted a generally positive picture about procurement. The architects said: “The rigorous and detailed design requirements needed for Passivhaus certification are easily fulfilled by an experienced architect.”

The project team commented about what could have been improved on the project. They said the client’s own M&E subcontractors showed disregard for the PH standards and quickly fell back into old habits if not constantly monitored. Since the M&E subcontractors were directly employed by the client, Bere had no contractual influence over them. Frustration sometimes arose between the main contractor’s site team and their air tightness champion, Dominic Danner, who was monitoring quality on site. While the main contractor wanted to obtain the Passivhaus standard, they were less willing to adapt their construction methods to suit, or to be delayed by waiting for the client’s own M&E contractors to correct their work. Where Passivhaus goes beyond Building Regulations it proved challenging to get some subcontractors to understand why Passivhaus should be adopted.

Dominic experienced difficulties with some sub-contractors. 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’ – responsible for M&E integration from design through to construction.

The main contractor stated 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.” They noted that design variations were particularly expensive with Passivhaus, and it is more important than usual to keep variations to a minimum, even if this means starting on site later. As the contractors’ site management and office-based staff did not always understand the complexities of Passivhaus, they recognised that people managing site work need to accept that more exacting work is needed.

The project team also made suggestions about how problems could be resolved in the future. They felt that more control is needed on site than usual and the construction industry generally needs to improve skills to achieve the demands of Passivhaus construction. This includes budgeted cost specifically for inspection.

The client was always supportive of achieving certification. He appreciated the commercial, comfort and health benefits of certification (over the environmental), including increased value, improved quality of workmanship, and increased longevity of the building.

Credit: Tim Crocker

Key Observations

1. The design and detailing have achieved a high standard of air tightness and heat loss, greatly improving upon Building Regulations standards.
2. Thermography indicated that the building has no unexpected cold bridging.
3. The heat recovery ventilation system was designed and commissioned to a high standard and appears to be performing correctly.
4. Bere felt working in PHPP during the early design stages was essential in achieving the Passivhaus standard upon completion.
5. SAP and PHPP yield very different estimates of fabric and infiltration heat loss.
6. Better skills and coordination are needed in the construction supply chain concerning Passivhaus standards in order to help lower the cost of Passivhaus delivery.
7. There were complications and knock-on effects with the main contractor under-pricing the M&E work, due to their in-experience with Passivhaus.
8. Having a dedicated airtightness champion or a person with Passivhaus experience on site was invaluable.
9. Balancing the heating is much more difficult in a home with MVHR, when heat is provided along with fresh air, but was achieved on this project.
10. The filters for the MVHR were visibly dirty after six months' use and were replaced.
11. The heat meter in the solar thermal system package assumes a default flow and it was decided to check this as part of the BPE study by installing an additional meter.
12. Traditional standards of construction and methods of installation (eg windows) are often of insufficient for Passivhaus specification. If identified at a late stage, this may increase costs substantially. For example, the electrical contractor was confused by LED lighting, and wired the circuits for conventional lighting. Additionally the plumber installed copper pipes at standard spacing centres, which did not accommodate the specified Passivhaus pipe insulation requirement.

Key Lessons Learned

1. To help with the uptake of new construction skills, it helps if the architect takes an active role on site and assists in knowledge transfer to the site team.
2. Making the air barrier explicit on drawings helps reduce errors on site.
3. Owners should try to elect designers and contractors with sufficient experience or understanding of Passivhaus if they wish to achieve certification of their project, as design and site work requires meticulous detailing and execution, and greater site supervision than usual.
4. Contractors on Passivhaus projects must have high quality site management and supervision in place to meet the demanding standards of airtightness and insulation. Construction of Passivhaus projects requires a different attitude on site.
5. A late change to specialist equipment should be issued with drawings to show the revision in order to help the contractor implement the change.
6. Contractors should ensure that commissioning reports are sent to the design team as well as client or main contractor.
7. To be more confident in the results and decrease associated error, Coheating tests should be carried out between November and February to minimise the effects of solar gains which can make accurate analysis difficult to achieve.
8. Passivhaus specialists are available in Germany and Austria for support, but there is now a growing community of designers, contractors and specialist sub-contractors in the UK.
9. Providing a straightforward manual for occupants, beyond standard manuals, is helpful for occupants.
10. Having M&E expertise within the architectural practice is advantageous for integrated Passivhaus design, and a focussed 'Process Technologist' on the construction site will help the contractor with the installation and commissioning of building services.

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