Building Performance Evaluation

Final report

Domestic Buildings

Phase 1: Post construction and early occupation

Larch House and Lime House, Ebbw Vale

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Contents

1 Introduction and overview

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.

These two homes built in Ebbw Vale, South Wales, were designed to achieve exemplary energy use. They were conceived as prototypes to show that it is possible to build social housing that meets the demanding Passivhaus standard. It is among the first low cost passive houses in the UK, and probably the first in Wales.

It is an exposed site in one of the wettest parts of the UK, with mist and cloud being particular issues.

Lead designers Bere Architects won the project in an open competition to design 'The Welsh Passive House'. The competition was managed by BRE (Wales) with EU and Welsh Government funding. BRE (Wales) partnered with Blanau Gwent Council, who supplied the land, and who hosted educational visits to the houses. Originally the visits were to last a year, but this was extended to 18 months due to very high levels of interest in the project.

United Welsh (Housing Association) were Executive partners in the project. UWHA commissioned Bere Architects to manage a construction contract to build the houses using one of their contractors, Pendragon Design and Build. A key requirement of the project was to demonstrate Welsh skills and manufacturing capabilities wherever possible, and to highlight opportunities for Wales to develop future-orientated, low carbon leadership in the construction industry.

The designers used slightly different approaches to certifying the two homes as passive houses, with one based around peak heat loads, and the other around annual heat demand. This provides a useful comparison of the approaches, which has not been possible elsewhere.

Larch House was built first – from March to July 2010 – and is timber-clad. It has larger windows on the south side, and was more expensive to build than Lime House. Lime House, as the name suggests, has lime render. It was built from June 2010 to March 2011, and has a different specification for quite deliberate reasons – to act as a comparison for both construction costs and performance.

Larch House is larger, at 99 m^2 – a three-bedroom house – while Lime House has just two bedrooms, at 78 m^2.

Both houses have solar water heaters on the roof. Larch House, being larger, has a 4m2 collector, while Lime House has 3.3m^2. They also both have photovoltaic panels on the roof to generate electricity: 4.7m^2 in Larch House, and 1.89 kWp in Lime House.

Larch House is a modern, timber-clad design with exceptionally low heat loss and excellent air tightness

Sadly there was a delay in finding tenants to live in the homes, which means that even they were unoccupied until April 2012. Clearly this presents problems for ‘in-use’ monitoring, but although the houses are not lived in, they are being used by visitors to Future Works.

Like other passivhaus homes, the Larch and Lime Houses both have mechanical ventilation with heat recovery, extremely good insulation and airtightness, high performance glazing, and (apart from small towel radiators in bathrooms) only air-side heating.

The houses have been designed to the Lifetime Homes standard, intended to be flexible and adaptable enough to support the changing needs of occupants at different stages of life. They are constructed from natural materials, requiring little maintenance and suitable for reuse or recycling at the end of their life. Bere also favour natural materials in order to achieve good indoor air quality.

The houses are built using a closed panel timber frame system developed by Bere with a local Welsh factory, Holbrook timber frame. Holbrook were most familiar with manufacturing and erecting140mm timber stud wall panels for Premier Inns around the UK. The design techniques resulted from Bere's 18 month knowledge-transfer with Kaufmann Zimmerei of Vorarlberg, Austria, where Bere learned about the latest developments in the most advanced timber framing techniques.

However, Welsh timbers are of smaller section than Austrian timbers, they are faster-growing and so poorer quality. Hence the frames of the two houses were designed specifically around the small-section, fast-growing timber sections commonly produced in Wales (typically no greater than 215mm). These took the place of larger, slow-grown timber studs typical in Passivhaus construction (often up to 280–300mm in section), which would otherwise have been imported from outside the UK.

U-values for the walls are low even by Passivhaus standards: external walls are 0.095 W/(m2K), the roof is 0.074 W/(m2K), and the floor slab is 0.076 W/(m2K). These exceptional insulation values reflect the ‘extreme’ climate data used during the Passivhaus design and certification process, see below. The full implications of this strategy are discussed in Section 2 of the report.

Overall Larch House has a heat loss parameter of 62 ± 4 W/K for both ventilation and fabric losses and Lime House’s HLP is 45 ± 2 W/K (Siviour analysis in both cases, incorporating solar gains). Air pressure tests were repeated one year after completion and they showed excellent air tightness test results of 0.26 and 0.54 m^3/m^2/hour (Lime House), at 50 Pa.

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

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. Complete this section with conclusions and recommendations.

Design rationale

The brief was to provide two homes of less than 100m^2 that would meet the Passivhaus standard as well as all usual requirements for social housing – if possible at a similar cost to usual housing association construction costs. Usual costs were estimated at £1200/m^2 (excluding prelims), based on the construction of a single building. Small developments, built in terraces, are expected to achieve significantly lower build costs than one-off detached houses.

Larch House

Larch House, Bere's first Welsh Passivhaus Social Housing prototype, was certified by the Passivhaus Institute and also achieves Zero Carbon, Code 6 of the Code for Sustainable Homes. This is a three-bedroom house designed to minimize annual heat demand (13kW/m^2/yr) with a peak heat load of 11W/m^2.

It is located 300m up in the top of a valley, with particularly cold and cloudy winters and relatively little winter sun. Due to the lack of passivhaus precedents for such misty and cold winter conditions, the BRE said the designs should use weather data based on a 'once in 10 years' extreme worst case scenario. At the time this seemed like a good idea, however Wolfgang Feist pointed out in a BRE presentation at Ecobuild 2011 that if normal weather data for the location had been used, only 100 Watts of extra power would have been needed to meet the extra heat demand for such an extreme event.

A paper presented to the International Passivhaus Conference (Justin Bere, 2011, see p.11 of this report) concluded that average weather data should always be used in future projects. The paper argued this would save over 10% of construction costs compared to 10-year worst-case weather data.

To meet the ‘worst case’ local climatic conditions Bere designed to in this project, the specification included 425mm of insulation in the walls, 480mm under the ground floor slab, and 560mm in the roof. The windows occupy 55% of the south elevation to maximize the potential for solar gains during the winter.

The house was designed to achieve excellent comfort and minimal energy bills even in extreme weather conditions, together with bright and airy interior spaces. However, the high quality windows are very large and therefore expensive, when compared to most UK low-cost social housing and these large windows require shading in summer. Both these factors adversely affected the build cost of the house when compared to the cost of average UK social housing.

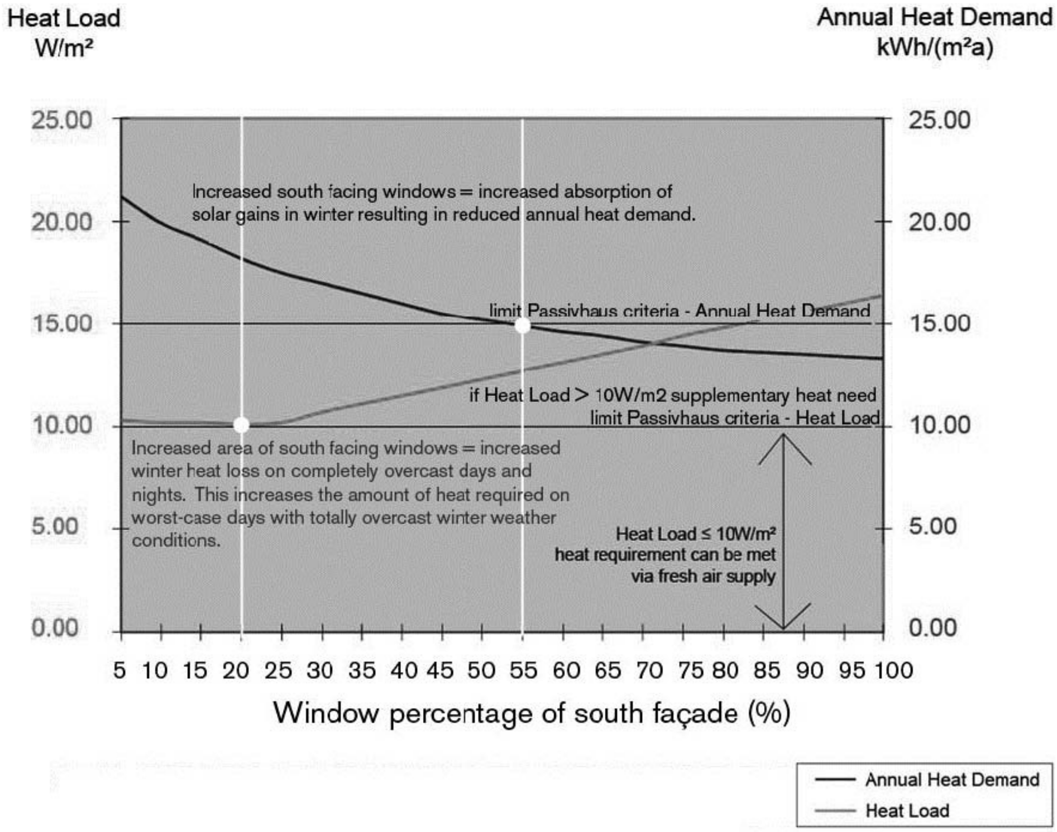
Lime House

So for Bere’s second Welsh Passivhaus Social Housing prototype, the Lime House, they wanted to find a way to overcome the costs associated with large windows and retractable blinds.

Lime House was also a certified Passivhaus, also using extreme 10 year ‘worst-case’ weather data, but it uses a different method of achieving Passivhaus certification, based on the peak heat load. (This is a new and less well-known method, which requires homes to use no more than 10W/m^2 of heat on the coldest expected day, instead of the more familiar 15 kWh/m^2 averaged over the whole year.)

When there is a shortage of sun, solar gains become less significant and internal heat gains become more important. To ensure the peak heat load remained below 10W/m^2 in an extreme weather event, Bere’s work using the Passive House Planning Package (PHPP) led them to reduce the amount of glazing, assuming the same fabric specification as the Larch House.

They found that reducing the south facing glazing to 20% of the elevation enabled them to keep the peak heat load below the limit of 10W/m^2 in the event of a 10-year peak (i.e. cold) weather scenario, while at the same time maintaining an acceptable annual heat demand (17kWh/m^2/a). This approach enabled them to rely primarily on air-side heating to meet the peak load. (See PHPP output files in the Appendices of this report.)



The team's work optimising the glazing on the south side found that a 20% glazing ratio was best when focussing solely on peak heating load, but 55% was best when focussing on the annual heat demand – as Passivhaus requires.

A design optimization graph produced by Robert McLeod (BRE) and Carine Oberweis (Bere) helped to understand the building physics that determined the glazing areas. This graph clearly showed two discrete optimisation points with respect to glazing areas – depending on whether Annual Energy Demand or Peak Load is being optimised.

The worst-case weather data for Ebbw Vale, produced by the BRE, is almost twice as demanding as either Manchester or Innsbruck mean data. With normal weather data, there would be a minor difference between the certification method based on annual heat demand and the one based on peak heat-load. However, this extreme weather data meant there was a much more pronounced difference between them.

It resulted in two very different design outcomes: the annual heat demand method seemed to prioritise solar heat gains, whereas the peak heat load method favoured internal heat gains and reducing fabric transmission losses. The peak heat-load method of design resulted in the cheapest building, mainly because smaller windows save window costs and, if the smaller windows do not require summer shading, the cost of blinds can be eliminated.

These elevations show Larch House's much higher glazing ratio (55%) on the south side, compared to Lime House's 20% south-side glazing ratio. The difference is down to different weather data used for certification.

The Lime House was also more economical because beneath the 10W/m^2 peak load, towel radiators were not needed in the bathrooms. Heat supplied through the low-volume 'hygiene' air supply (designed to minimise fan power use while maintaining low levels of airborne CO2 and optimum indoor humidity levels) was sufficient.

However, even in the Lime House, using extreme worst-case weather data resulted in costs that are prohibitive to the uptake of low energy housing by social housing providers in a period of low government expenditure. Since both houses proved very successful in maintaining comfortable conditions by air-heating in an unusually cold winter, Bere decided to investigate the savings that they could achieve in future using average weather data for Wales or the North of England. They also decided to check for any associated risks.

Using Manchester mean weather data, which is milder and less cloudy, would have allowed certification for a 33% glazing ratio for the south side of both homes. This would also have allowed a cheaper fabric specification.

When Bere re-designed the two houses with average (Manchester) weather data they found that this significantly reduced or even eliminated the difference between using ‘annual heat demand’ and ‘peak load’ in certification. Both certification methods allowed 33% south-facing glazing and an identical (reduced) fabric specification compared to the houses that were actually built. PHPP indicates that internal blinds would be sufficient to maintain comfort in summer.

Cost consultant Richard Whidborne then re-analysed the cost of the re-designed Larch House compared to the Royal Institute of Chartered Surveyors ‘BCIS’ database for a one-off detached house built in the previous 10 years.

Richard Whidborne found that Larch House, with worst-case weather data as built, cost 22% more than typical low cost housing. The extra cost came from:

- a 55% glazing to south elevation
- external solar blinds
- 425mm mineral wool in walls in three layers
- 560mm mineral wool in the roof, and
- 480mm expanded polystyrene under the ground slab.

