BPE Dissemination

Camden Passivhaus – The case study

This 101 m2 (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. It is London's first certified Passivhaus dwelling, 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. Photo credit Tim Crocker

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.

A two year evaluation of this dwelling is currently being 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

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

Building type, sector and stage

Building type :
Domestic
Non domestic
New build
Refurbishment
Sector :
Private new build
Social housing new build
Schools
Office
Industrial
Other (Library)
Stage :
Post completion
Post occupancy
Under construction
In operation

disseminating knowledge to the wider house building sector and encouraging further evaluations.

To determine the effectiveness of the design and delivery strategy in Camden Passivhaus, real fabric performance indicators was compared 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
- Airtightness tests
- Co-heating 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 is currently undergoing a two year programme (Phase 2) of in-use performance, examining energy consumption and building services systems' performance over time. This study is due for completion 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.

Table 1. Building overview, project delivery team and Building Performance Evaluation team

Building Overview
Cost: £450,000, including site retaining walls
Size: 101m² (TFA) 118m² (GIA)
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
• 3m² vacuum tube solar panel
• Condensing gas boiler
• Ventilation heater battery

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
bere:architects
Jason Palmer
University College London
Good Homes Alliance

Design Targets

The following design targets in Table 2 were set to in order to achieve overarching Passivhaus requirements. The following design targets in Table 2 were set to in order to achieve overarching Passivhaus requirements.

Table 2: Design targets

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%

Construction

The house has 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 were prefabricated in Austria. bere:architects 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 pre-fabricated timber buildings to help design and build the superstructure.

Figure 2: Kaufmann Zimmerei factory.
Photo credit Kaufmann Zimmerei

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.

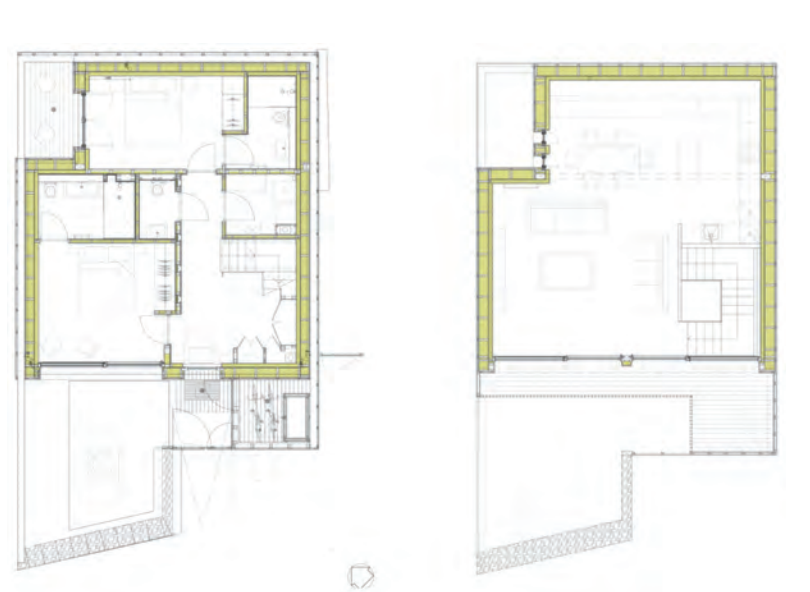

Figure 3: Ground floor and first floor layouts

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 ivy-covered 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, dining 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

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.

Due to the height restrictions coming from planning, bere:architects designed the building to be up to three metres below the neighbouring gardens and he roof to have 400mm of insulation using high performing rigid foam with a thermal 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/m2K. 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/m2K. 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.

Figure 4: First floor living room and kitchen. Photo credit Tim Crocker

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:architects now have a good understanding of the type of junctions which are the most difficult to hit the 0.01 W/mK limit. In a timber frame building like this it was the heavy structural elements, in this case those supporting the balcony and the clerestory windows that were the most troublesome.

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.

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.

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.

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 m3/m2hr at 50 Pa (0.44 ACH at 50 Pa).