Richard Whidborne then repeated the analysis assuming that Larch House had been certified with mean weather data. He used a revised fabric specification calculated using the normal 'average' weather data in the Passivhaus Planning Package (PHPP), rather than the extreme worst-case weather data that had been in the competition brief. This found that the construction cost for this less demanding scenario would have been significantly lower: just 9% more than typical low cost housing. Here the design would have included:

- 33% glazing to south elevation
- no solar blinds
- 240mm mineral wool in walls in only two layers
- 420mm mineral wool in the roof
- 240mm expanded polystyrene under ground slab.

It was clear that using average weather data would have saved a lot of money, but what about the risk of being unable to meet the heating requirement in extreme worst case weather conditions? To explore this, Bere put the 10-year worst-case weather data back into Option 2 (with the reduced fabric specification).

The peak heat load went up to 11W/m^2. This is just 1W/m^2 above the capacity of the air-side heating, and in a 100m^2 house equates to just 100 Watts. This is a very small additional heating demand that can be supplied by just one old-fashioned (incandescent) light bulb! Alternatively the heat could come from one emergency fan heater, or a towel radiator in the bathroom, which would supply the additional heat needed in an extreme 10-year worst-case weather scenario.

Bere concluded from this that in future it would be better, and more cost-effective, to design using mean local weather data rather than the 10-year worst-case scenario – with supplementary heating for periods of extreme or prolonged cold. This would bring considerable savings in construction costs for the fabric, and would make passive house standards more realistic for social housing in the UK.

Naturally, this would raise energy use and CO_2 when the extra heating is used, but the impact is probably small compared to the savings achieved from passive house designs overall. As in other aspects of low carbon design, the marginal savings from extra effort/cost tail off as standards are raised. It is almost certainly more efficient in terms of energy/CO_2 savings to persuade more housing associations that passive house designs are achievable and affordable than to insist on even higher fabric performance that deter many such developers from even trying.

Bere also concluded, based on considering other housing types, that terraced homes are more economical and therefore better-suited to social housing. Bere believes it would be more cost-effective to build passive house terraces than detached homes like Larch and Lime House.

A major objective of this project was to achieve comfortable and healthy homes while minimising energy use. 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.

Design and specification – the building

The competition brief was to design ‘The Welsh Passivhaus’. BRE Wales wanted cost-effective houses that would be replicable by housing associations – they did not want a ‘tick-box’ approach to sustainability. They wanted a ‘fabric first’ approach to saving energy rather than bolt-on technologies to generate energy.

The passive house methodology was chosen to predict the energy consumption of the winning scheme. The fundamentals of the passive house approach are to keep the heat load below 15kWh/m^2/y and to keep total primary energy use (that is, consumption including transmission losses) below 120kWh/m^2/y. These requirements reduce operational costs to a small fraction of normal building control requirements and the standard requires this to be achieved at the same time as providing a very high quality living environment, in terms of comfort and health.

The Passivhaus energy consumption target is absolute, and cannot be offset by generating power from renewables. While the standard allows design flexibility, the prescribed means of measuring predicted building performance is rigorous, and the target is very demanding. The combination of these factors always steers the designer, using climate data specific to locations throughout Northern Europe, towards a strategy which includes:

1. High level of insulation
2. Minimal calculated thermal bridges
3. Very draught-free construction under pressure-testing, and
4. Heat-recovery ‘hygiene’ ventilation.

In addition, the competition organisers wanted the house to achieve Code 4 or 5 of the Code for Sustainable Homes. It was decided to achieve this using on-site renewables. When Bere found that Code 6 could be achieved by simply adding photovoltaic panels to the south facing roof slope of the Larch House, additional funding was provided to achieve the UK’s first Code 6, Zero Carbon Passive House.

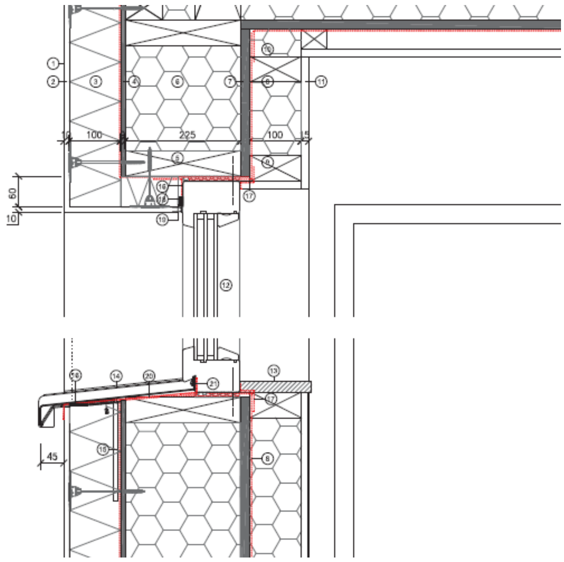
Another requirement of the brief was to consider how the building might mesh with local industry and manufacturing. Bere chose to use timber as the main material, as this is a plentiful and under-used resource in Wales. It is also a low carbon, particularly if the raw materials are grown and processed locally. Bere researched and described their vision for the development of Forestry in Wales in ‘Integrated Strategies for the Welsh Timber Industry’, published in 2011 (available for download on Bere’s website, here: www.bere.co.uk/research/integrated-strategies-welsh-timber-industry)

One of the main characteristics of the project is that the owner was willing to implement as many low carbon technologies as possible. The architects’ concept was to design an exemplary low carbon home. The low carbon technologies used in the house are:

- A photovoltaic array to generate electricity
- A solar collector to provide hot water;
- Heat recovery ventilation (HRV); and
- Rain water harvesting using water butts for economy.

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

Air tightness and insulation were critical in meeting the low space heating requirements of passive house standard, and Bere went to great lengths to describe to contractors precisely how to install membranes at junctions – especially wall-window and wall-roof, see below. (Significant junctions were drawn at three key stages of construction to help the contractor.)



All Bere's details clearly show where to install the air tightness membranes (marked in red). This makes it much easier for the construction team to ensure there is a continuous air barrier, and so achieve good air tightness.

The Passivhaus standard requires thermal bridges of less than 0.01W/mK. Bere Architects used (two-dimension) HEAT2 software to analyse significant junction details, and found that nearly all of the junctions complied with this requirement.

Thermal bridge analysis

In February 2011, Bere Architects carried out a thermal imaging survey of the Larch and Lime House. This highlighted a small but significant increase in heat loss around the plinth of the buildings, and prompted further three-dimension thermal analysis.

A subsequent thermal bridging analysis, using Therm v5.2, examined five key details, including plinth connections, door thresholds and window sill and head details.

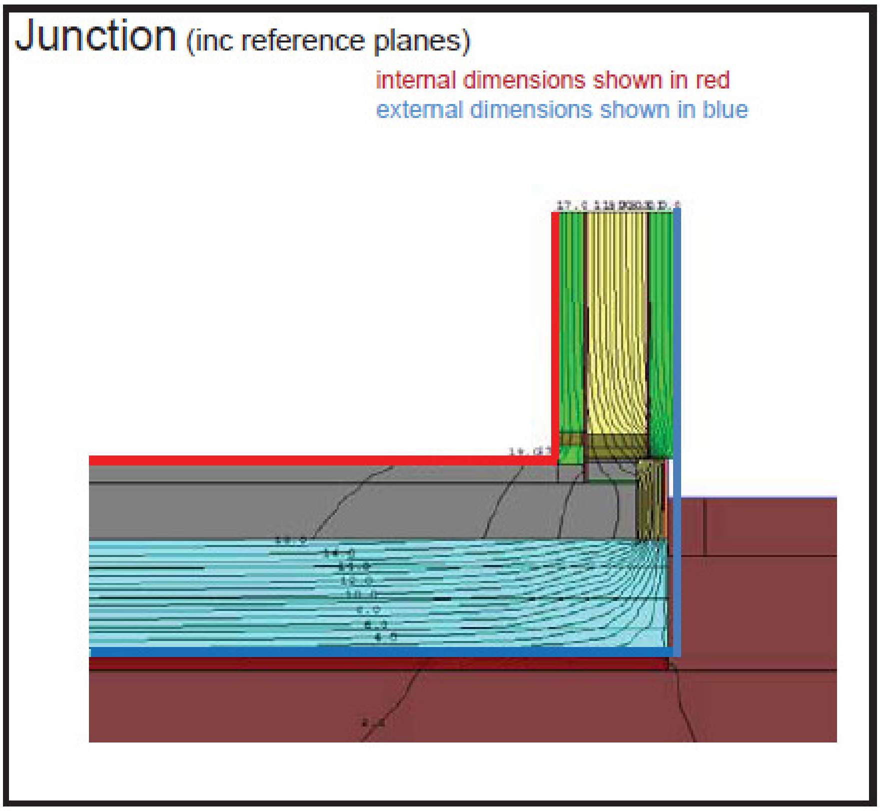
The external 'Psi value' (a measure of the linear transmittance of a thermal bridge, measured in W/mK) calculated for the plinth was found to be positive, showing a correlation with the findings of the thermal imaging analysis. The thermal bridge was not significant enough to affect the Passivhaus certification, but this is nevertheless an important outcome of the research project. Creating a thermal bridge-free equivalent for this detail would clearly have structural and cost implications, but this clearly merits further consideration.

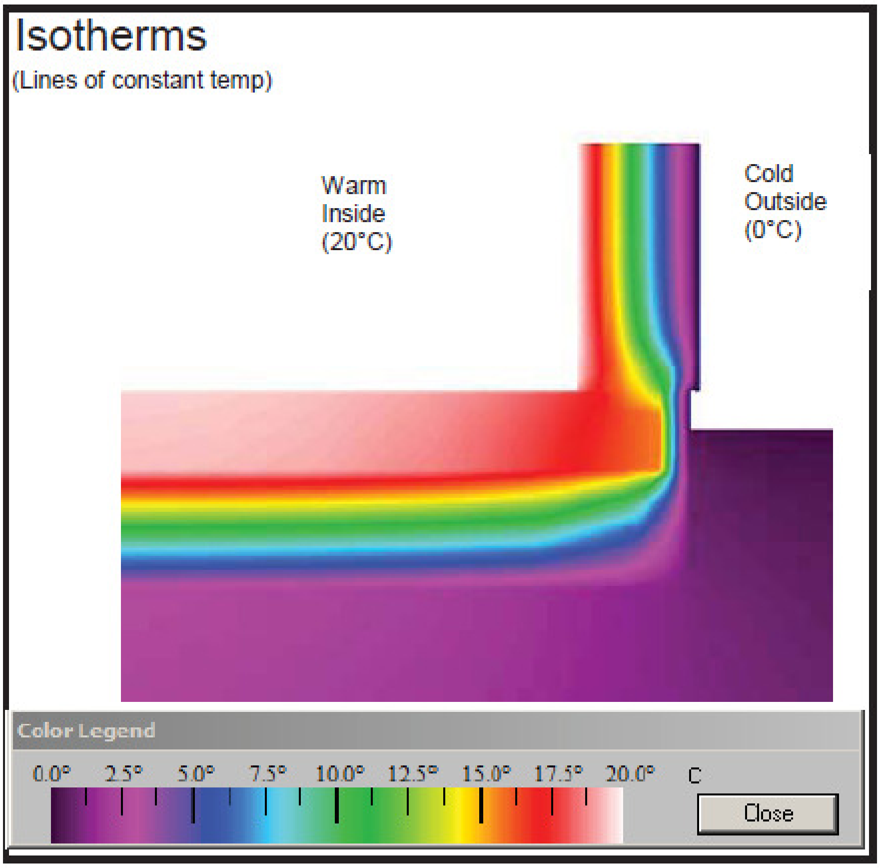
The thermographic photos of Lime House taken in February 2011 pointed to a possible weak link in the construction: heat loss through the plinth

Picture markings:

Measurement Objects	Temp. [°C]	Emiss.	Refl. temp. [°C]
Measure point 1	0.7	0.95	20.0
Measure point 2	1.9	0.95	20.0
Measure point 3	3.2	0.95	20.0
Measure point 4	2.6	0.95	20.0
Measure point 5	2.1	0.95	20.0
Measure point 6	2.8	0.95	20.0

The thermal image shows a higher surface temperature on the south side (M2: 1.9°C) than the west side (M1: 0.7°C). This indicates that even on an overcast day in winter the orientation affects surface temperature. The ground temperature is also higher than walls of the house. A surface temperature of 2.8°C at Measure point 6 suggests the plinth is a possible weak link.


Junction (inc reference planes)
internal dimensions shown in red
external dimensions shown in blue



Modelling using Therm 5.2 found that the Internal Psi at this junction was 0.13, and the External Psi was 0.02 W/mK. This compared to an excellent modelled floor u-value of just 0.07 W/m^{2}K. This suggests that the plinth is indeed a weak link in the fabric – partly because other parts of the building are so well insulated.

The window joinery for Larch House was high specification, with low u-values and very good draught seals. They were imported from Germany, while the window joinery of the Lime House was made in Wales to designs developed by Bere with Bill Robertson (a passivhaus window designer Bere worked with previously), Bayer Schreinerei (manufacturers of the windows in the Larch House), and a small group of carpentry workshops brought together for the project by Woodknowledge Wales.

Bere managed to get the windows certified passivhaus (the first UK-designed windows to be certified). They also organised the supply of Puren structural insulation from Germany. This was needed by the Welsh joiners to construct the laminated frames.

The joinery had very good draught-seals. Triple-glazed, passivhaus-certified windows achieve Uw-values of 0.6 W/m^{2}K (throughout, excluding the frames). The overall window for Larch House u-values were around 0.8 W/m^{2}K – 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. The operating controls of the blinds in the Larch House were not supplied and installed as specified, but due to the nature of the building contract they were accepted on this project.

In future, however, Bere recommend that remote controls (which the UK importers issue as standard) are not used – to avoid the risk of losing or damaging a remote control. Instead, they say they should be replaced by wall-mounted 'up-down' controls adjacent to each window. This requires non-standard control gear, which is expensive to retrofit and so this should be emphasised in the specification.

Further, the UK distributors normally supply simple controls that lower the blinds to cut out sunshine, whether summer or winter. This is fine in summer, when sunshine is not generally wanted inside the house, but it is an unsuitable control method in winter, because the blinds do not allow solar gains when available and needed. The wrongly supplied and installed controls were discovered by Bere while testing in January 2012 and the automatic feature has now been removed. This means that building occupants will need to remember to lower blinds in the summer before leaving the house for work, or other extended periods when the house is unoccupied.

Design and specification – the services

Building services were designed by Alan Clarke with assistance from Andrew Farr from the Green Building Store (ventilation design and commissioning), in conjunction with Bere Architects.

Ventilation

The ventilation systems for both homes are very similar. In both cases, heat recovery ventilation systems provide supply and extract ventilation. They also provide space heating. Both systems use a Paul Focus 200 HRV unit and a VEAB hot water heating coil. Heated air is carried in insulated ductwork to the bedrooms and the living room, plus the dining area in Larch house.

Air is extracted from the bathroom, shower room, airing cupboard, and the kitchen. Extract air returns to the heat recovery ventilation – near the front door in Larch House, and under the landing (in the utility cupboard next to the kitchen) in Lime House. Terminals are Lindab steel terminals and extract valves, with a filtered kitchen extract grille, and flow rates adjustable at the terminal.

Ductwork is also Lindab: spiral-wound galvanised metal, with push-fit connectors that have integral rubber seals. Having used other cheaper ductwork in earlier projects, Bere now exclusively use Lindab ductwork. This is because screws and sealing tapes or compounds are not required, which is quicker to install and ensures a higher quality air tight joint than alternative systems. Long-term reliability is also much better due to the integral rubber seals.

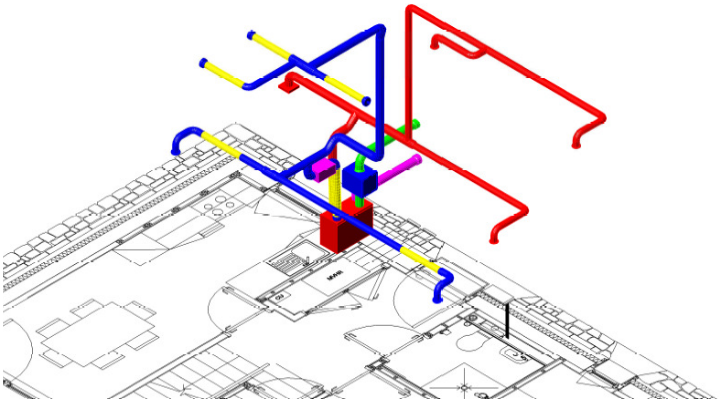
The insulation for heated ducts is mineral fibre and foil, and insulation of ducts between the HRV and the exterior of the house is Armaflex. Electric pre-heating protects the heat exchanger against frost using a Paul ISO unit with G4 pre-filter and a PTC ("positive temperature co-efficient") electric element controlled by an electronic thermostat to raise supply air to the HRV to a set point of -1℃. This prevents frost from blocking the HRV intake, which is essential for HRV to function when the outdoor temperature falls below freezing.

(Of course, the heating element uses electricity, which increases CO_2 emissions, but it is simple and inexpensive to install. The alternatives to this element are using a ground to air or ground to brine heat exchanger. Although these would both reduce electricity use, they are both more complex and more expensive.)

Larch House

In Larch House the HRV unit is located in a the storage cupboard by the front door. Intake and exhaust terminals face onto the street. Ducts run in a limited zone between joists from the HRV unit to the kitchen, dining, shower room and living areas. The ducts rise in the airing cupboard to run in lowered bathroom and landing ceilings.

Bedroom supply terminals are mounted on the walls, and the ceiling is higher in bedrooms. (See schematic below.)



Damp exhaust air is removed from the kitchen and bathroom ceilings (shown in red), passed through the heat exchanger in the HRV, and pre-heated fresh air is brought into bedrooms and living areas (shown in blue).

Supply is over doors using a terminal designed to circulate the supply air across the room with the return path at low level under the door

On the ground floor directional ceiling mounted terminals are used to distribute air southwards across rooms from the duct zone at the north of the building

A heater battery is installed directly above the HRV and this is supplied with hot water from the central heating boiler (a Rehema Avanta 18s) in the airing cupboard upstairs. The heater battery is on the left of the picture below, with foil-covered insulation. The intake and exhaust ducts are on the right and insulated with vapour-impermeable Armaflex insulation. The frost heater and pre-filter are in the black insulated box on the right.

The HRV draws air in from outside through the black frost heater (right), pushes it through a foil-covered heater battery and around the house

The boiler also serves towel radiators in the shower room and bathroom, and also a small radiator in the airing cupboard for drying clothes. These are heated in parallel with the duct heater under common control of a room thermostat in the living room (a Honeywell DT90).

There are two reasons for using radiators in parallel. First, as a highly-glazed house, Larch House has a design peak heating load a little higher than can be met through the ventilation air alone, so a supplement is needed. (Even though it meets the 15kWh/m²/y Passivhaus target.)

Second, the air heater's output is less than 1kW while the minimum output of the boiler is 6kW. This means there is a risk of the boiler overheating, and including the radiators in the circuit provides sufficient thermal mass to limit any temperature rise.

The project team checked the rise in temperature and it found that the boiler flow temperature rises steadily until the boiler ceases firing at 5°C above the boiler flow set point, and then cools again as the pump continues to run. The boiler cycles on this basis while there is demand for heating and there has been no sign of the boiler temperature rising too fast or the boiler controls locking out.

Typical running temperatures are 75°C flow (boiler set point) and 65°C return. It was intended to run at lower temperatures but the heating coil installed was smaller than originally specified. As the house was due to open for the Eisteddfod (a Welsh cultural festival), and the boiler temperature could be adjusted, the m&e designer decided to leave the system as built but to fit a larger coil (with lower water temperatures) in the second house to compare performance.

At these water temperatures the temperatures at the coil (measured externally on the copper pipe) were 68°C flow and 64°C return. The air temperature off coil is 44°C. This rises slightly as the system temperature fluctuates, but has not been seen to exceed 50°C. The slight under-capacity in the heating system is not expected to be an issue here as there is ample capacity in the towel radiators.

With off-coil temperature of 44°C the supply air temperatures were measured as follows:

Room	**Supply air °C**
Living	37
Dining	38
Bed 1	35
Bed 2	33
Bed 3	33

There appeared to be significant duct heat loss, about 10°C in some cases, though there was still no problem maintaining desired room temperatures in winter. The bedrooms, with longer duct runs, suffered the most heat loss – and this is probably better, since many people prefer cooler temperatures in bedrooms.

The heating is controlled using a simple room thermostat. This has an on/off button and up/down arrows to adjust temperature, which is displayed on an LCD screen. The hope is that this digital controller will avoid the common misinterpretation of a rotary thermostat as a “tap” with the higher setting correlating to more power.

For these homes power is very limited – with air distribution heating – so using constant set point (not running heating intermittently) is more important than usual. Thermostatic radiator valves (TRVs) are fitted to radiators to limit bathroom temperatures, as these heaters have excess capacity. The extra capacity may be absorbed when drying towels or other clothing, but it needs to be controlled to avoid overheating at other times.

There is no air temperature control in the duct for the heating circuit – the boiler controls limit air temperature. There is no need to interlock heating and ventilation controls as the Focus heat recovery ventilation has no summer bypass.

Re-commissioning Larch House

The ventilation system was checked and re-commissioned by Green Building Store, as described in more detail below.

Key findings were as follows:

1. Insect screens in the intake louvres were badly blocked (see photo below). The constant volume fans were running noisily to compensate for the extra pressure loss. The screens were built into the external terminals and could not be accessed for cleaning team decided to remove them, relying instead on the easily-replaceable pre-filter to remove fluff and insects as this filter will be changed regularly.

Built-in insect screens in the external intake terminals were hard to access and became blocked. The project team removed them and relied on the pre-filters to remove insects.

2. The engineers measured flow rate and power consumption of the heat recovery ventilation with dirty and clean filters. These showed equal flow rates and 5% increase in power consumption with the dirty filters, demonstrating that the constant volume fans were working effectively.

3. Overall specific fan power (of the unit as a whole including controls) was measured at 28Wh/m³ for 90m³/h (three-person average) and 0.33Wh/m³ for 120m³/hr (four-person average). This 120m³/h figure compares with Passiv Haus Institute test figure of 0.36Wh/m³ and SAP Appendix Q test figure of 0.27Wh/ m³ (SAP Appendix Q is from the UK Building Regulations, and it gives guidance on testing products used for ventilation).

(Note 1: The Passive Haus Institute test should include the frost heater installation and Appendix Q does not. Neither test would explicitly include the air heater (around 20Pa.

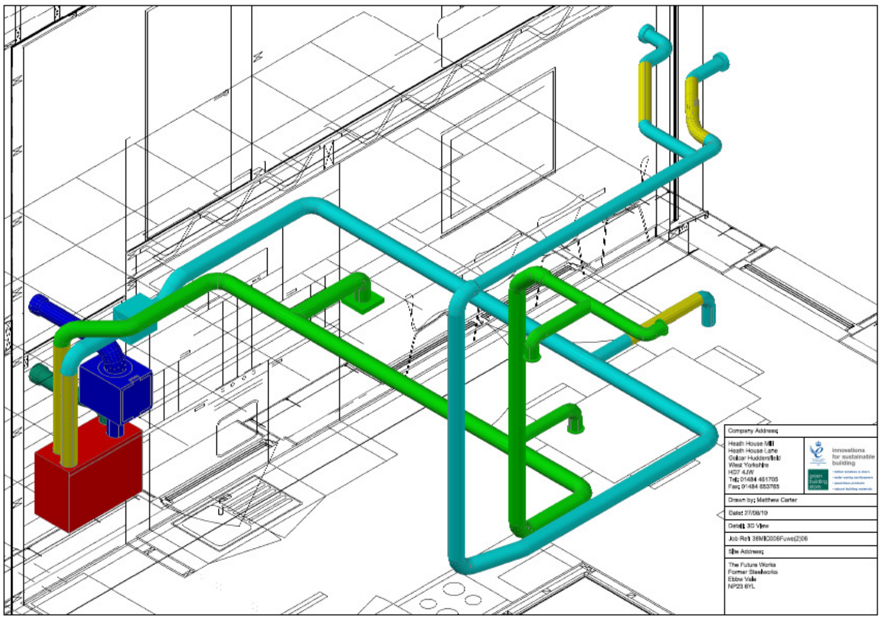
Note 2: Throughout this report ventilation flow-rate is reported in m³/hr, where 1 l/s = 3.6m³/hr and specific fan power in Wh/m³ (ie W/(m³/h)) where 1 W/(l/s) = 0.28Wh/m³.)

4. The air transfer paths via door undercuts from bedrooms were too small at <5mm giving rise to airflow speeds of >1.3 m/s. This exceeds the Passivhaus specification as it leads to over-pressurisation of the external fabric of the room concerned, with an impact on infiltration heat loss. The door undercuts are too small because carpets were fitted – apparently not allowed for in the design/construction.

Lime House

The HRV unit in Lime House is located in the cupboard under the landing – off the kitchen. (It was not installed under the stairs because this would make it hard to get the ducts into the ceiling void.) The external terminals are on the garden side of the house, and again a simple heater battery in the ductwork heats the supply air.

Ducts have to run in the first floor to get around the staircase, before rising in the airing cupboard to serve bedrooms and bathroom via a lowered ceiling void, as in Larch house. The schematic for Lime House is shown below.



The HRV system in Lime House draws air out of the kitchen and bathrooms and supplies fresh air to the bedrooms and living room. Extract ductwork is shown green, and air supply ductwork is shown blue.