BRE did an airtightness test (both pressurisation and depressurisation) on 7th September 2011 as part of the Technology Strategy Board's BPE funded programme. It had already been occupied, and all air inlets and extracts were temporarily sealed. This test yielded a result of 0.53 m3/m2h at 50 Pa (0.59 ACH at 50 Pa). This bettered the design target of 0.6

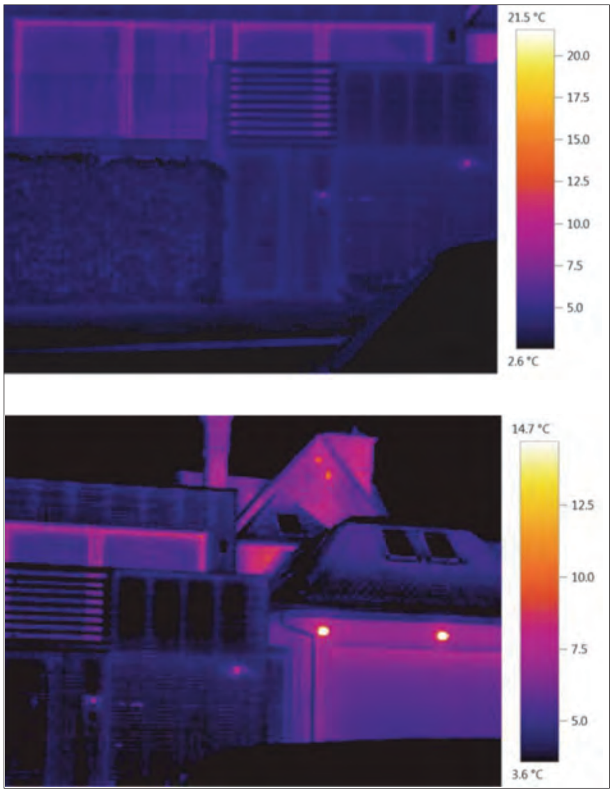

Figure 5: Thermal images

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 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 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 errors in the tested values stem 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

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. 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