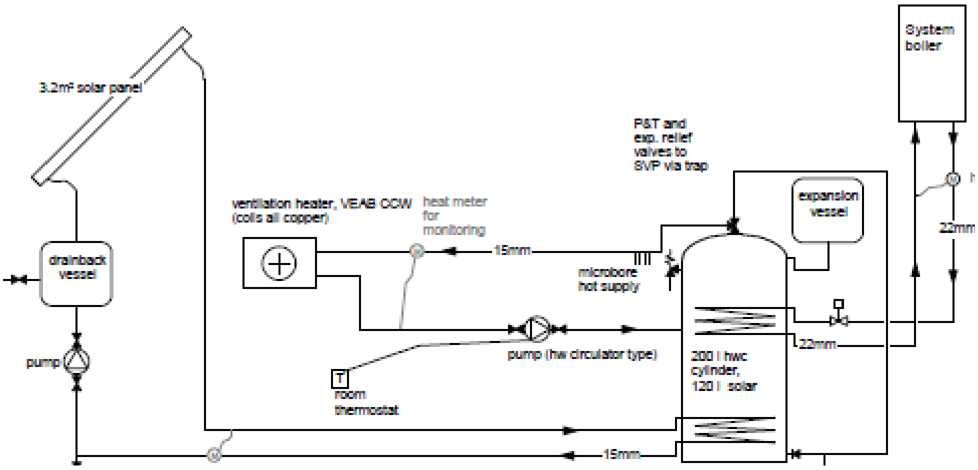
The photo below shows the HRV installation in Lime House. The frost heater is on the right, with silver ducting on the left covering silencers on supply and extract, and the heater battery is suspended from the ceiling. The thermostat controlling the frost heater is on the wall on the left, with the main HRV controls on the right. There are boost ventilation controls in the kitchen and outside the bathroom. These switch the HRV to the highest flow-rate for 15 minutes.

Incoming air enters the HRV from the back wall, towards the top, via the frost heater to the right. It passes through the heat-exchanger in the HRV, and then on through the heater battery at the top near the ceiling. Then it circulates around the house, to return as extract air through the vertical duct towards the back. Finally extract air passes once more through the HRV unit to leave the house through the lower duct in the back wall.

Lime House was certified as passive house on the 10W/m²/y criterion rather than 15kWh/m/y. This means it can be heated solely via the ventilation air, and BRE decided that only air-side heating should be used. To avoid the mismatch between boiler output and air heater power some sort of thermal store was required, and past experience suggested that standard thermal stores tend to be poor at using solar thermal energy.

(It is best to distinguish standard thermal stores from hot water cylinders that contain hot water used for taps. There are problems with controlling top-up heating from a boiler in conjunction with solar water heating. Standard thermal stores are also usually run significantly hotter than domestic hot water temperature as hot water is heated on demand via a heat exchanger coil in the store. Both of these reduce the efficiency of the solar thermal installation, increasing cylinder heat loss.)

Noting that the air heater battery uses copper tube (not steel as in radiators), the engineers decided to use the domestic hot water directly in the air heater. This means the hot water cylinder can be operated in the usual way, with stratification: the water in the cylinder forming layers of different temperature, with hot water at the top. This optimises the solar thermal performance. A twin coil cylinder is used, with upper coil heated by the boiler and lower coil by the solar panel, see schematic below.



The 210-litre hot water cylinder is at the heart of Lime House's space and water heating. This stores hot water from the solar water heater on the roof, provides hot water for taps, and hot water for the heating coil in the ventilation system.

(There were some late changes compared to this drawing, and ultimately the solar thermal was changed from a drainback system to pressurised, and the mixing valve was omitted from the hot water cylinder.)

The coil temperatures in the cylinder proved critical, as 100% air heating has to come from water at standard domestic hot water storage temperatures of around 55℃. A larger capacity heater battery was fitted and this provides air at 49℃ for water flow and return temperatures at the heater of 53℃/46℃ and a cylinder set point of 55℃.

As with Larch House, heating controls are a room thermostat with an on/off button. Boiler controls are fitted but set to continuous hot water, with cylinder temperature controlled using a temperature sensor connected to the boiler. A standard high limit thermostat is included on the power supply to a two-port valve, and the boiler controls the valve to permit run-on as required.

In initial commissioning the airflow was set by Green Building Store to sensible levels for ventilation, putting 60% of the air into the bedrooms and 40% into the living room. Most of the extract is downstairs so some of the ventilation air from bedrooms is drawn through downstairs rooms, providing more fresh air when bedrooms are unoccupied.

Although this is a good arrangement for fresh air supply, it proved less good for heating: during the first winter of operation room temperatures were typically 2℃ higher upstairs than downstairs, so the ventilation was re-adjusted to provide 60% downstairs and 40% upstairs. This meant the living room terminal had to be set to maximum opening.

This issue seems to be an unavoidable aspect of air-heating – the engineers are interested to see how it works out in practice when the house is occupied and internal gains are added to the mix. For future designs using air-side heating, we recommend very careful consideration of the heating supply from the ventilation based on:

- ventilation rates
- duct heat losses
- room heat losses
- desired room temperatures
- relative humidity levels of the air, and
- the buoyancy driven circulation between floors.

It will not be simple.

With an off-coil temperature of 49℃, supply air temperatures were measured at the terminals as shown below.

Room	Supply air ℃	Airflow m³/hr	Power W
Living	45	48	400
Bed 1	39	25	160
Bed 2	38	16	100

(Power is evaluated assuming a room temperature of 20℃.) This indicates a significantly higher heating input downstairs than upstairs, which will hopefully redress the temperature imbalance experienced previously, when the total heat input upstairs was around 10% more than downstairs.

Again the ventilation system was examined and re-commissioned by Green Building store as detailed below. Findings were essentially the same as for Larch House. One issue found with the constant volume fans used is that they do not go down to very low flow volumes, with a minimum around 70m³/hr (19 l/s). Here the fan speeds were set at 90m³/hr for Speed 1 and 120m³/hr for Speed. This implies that for three-person occupancy Speed 1 would be the usual operating mode, while four-person occupancy would use Speed 2.

Flow rates were also checked with heating both on and off. This made no significant difference.

Filters were noticeably cleaner than in Larch House – building work in progress on an adjacent site across the road may have dirtied the Larch House filters. Filters will be monitored throughout the Phase 2 study to see whether orientation and the prevailing wind affect dirt in the filters. (Larch intake and extract face North, Lime's face South.)

Hot water and solar thermal

Both houses use a Filsol solar thermal collector, specified as Filsol is the only Welsh manufacturer of solar collectors. Larch House has a total of 4m² and Lime House 3.3m², to suit the size and expected occupancy of the houses. The hot water cylinders are un-vented copper cylinders specified with higher than normal levels of insulation: 100mm thick. This required a basic cylinder diameter of 400mm to give 600mm overall to fit in the airing cupboards. The capacity in both cases is approx 200 litres.

Hot water distribution is via microbore pipework, a method of minimising draw-off deadlegs. So basins, sinks and showers are fed with individual 10mm plastic pipework, which using an unvented system can provide around 7-8 l/m over distances of up to 10m.

As per the Code for Sustainable Homes (CSH), flow-rates are limited by restrictors, and the pipework diameter has not reduced flows below those specified. Wait for hot water is minimal, only a few seconds. The bath uses 15mm pipework to fill the bath faster, considering that waiting for hot water in the bath is not important.

Note that CSH Levels 5 and 6 were to be met using water efficiency measures only – the design team decided that rainwater collection does not make sense in an area with surplus water. Concentrating on minimising water use also cuts the use of energy for hot water – by far the largest energy consumption in water systems.

The Larch House solar thermal system was designed to use a pressurised system whereas the designers wanted to use a drain-back system in Lime House to compare operation and reliability of the different approaches. However, the installers felt there was not room for a drainback tank in the airing cupboard and fitted it in the loft of Lime House. This is inaccessible and not frost-free, so it is not a viable location and the installer converted it to a pressurised system as for Larch House.

The systems have not always worked well and a solar specialist, Llanisolar was commissioned to examine the systems. Their findings are covered below.

Llanisolar's principal finding was that the switch from drain-back to pressurised system in Lime house was not carried out with the correct pump station. This led to heat loss from the cylinder to panels, which cannot happen with a drain-back system but in a pressurised one a non-return valve is needed to prevent this. The modifications seemed to be on the initiative of the installer and the correct type of pump station and expansion vessel has now been installed, however when monitoring equipment was installed in October 2011 the system had lost pressure and the pump was unable to circulate fluid.

The Llanisolar report also found that the return temperature sensors were not fitted correctly – these are needed for kWh monitoring only so do not affect operation but did lead to odd readings on the public display panels. When installing the monitoring equipment these sensors were found to be fitted securely but to the flow pipework instead of the return, and had to be refitted to the correct pipes in both houses.

Also at the October visit Larch House's system had ceased working, with the pump no longer running. This has now been resolved, but the problems lay partly with inexperienced solar water installation companies. Architect Justin Bere thinks that greater regulation of plumbers and electricians is needed, with an independent regulator and quality grading based on past work.

Procurement, Construction and Delivery

Although the design team signed a design and build contract, the design was fully detailed by the design team as they and the client realised that this was the only way to achieve Passivhaus Certification. In addition, Bere provided on-site training, and they were paid by the Housing Association up to completion of the works.

Contractor Pendragon Design and Build was nevertheless technically answerable to United Welsh Housing Association. The ambiguity of the arrangement caused a few minor difficulties, such as the inability to issue instructions to rectify work that did not comply with the specification, however the works were mostly carried out satisfactorily due to a diligent site manager.

Timber framing was fundamental to the success of the design, and BRE Wales found a recommended timber frame delivery partner, Holbrook Timber Frame of Brigend. Holbrook's speciality was the design and build of Premier Inn hotels across the UK. Holbrook's approach needed considerable development from a 140mm timber stud frame system with little attention paid to cold bridging or air-tightness, to the very demanding requirements of passivhaus. However Holbrook and the designers worked closely together and came up with construction methods suitable for locally-produced timber.

Both houses were delivered by Pendragon Design and Build, under 4-month building contracts, with their normal supply chain and sub-contractors, with the addition of Holbrook Timber Frame, who were sub-contracted by Pendragon.

Tendering

Tendering was negotiated and based upon full Bills of Quantities, prepared by Richard Whidborne, the design team quantity surveyor.

Summary of design changes

There were no significant design changes due to shortage of time to achieve the construction deadlines. However UWHA, the housing association, changed the spec of lavatories from the wall-hung units specified to floor mounted units that their maintenance team were familiar with. However this resulted in cutting of the bathroom floor covings deemed by the architect as 'unsightly'.

Holbrook Timber Frame changed the airtightness detail around the support detail for the first floor joists of the second frame that they built, for the Lime House. This was only found after the building failed its first air test. A compromise solution was proposed by Holbrook and agreed with UWHA, but this resulted in a poorer air test result than the Larch House, although still a pass and still dramatically better than UK building regulations.

Routing of ducts up through cylinder cupboard also meant a smaller hot water tank was used to gain space: a 210 litre cylinder was used instead of the planned 250 litre tank, which brought the cylinder diameter down to 600mm.

Problems encountered on site

There were very few significant problems encountered on site, apart from the installation of the external lime render on the second (Lime) house. The application of the render proved to be weather-dependent. It was applied in sub-optimal weather conditions in the Autumn. When cracking occurred over the winter, the cracks were repaired with incorrect products and the building was eventually painted to achieve a satisfactory appearance.

Regarding building services, there were small problems in Larch House, where the duct heater supplied was under-powered, but in order to meet the programme it was retained and a towel radiator compensated and provided extra heating. There was also some confusion about the duct terminals, with duct routes needing adjustment through the slate wall. Initially, the external ventilation ducts were poorly insulated too, but this has now been improved.

In Lime House, the duct routes were not coordinated into the design of the floor. This was resolved on site by inserting extra bends and junctions – which may have marginally increased fan energy by adding to pressure drops.

More seriously, the heat recovery ventilation unit for Lime House was supplied with the wrong handing for installation (i.e. with connections on the wrong side), and installed as such. It had to be changed.

The drainback solar thermal was also installed in the cold loft, not in the cylinder cupboard as specified. The installer claimed it would not fit in the cupboard so they converted to a pressurised system, but without the correct components. Eventually a new pump station and expansion vessel had to be fitted.

Both houses also had some difficulty getting anyone to insulate pipes properly.

SAP Assessment and Code for Sustainable Homes

Both houses achieved very good SAP Ratings: Lime House was A-rated, with a SAP Rating of 97, and estimated annual energy consumption of -14kWh/m^2, while Larch House achieved an even more impressive SAP Rating of 112, with estimated annual energy consumption of -52kWh/m^2 (!).

On the Code for Sustainable Homes, Larch House achieved Code Level 6 - the first Passivhaus to do so.

Lime House was intended to be Level 5, but it appears that somewhere between the solar installer, the M&E consultant, Bere Architects and the SAP-Code assessor, a 1.89kWp PV system was installed instead of a 2.0kWp. It is unclear how this happened. This brought the assessment to 99.1% improvement instead of 100%, and as a result the house's final assessment was Level 4. The housing association was not prepared to pay for the system to be upgraded. Bere Architects claim that Lime House would have reached Code 5 if the house had been assessed under SAP 2009.

Handover

When the house was complete and handed over to United Welsh Housing Association, the architects provided a user guide with information about how to manage the building. The Housing Association is satisfied with the handover process and reportedly finds the user manual inside the utility rooms easy to understand and very useful.

Bere also held a ‘Soft Landings’ event to explain how to get the most from the building.

The Soft Landings event included a demonstration of the HRV (above), and how to change the filter (below), and it was filmed by Splash TV

Ideally, of course, the tenants of the homes would have participated in this handover process, but this was not possible because the United Welsh Housing Association was not handed over the homes until after 18 months of tours and events organised and presented by Blanau Gwent Council and the BRE Wales. However the tenants moved into the homes in an event held at the start of the Phase 2 monitoring project.

Simple User Guides were produced for both homes to show tenants how to use their homes effectively

Conclusions and key findings for this section

1. There is a tension in setting the air change rate 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).

2. The intake meshes for the HRV were visibly dirty after six months' use, and needed to be removed.

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

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

5. Better training and certification is required in the UK to ensure that all approved contractors can be trusted to install systems competently.

6. Balancing the heating is more difficult in a passive house using air-side heating, 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.

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. Designers should try to reduce the risk of errors by careful specification of staged air tests.

7. Designers should also reduce conflict on site by requiring the contractor to provide a detailed programme at tender stage showing how staged air tests fit within the programme.

8. Bere concluded that it would be more economical – and therefore better suited to models of social housing delivery – to build terraced passive houses than detached homes like these.

9. The project team also concluded that it is significantly more expensive to design passive houses to meet the peak heating load for extreme 10-year worst-case external temperatures. For Larch House it cost 22% more than a typical social housing home.

10. The team recommends instead designing for *average* external temperatures, accepting that extra heating will be needed for the rare occasions when there are extreme cold temperatures. (This would raise energy use and CO_2 when the extra heating is used, but the impact is probably small compared to the savings achieved from passive house designs overall.)

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

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. Ensure that information on u-value measurements; thermography, air-tightness, any testing on party wall bypasses and any co-heating tests are covered. 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. 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. 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:

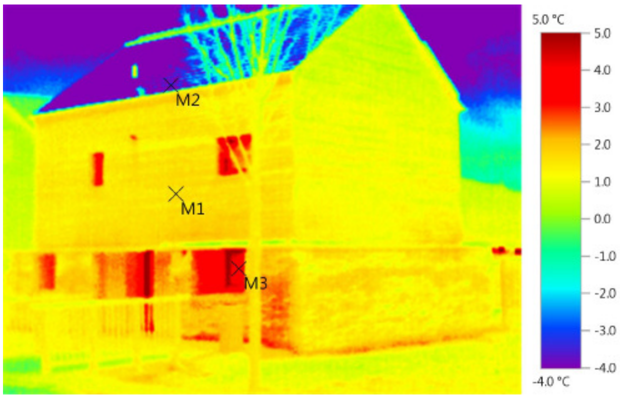
- a thermographic survey
- a heat flux study
- an air tightness test
- a co-heating test, and
- services tests.

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 thermographic surveys of both homes on the 14th February 2011. They followed the BS standard for such studies. The houses were measured at 25°C internally (much warmer than usual – it was during the co-heating test), while it was 3-5°C outside: a healthy temperature difference.

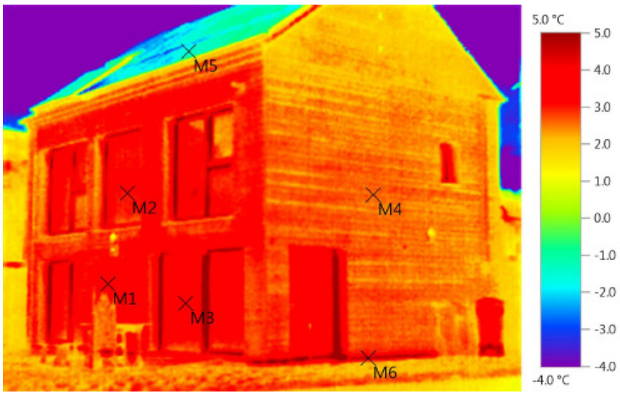
Larch House



There is minimal heat loss through the walls of Larch House – even though the house was heated to 25°C internally

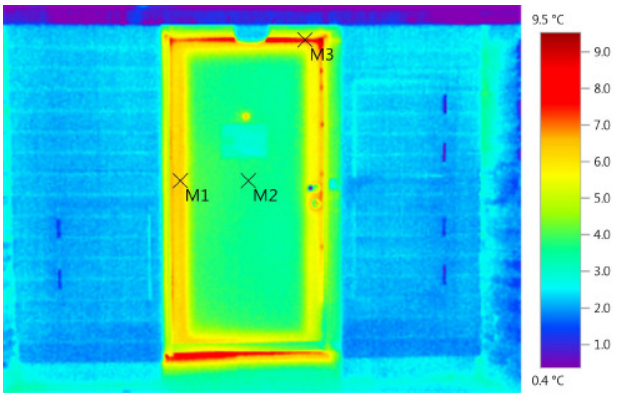
The survey showed surface temperatures for the walls as almost exactly the same as ambient temperature, but this was at least partly due to the air gap between timber cladding and the insulation behind. Windows had a slightly higher surface temperature – 3°C – showing that even triple glazing does not completely prevent heat loss through glass. (Some caution is needed when comparing surface temperatures of glass and timber because of different reflectivities and absorption of moisture.)

The photos reveal a cold bridge at the plinth, below the timber cladding, although the bridge may appear more pronounced than in reality because the timber cladding conceals the true wall temperatures.



The south and east walls are slightly warmer than the north and west ones – because of partial warming by the diffuse sun.

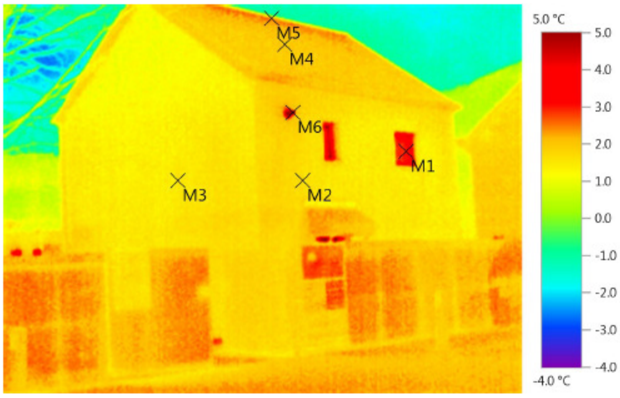
The study showed that the edges of windows (the reveals) have almost unavoidable heat loss caused by thermal bridging. Even here, though, the surface temperature was only two or three degrees above ambient temperature.



There were problems with air tightness of Larch House's front door after it was damaged on site, and even after a 'Plano' insert was used below the door, further adjustment is still needed to pull the door against its seals

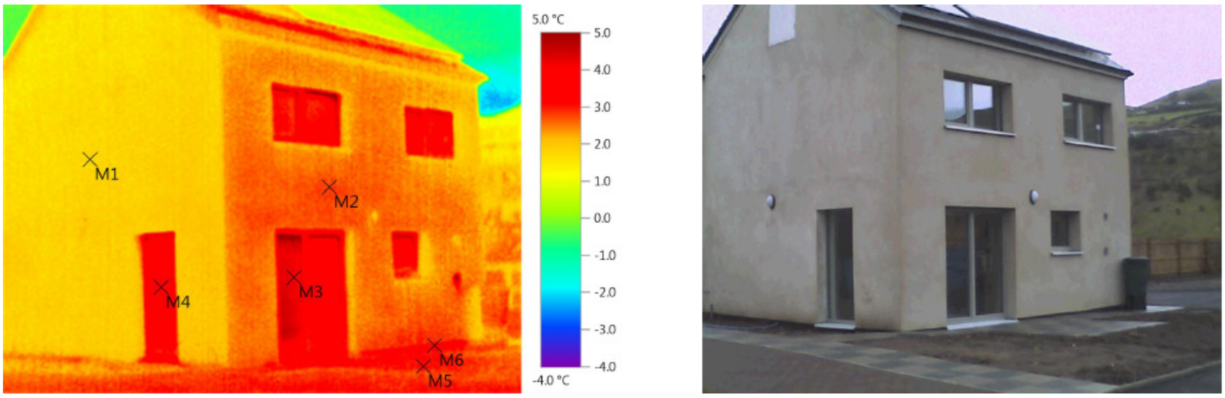
Lime House

Lime House revealed a similar story, with even surface temperatures on the walls, and the only weak links the windows, door and plinth. Despite the cold roof construction (with insulation laid between/on joists), there is no significant difference in temperature between the wall of the loft and the heated part of the house on the gable end.



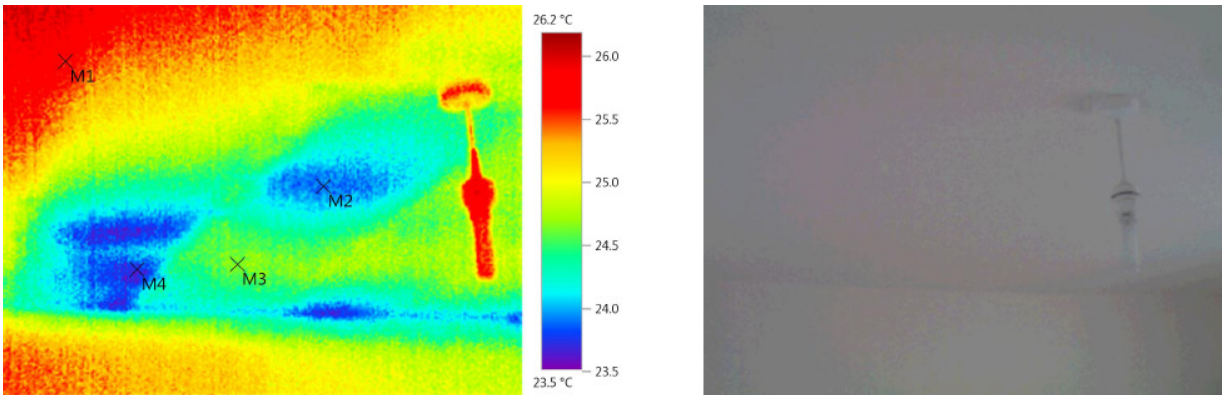
In Lime House too, the windows and plinth had higher surface temperatures than the walls – a 3 or 4°C difference

The images below suggest that the thermal bridge at the plinth may be less significant in Lime House than Larch House, although this could be an artefact of the timber cladding on Larch House, which exaggerates the contrast.

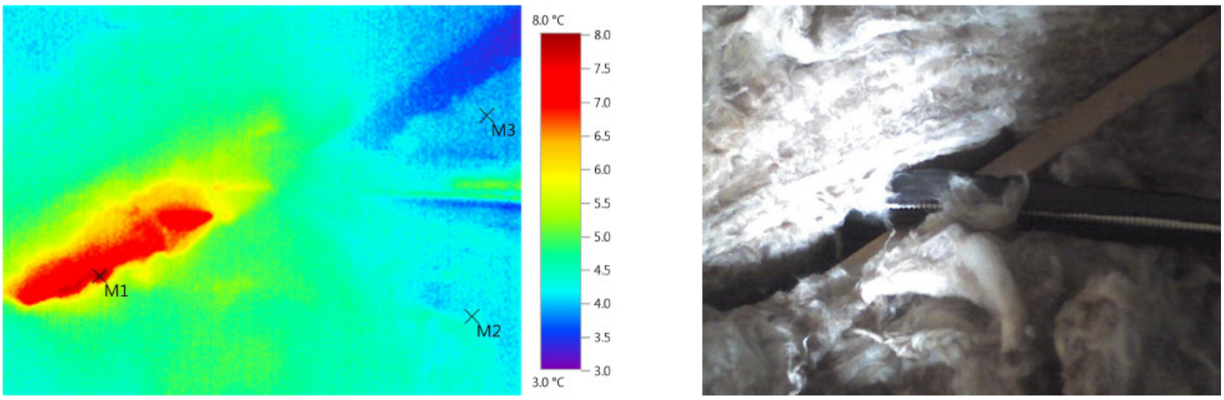


The south side (right) of Lime House is 1.2°C warmer than the west side (left) too, once again the effect of diffuse sunlight even on a cloudy day

Because of suspicions about flaws in the loft insulation, Bere took more thermographic photos inside Lime House (below). These found faults in the solar water heating pipework, and suggested that the loft insulation had been moved when the solar heating was installed, and this left some parts of the ceilings less well insulated than others, with a 2℃ difference in surface temperature across the ceiling in one room.



Internal thermographic photo's suggested possible weaknesses in the loft insulation



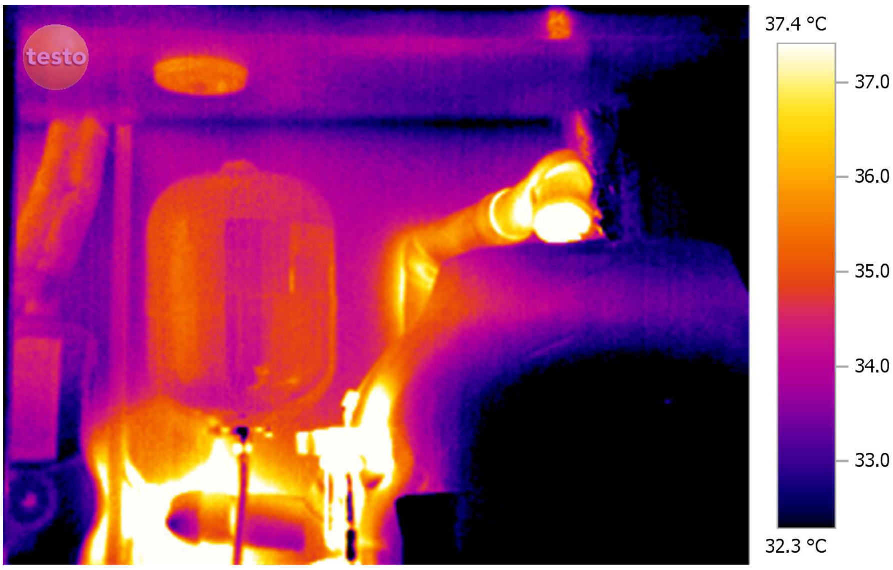
Examining the loft indicated that lagging had been moved to accommodate plumbing for the solar water heating

Bere concluded that it might have helped to use Warmcell (loose recycled cellulose) insulation, or a pipe sleeve through the insulation, to make it easier to install the solar water heating without disrupting the insulation. Alternatively, they could have installed the solar water heating first, and then insulated the loft.