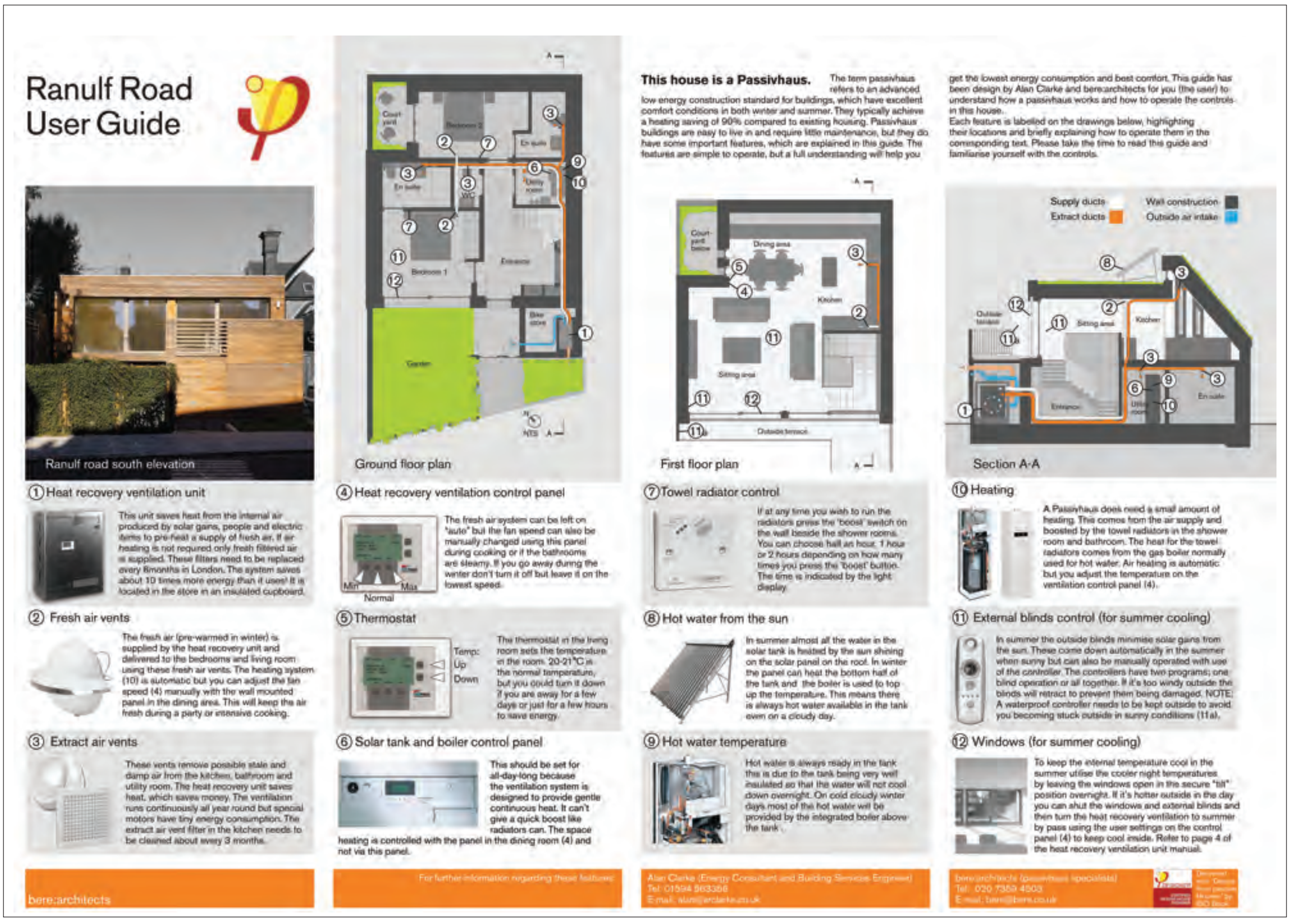

Figure 6: A1 User guide

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.

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 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.

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.

Figure 7: Ventilation system testing

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:architects say they would use this system

Figure 8: Initial Solar thermal orientation.
Photo credit bere:architects

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 way. 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 system. No new drawings were issued showing this change, but 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:architects or the client. The panel 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:architects' 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 in the utility room, easy to understand and very useful.

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 voiced 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:architects believe 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.

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.

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."

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.

The procurement route was traditional, with selective tendering. bere:architects 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:architects found the sub-contractors reluctant to employ new techniques. This meant that they 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:architects 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:architects 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:architects 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. 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:architects 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.

Conclusion

Table 3 below compares predicted values for heat loss performance against real, tested values. From testing it can be seen that Camden Passivhaus performs well, with real values equal or better than predicted values.

Key lessons learned

- 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.
- Making the air barrier explicit on drawings helps reduce errors on site.
- 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.
- 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.
- A late change to specialist equipment should be issued with drawings to show the revision in order to help the contractor implement the change.
- Contractors should ensure that commissioning reports are sent to the design team as well as client or main contractor.
- To be more confident in the results and decrease associated error, co-heating tests should be carried out between November and February to minimise the effects of solar gains which can make accurate analysis difficult to achieve.
- 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.
- Providing a straightforward manual for occupants, beyond standard manuals, is helpful for occupants.
- 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.

Table 3: Closing the performance gap

	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

Unique reference number	450023 (phase 1) 450049 (phase 2)
Name of project	Camden Passivhaus
Address	Ranulf Road
Post code	NW2 2BU
Procurement method	Traditional
Occupation date	December 2010
Project team	bere:architects, University College London, Jason Palmer , Good Homes Alliance
Contact details	Clients - Mr and Mrs Terry, Project lead – bere:architects
TSB evaluator name and details	Ian Mawditt , ian@fourwalls-uk.com
Floor areas	101m² (TFA) 118m² (GIA)
Fabric performance	As-built whole house heat loss parameter: 35 ± 15 W/K
Occupancy pattern	Professional couple
Energy calculations	13 kWh/(m²a) PHPP
Occupancy survey	
Carbon Buzz/ EST cross reference/ link	
url of project team	www.bere.co.uk
Key features	Passivhaus, Prefabrication, Timber frame, Triple glazing, Solar thermal, Heat recovery ventilation, Green roof, Rain water harvesting, Low Carbon, Natural materials