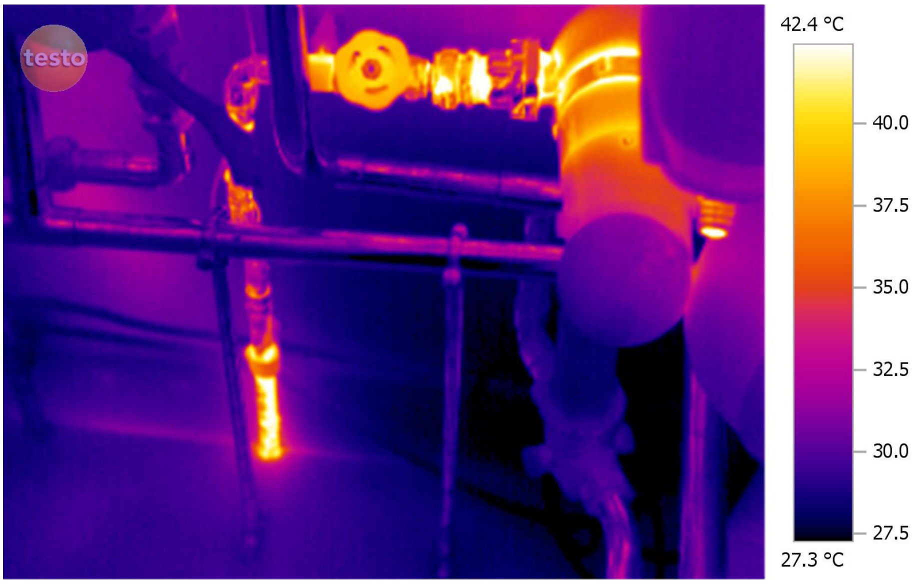
Hot water pipework

As well as the thermal bridge analysis reported above, Bere Architects took thermal images of the pipework in the bathroom cupboard of Lime House. They suspected a problem because the temperature fell about 1°C in the bedroom when the door to the bathroom was closed, indicating that the heat lost through the pipes is raising the temperature upstairs.

The contractor had not followed the specification of long, single-stemmed pipe brackets in order to enable pipework to be properly insulated. As this was a design and build contract, Bere were unable to insist on corrections. The problems were uncovered by thermal images showing high heat loss from the airing cupboard pipework in both houses (see Lime House photo below). This indicated that better-fitting pipe insulation was needed.



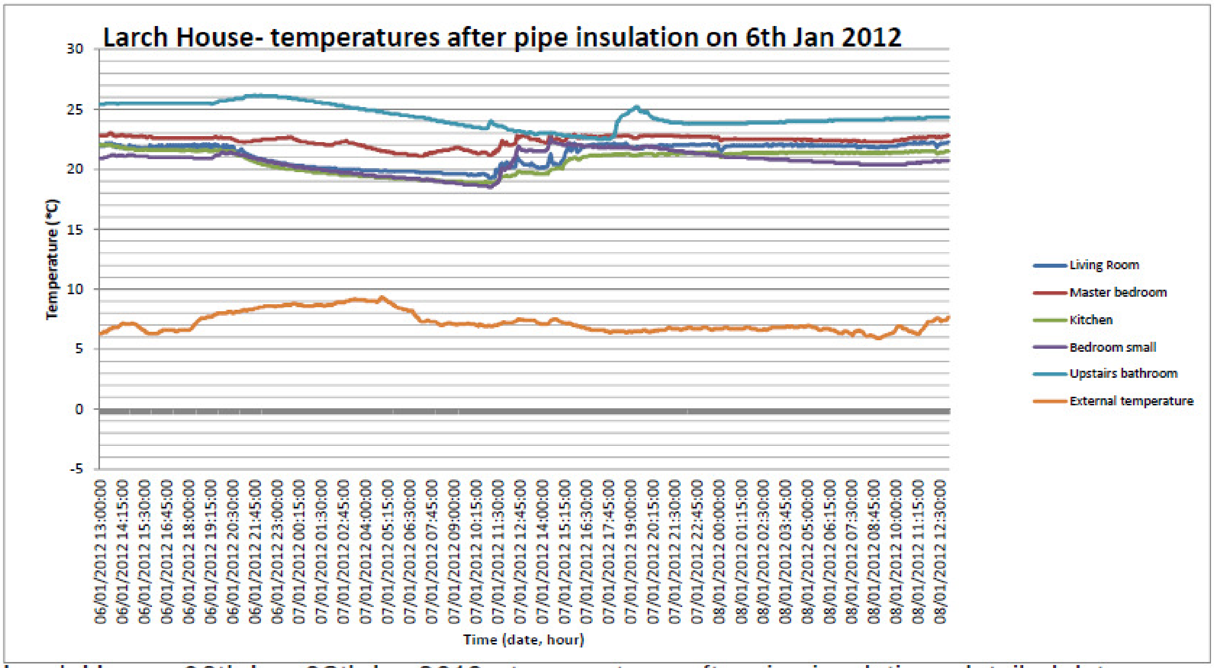
There are high losses around pipework to the hot water cylinder and the expansion vessel, with surface temperatures over 37°C



Short sections of inadequately lagged pipework was also leading to heat loss (although this is by no means unusual in new heating installations)

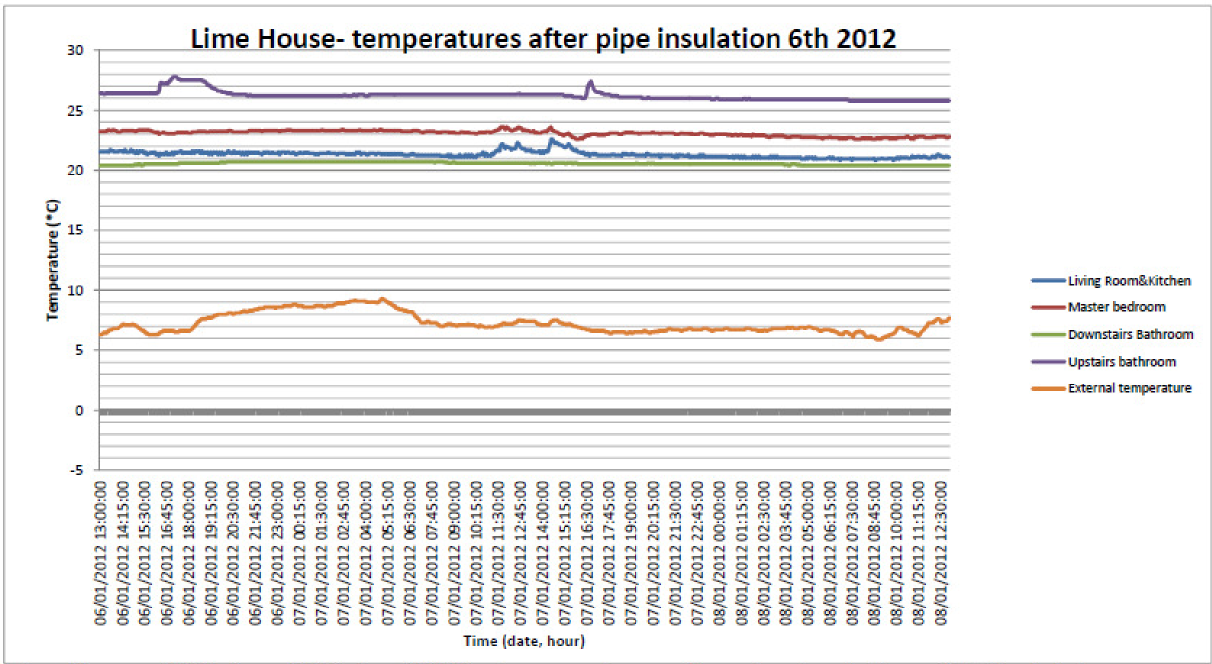
Areas of poorly lagged pipework in the hot water cupboards of both houses had additional insulation on the 6th January. Monitoring data before and after the pipework insulation was improved showed a very modest fall in upstairs temperature, and limited convergence of temperature between different areas in Larch House (see graph below).

It was difficult to install extra insulation in both cases because of limited space around the plumbing. Bere recommended that plumbers consider space for insulation when they install heating equipment.



Larch House- 06th Jan -08th Jan 2012 - temperatures after pipe insulation - detailed data

The intervention in the hot water cupboard of Larch House reduced the temperature of the upstairs bathroom, so almost certainly saved energy



LimeHouse- 06th Jan -08th Jan 2012 - temperatures after pipe insulation- detailed data

Extra lagging of hot water pipework in Lime House also reduced the temperature of the upstairs bathroom, but made no discernable difference to the temperature of other rooms

Heat Flux Study

The Welsh School of Architecture 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

The homes were originally tested in July 2010.

Gaia Aldas did repeat air tightness tests on both houses on the 16 July 2011. They followed ATTMA TSL1, 2010, Method B:

- temporary sealing of the supply and extract external grilles to the heat recovery ventilation
- all external doors and windows, other than that where the test equipment was mounted, were shut for the duration of testing, and
- internal doors were kept open to ensure each house acted as a single volume.

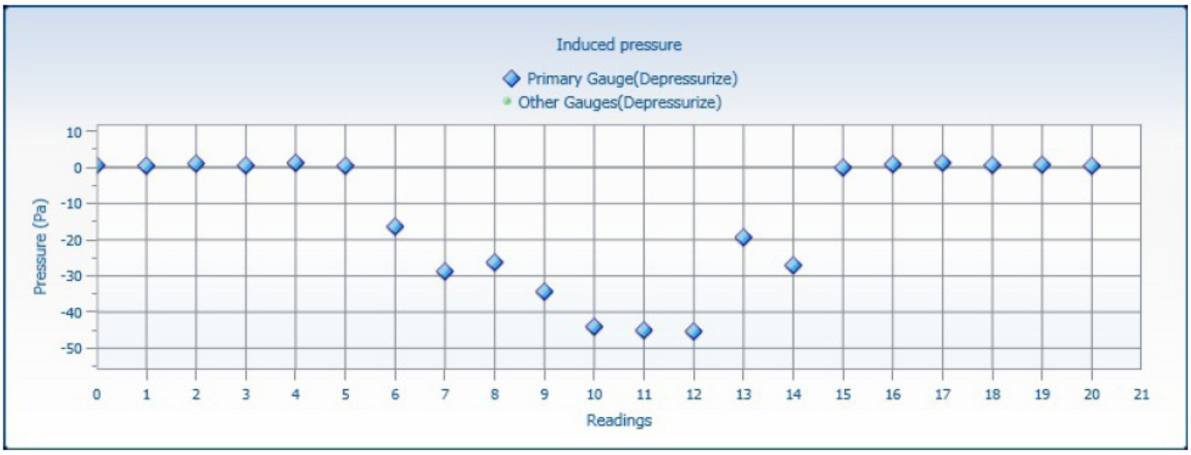
Both pressurisation and depressurisation testing was carried out and the results averaged, as required by the PassivHaus Institute and UK certifying authorities. The volumes and areas of envelope are shown in the table below.

Dwelling	Volume m^3	Envelope area m^2
Larch House, Plot 1, "The Works", Ebbw Vale NP23 6AA	***279***	***271***
Lime House, Plot 2, "The Works", Ebbw Vale NP23 6AA	***210***	***214***

The depressurised findings for Larch House are shown in the table and graph below.

Reading:	1	2	3	4	5	6	7	8	9
Induced Pressure [Pa]	-16.3	-28.7	-26.2	-34.3	-44.0	-45.0	-45.3	-19.3	-27.0
Door Fan pressure, [Pa]	99	261	208	312	433	438	439	130	213
Total flow, Q_r [m^3/h]	28.0	49.0	43.1	54.1	64.4	64.8	64.9	32.9	43.7
Corrected flow, Q_{env} [m^3/h]	29.4	51.5	45.3	56.8	67.6	68.0	68.1	34.5	45.9
Error [%]	-3.5%	6.9%	1.4%	2.0%	-0.9%	-2.2%	-2.6%	-1.0%	0.3%

Graph of imposed pressure differentials:



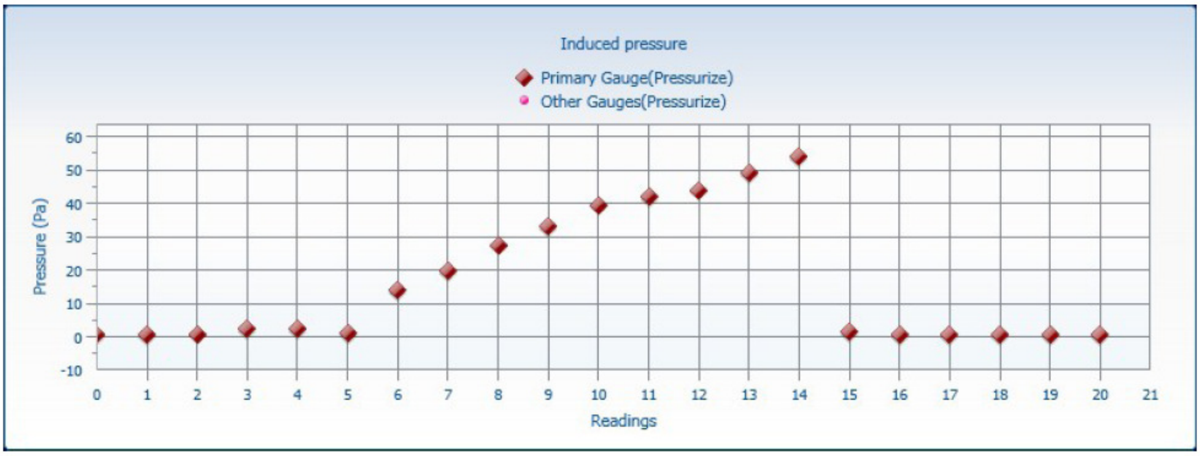
And the pressurised findings for Larch House are shown here:

Results:

All results are compared to the standards set in Building Regulations 'Approved Document L1A – Conservation of fuel and power in new dwellings (2006)'. Results are calculated using the formula set out in ATTMA TSL1 (section 3.2). The readings collected are detailed below.

Reading:	1	2	3	4	5	6	7	8	9
Induced Pressure [Pa]	14.0	19.7	27.5	33.0	39.5	42.0	44.0	49.0	54.0
Door Fan pressure, [Pa]	70	99	171	237	312	362	386	395	443
Total flow, Q_r [m^3/h]	22.8	28.0	38.6	46.5	54.1	58.6	60.7	61.4	65.2
Corrected flow, Q_{env} [m^3/h]	24.1	29.6	40.7	49.0	57.1	61.9	64.0	64.8	68.8
Error [%]	2.9%	-5.6%	-1.8%	1.6%	2.0%	5.1%	4.6%	-3.1%	-5.0%

Graph of imposed pressure differentials:

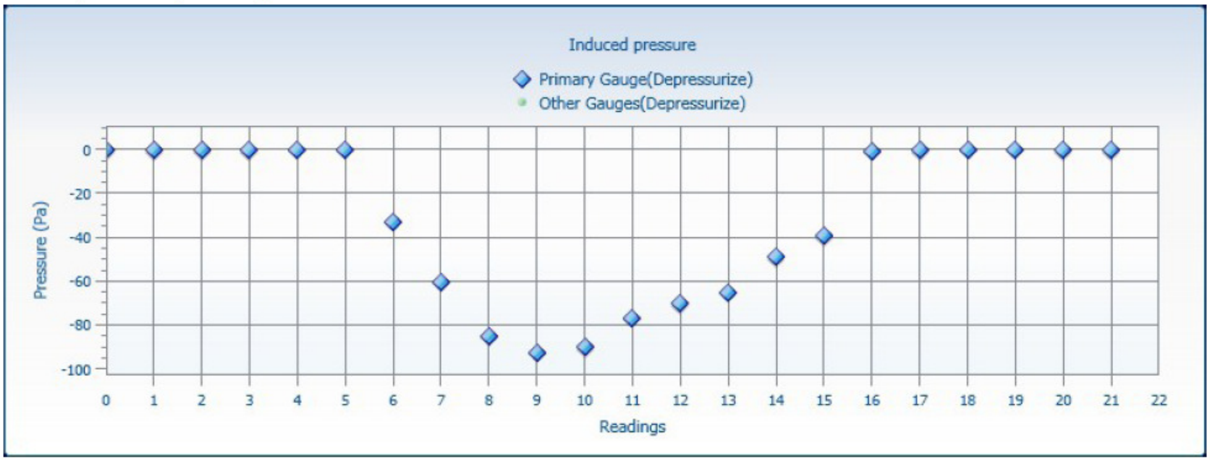


The combined results suggested an air permeability of 0.263 m3/m2/h at 50 Pa for Larch House. This is a truly impressive figure, and situates this house among the most airtight homes in the UK.

The findings for Lime House were not quite as good, and depressurisation test results are shown below.

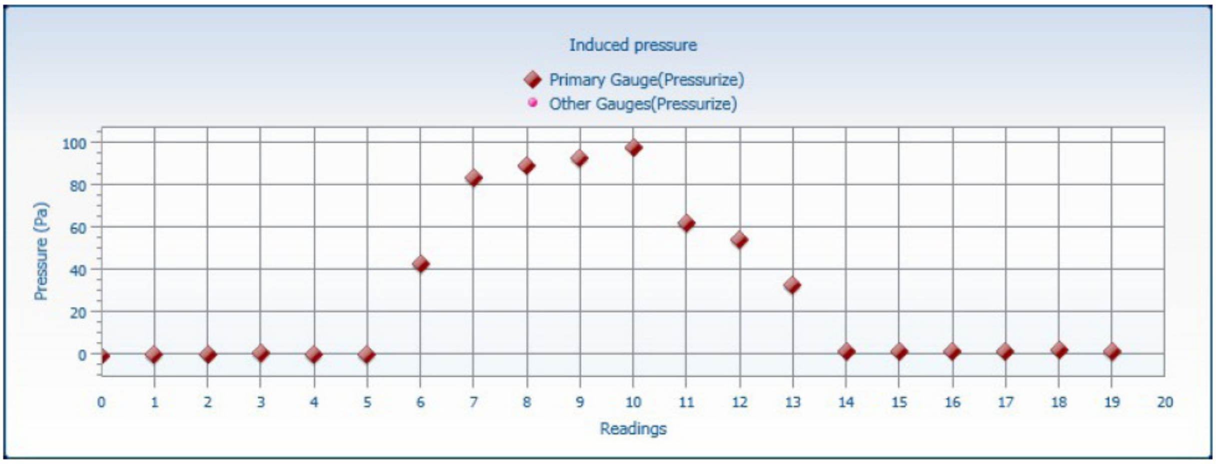
Reading:	1	2	3	4	5	6	7	8	9	10
Induced Pressure [Pa]	-32.7	-60.4	-84.9	-92.5	-90.0	-76.6	-70.2	-65.0	-49.1	-39.3
Door Fan pressure, [Pa]	49.3	110	169	192	185	150	135	133	82.5	58
Total flow, Q_r [m^3/h]	83.0	128.1	161.6	173.2	169.7	151.5	143.1	142.0	109.6	90.6
Corrected flow, Q_{env} [m^3/h]	86.4	133.4	168.4	180.4	176.8	157.9	149.1	147.9	114.2	94.4
Error [%]	1.3%	0.1%	-1.3%	-0.7%	-0.7%	-0.3%	0.3%	5.2%	-0.4%	-3.2%

Graph of imposed pressure differentials:



And under pressurisation, here:

Reading:	1	2	3	4	5	6	7	8
Induced Pressure [Pa]	42.7	83.2	89.4	92.5	98	62	54	32.5
Door Fan pressure, [Pa]	75	145	162	179	192	109	92	56
Total flow, Q_r [m^3/h]	104.1	148.8	158.0	166.7	173.2	127.5	116.3	88.9
Corrected flow, Q_{env} [m^3/h]	109.3	156.1	165.8	175.0	181.8	133.8	122.0	93.3
Error [%]	0.8%	-2.9%	-1.1%	2.3%	2.7%	-1.0%	-2.0%	1.3%



The combined air permeability for Lime House was around double that for Larch House: 0.543 m3/m2/h at 50 Pa. Bere say that the reason for the difference between the two air tests is that while they helped to train the window installers for Larch House, and monitored them closely on site, the learning was not carried over to the installers for Lime House.

Indeed, the contractor used different carpenters for Lime House than those used for Larch House. To compound the problem, Bere hold that the contractors also changed the air tightness detail used for Lime House. By the time this was discovered it would have been very costly to completely correct and Bere were forced to accept a compromise repair and an inferior air test result.

A comparison of the test results showing how the homes compare now, and how they compared when the homes were first completed, is shown in the table below (in air chages/hour). There is a considerable difference between measurements taken using a blower door as compared to when the equipment is mounted in a window because, naturally, the window test incorporates airtightness around the front door. The front door is evidently one of the major paths for air to enter or leave both homes.

Dwelling	Test Date	ACH^{-1} @ 50 Pa	Notes
Larch House	19th July 2010	0.23	Test equipment mounted in front door
	27th May 2011	0.61	Test equipment mounted in window
	16th July 2011	0.26	Test equipment mounted in front door
Lime House	23rd November 2010	0.35	Test equipment mounted in front door
	27th May 2011	0.70	Test equipment mounted in window
	16th July 2011	0.55	Test equipment mounted in front door

Comparing the like-for-like results in the two dwellings, the Larch House worsened slightly since first tested in July 2010, while the Lime House has deteriorated more substantially over a shorter period. Bere believe this is due to a BT cable duct installed after the first air test, which created a 20mm-diameter hole from the outside of the building into the living room, and then covered over by a BT faceplate. Justin Bere discovered this pipe in thermal imaging checks carried out in January 2012, but this leak was not discovered by the air tester.

Plaster cracks, which the air tester thought to be the cause of increased leakage, probably have no bearing on the air tightness of either house, since the line of air tightness is in a protected position, 100mm behind the line of plaster and designed to allow for movement in the timber framed buildings.

However even accepting the deterioration, both dwellings continue to meet the PassivHaus target of an air change rate of 0.6 ACH-1 @ 50 Pa or less when tested using door-mounted equipment.

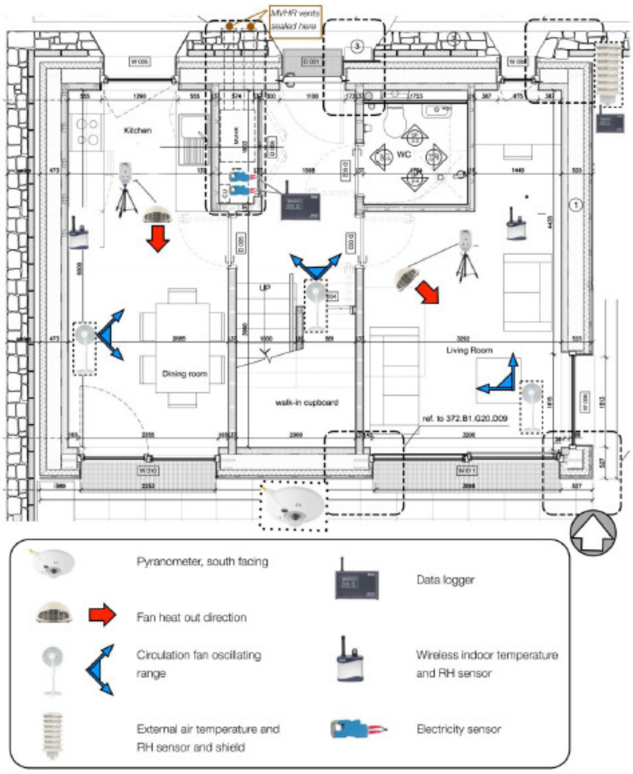
Gaia Aldas also concluded from their analysis that they should carry out acceptance tests with door fan equipment mounted in windows rather than door should as their normal practice – this is more revealing as a true measure of air tightness. (It also shows up weaknesses in door installation, as happened in Larch House here.)

Co-heating Test

A co-heating test was carried out by WSA in Ebbw Vale for 13 days between at the end of January 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.

To summarise the method:

- the houses were heated to 25°C for an extended period, using electric fan heaters and mixer fans
- the HRV inlet and extract vents were sealed
- internal temperature and RH were monitored
- external weather conditions (temperature, wind speed, solar gain) were also monitored.
- WSA calculated a simple heat loss coefficient (by dividing total energy by the hourly temperature difference)
- WSA used a more sophisticated Siviour analysis, which incorporates the effect of solar gain.



Electric heaters and sensors were set up as shown during the co-heating tests

Temperature monitoring equipment set up in Larch House during the co-heating test

The co-heating tests found heat loss coefficients as follows:

	Lime House	Larch House
Simple HLC	41+/- 8 W/K	60+/- 14 W/K
Siviour HLC	45 +/- 2 W/K	62 +/- 4 W/K

There is a moderate discrepancy between the simple heat loss coefficients, and the Siviour results, but the two results are consistent (in that both results lie in the error bars for the other). WSA believe that the Siviour results are more reliable.

Services Testing

Recommissioning of heat recovery ventilation

After rigorous fabric testing with the airtighness and other tests, the heat recovery ventilation unit was checked to ensure the system was balanced, and that everything was still performing correctly.

This re-commissioning was performed by Andrew Farr, a ventilation systems expert from the Green Building Store, responsible for the original supply of this energy saving system. The visit highlighted just how much construction site dust and dirt had been trapped by the building's air filtration system during the six months since the building's completion, and that cleaning the filters was a simple way to keep the building's indoor air quality at a very high standard.

Green Building Store's Andrew Farr re-balanced the HRV after airtightness and other system tests

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.

4. There is a thermal bridge at the plinth of both homes.

5. Extra lagging on hot water pipework brings some saving in heating energy, and should help improve user comfort by reducing the risk of overheating from pipework losses.

6. The solar thermal has proved unreliable, often not working at all, with problems due to poor installation.

Conclusions and key findings for other projects

1. Co-heating tests should be carried out between November and February to be more confident of a large enough temperature difference.

2. It is difficult to install adequate insulation in hot water cupboards when pipework is cramped, where is uses small clip brackets, and where pipework crossovers are too tight. This leads to unnecessary heat losses and can create overheating problems. Plumbers should try to bear lagging in mind when they install heating systems.

3. Training is needed in the UK in adjustment and commissioning doors using advanced, adjustable ironmongery.

4. Do not assume that operatives who work on the first dwelling of a development will necessarily work on other dwellings. This may mean that specialist training (for example, to meet airtightness objectives) has to be repeated.

5. Do not assume that solar thermal systems are installed correctly, and where possible test at the earliest opportunity.

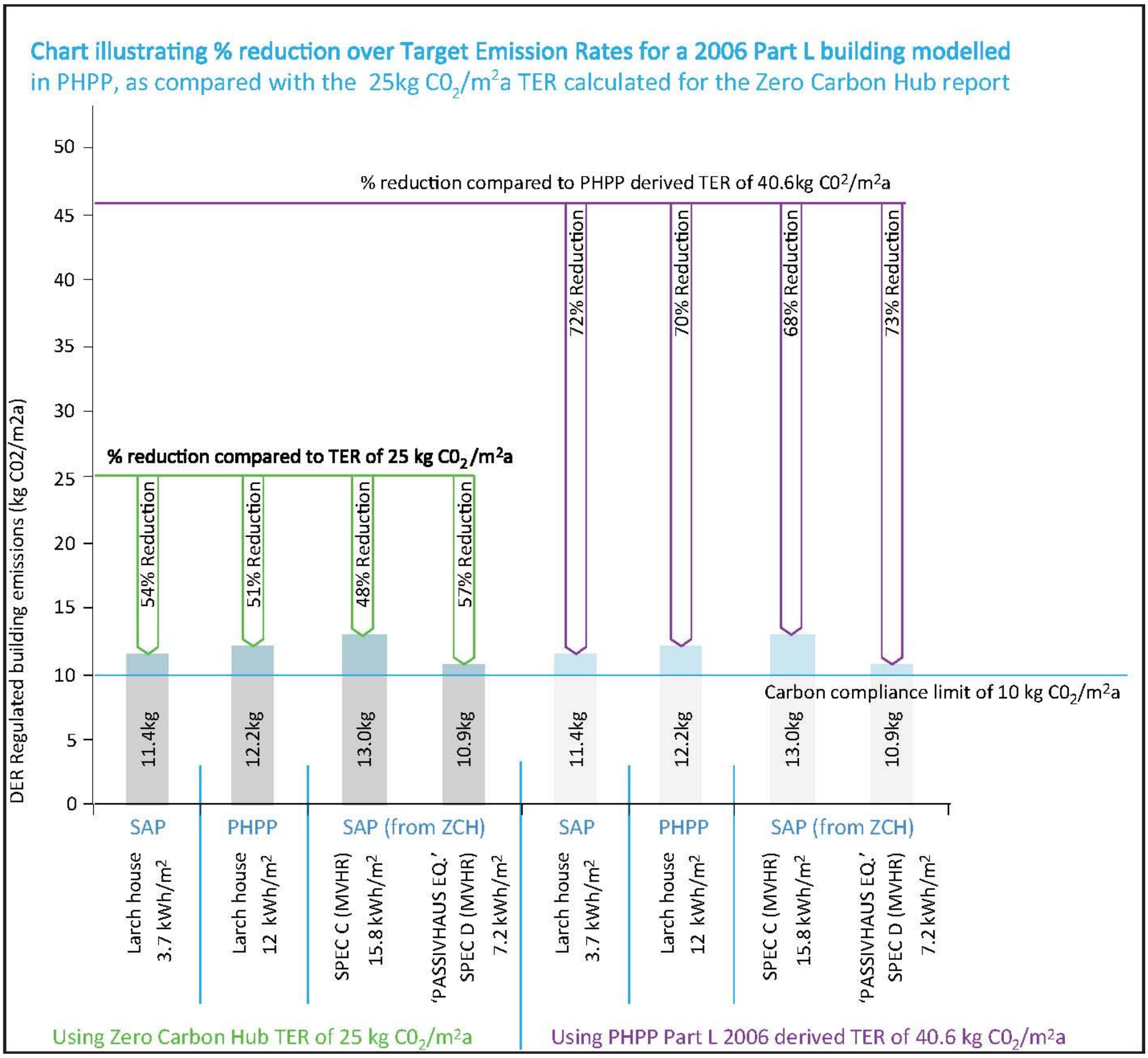
4 Review of building services and energy systems

Technology Strategy Board guidance on section requirements:	Explain what commissioning was carried out, what problems were discovered and how these were addressed. Discuss as to whether the initial installation and commissioning was found to be correct and any remedial actions taken. 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. 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 HRV has necessitated removal of insulation in some areas of roof). 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. Describe the operational settings for the systems and how these are set. 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.

Commissioning

Andrew Farr from the Green Building Store commissioned the ventilation system using two different anemometers, the second more accurate than the first. 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.



This chart summarises the relationship between energy requirements of SAP, Passive House Planning Package, and the Building Regulations

Second Commissioning

Green Building Store was asked to re-commission the heat recovery ventilation in June 2011, in preparation for the TSB monitoring.

When Andrew Farr from the Green Building Store arrived, the ventilation systems were running very noisily in both properties, with almost no air supplied from the air valves. On inspection it was found that intake and exhaust louvre meshes were blocked. See photo below.

The intake mesh (left) for the HRV was blocked with debris, while the and exhaust mesh (right) was clean

Andrew removed the meshes from both intake and exhaust vents. He felt that the built-in pre-filter in the HRV unit is easy to access and can quite adequately remove debris in future.

Lime House Commissioning

Andrew then measured air flow rates from all air valves, with the intake and exhaust mesh removed, but before changing the filters. The original figures from commissioning and the re-measured figures are shown in the table below.

	Original		**Re-measure**	
	Supply	Extract	Supply	Extract
Kitchen	0	48	0	54
Living Room	38	0	55	0
Shower WC	0	16	0	19
Master Bed	35	0	28	0
Bed 2	22	0	18	0
Bathroom	0	24	0	27
Airing Plant	0	7	0	7
	95	95	101	107
	0.00		5.77	
	95		104.00	

The apparent increase in air volume is explained by improved measuring methods. It is clear that the intake and exhaust volume flows remain constant, while there is a small change in fan power consumption. This is in line with expectations for the relatively low ventilation rates in this house. PAUL ventilation units have ‘constant volume’ fans, compensating for variation in resistance to air flow (pressure loss) to maintain a constant air-flow. As expected, it demonstrates that that poor filter maintenance affects the energy consumption of these units.

For standard HRV units without constant volume fans, you would expect the results to show no change in energy consumption but a significant change in air flow, resulting in potentially reduced air quality in the building.

Andrew then measured fan power using different filters (G4 and F8) and clean and dirty filters. Unsurprisingly, the dirty filter and the finer F8 filter both used more energy – about an extra 2 Watts on fan power of around 30W in both cases.

Re-commissioning was undertaken to allow for varying occupancy rates, as follows.

- Fan speed 1 – normal running for 3 occupants
- Fan speed 2 – normal running for 4 occupants
- 'Unoccupied setting' – which can be also be used as a reduced setting if required.

Air distribution by rooms			**Measured figures**					
Figures in m3/hr	Design figures		Fan Speed 1		Fan Speed 2		Fan Speed 3	
Room type	Supply	Extract	Supply	Extract	Supply	Extract	Supply	Extract
Theoretical Fan Speed			70%		100%		130%	
Level: Ground								
Kitchen		60		44		63		79
Living Room	60		48		67		80	
Shower WC		20		15.5		21		26
Level: First floor								
Master Bed	36		25		32		40	
Bed 2	24		16.0		19		27	
Bathroom		30		22		30		38
Airing Plant		10		7		9		11
Totals:	120	120	89	89	118	123	147	154
Balance deviation from supply/extract mean %			0.56		4.15		4.65	
Totals in m3/hr			88.75		120.50		150.50	
External measurements @ fan speed 2: Intake 121 Exhaust 126								

After re-commissioning, the energy consumption and fan speed setting were as shown in the table below.

Fan speed	Power (Watts)	Fan setting	Balance
1	24	20%	+3
2	42	40%	0
3	65	48%	0

Andrew also noted when he visited that there should be a door seal between the kitchen and the plant room in Lime House. There is no requirement to ventilate this space, and this would prevent noise from passing from the plant room into the kitchen.

Larch House Commissioning

Andrew repeated the tests and commissioning in Larch House, and found very similar patterns of both air volumes and fan energy consumption.

He also examined the air paths under doorways, and his findings are summarised below. Andrew was most concerned about the size of the air path beneath bedroom doors – less than 5mm for both Bedrooms 1 and 2 even without carpets. This limits ventilation when the doors are closed and needs to be resolved. If carpets are laid when the house is occupied this will mean there is inadequate ventilation in bedrooms.

	Transfer air paths	**Air speed**
Double door plantroom	12mm	0m/s
Kitchen / Dinning	10 mm	0.75m/s
WC / Shower	13mm	0.7m/s
Master Bedroom	5 -8mm	1.2m/s
Bedroom 2	< 5mm	>1.3m/s
Bedroom 3	< 5mm	>1.3m/s
Bathroom	< 5mm	>1.3m/s
Double door plantroom	12mm	0.12m/s

For this Larch House an additional test was carried out to look at air distribution and heating. The hypothesis was that when in heating mode more air would come out of the upstairs supplies and less from the ground floor due to the thermal buoyancy effects in ductwork that has a very low pressure loss.

It is important to bear in mind that this is only one set of measurement data from one house, subject to variability within the measurement technique. However, there was no measurable change in the air distribution in heating and non-heating mode. This suggests that in this case there was no significant effect.

LIME HOUSE AND LARCH HOUSE: CONCLUSIONS

Overall there was little significant difference between the results of the first visit and this commissioning visit. The only major difference came as a result of the filters. The most significant issue picked up in the second commissioning visit was identifying inadequate air paths under doors – especially bedroom doors.

Conclusions and key findings for this section

1. The original objectives for building services were achieved successfully: the HRV is providing fresh air and sufficient heating, and there is no intrusive noise from fans; lighting and daylight are satisfactory; and although there have been some problems with hot water pipework and ensuring even temperatures between ground and first-floors, these have been largely resolved.
2. Bere attribute the ventilation success to the commitment of the ventilation designer, and to the fact that the designer also supplied the ductwork components and carried out commissioning. There was therefore no loss of knowledge between design and commissioning, as there inevitably is when a commissioning engineer checks a contractor's interpretation of the work of a design engineer. This is an important finding in the context of industry concern about the poor quality of design, commissioning and performance of many UK ventilation systems.
3. Poor maintenance of the HRV (and especially blockages to the air intake meshes and/or filters) does not affect the volume of air supplied using PAUL HRV, but it does push up fan energy use.
4. A dirty filter, or a higher-rated filter (F8 instead of G4) both increase fan energy use by about 2 Watts. Air volumes are unchanged.
5. 4. The HRV system assumes air can circulate between rooms under doors, with a 10mm gap under doors. However, even without carpets several doors had much narrower air gaps – less than 5mm in some cases. If future occupants lay carpets this will block air paths further, and mean there is inadequate air flow between rooms – especially in the bedrooms. This must be resolved here, and should be borne in mind for other projects using HRV.

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. 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. Summarise with conclusions and key findings.

Monitoring methods

The monitoring system at Ebbw Vale was designed, specified and overseen by Bere, working closely with Alan Clarke and the product manufacturer, Eltek Ltd. This was the second monitoring installation carried out by Bere, following the approach developed at the Camden Passivhaus with advice from Ian Ridley of UCL and Jez Wingfield of Leeds Metropolitan University.

Subsequently the Welsh School of Architecture were provided with equipment to download the data, and asked to carry out a weekly download, in order to ensure that data was downloaded by an independent party. The installation was overseen by Bere Architects using electricians and plumbers familiar with the site.

The monitoring aims to cover a number of aspects of these buildings, connected with both passive house standards and the Code for Sustainable Homes, with all meters and temperature sensors linked to a datalogger to record measurements at 5-minute intervals for remote upload. Monitoring includes:

- Total energy use for gas and electricity in each house – using an additional export meter to monitor actual household usage before PV input considered
- Heating energy use – using a heat meter to separate space heating from hot water (two in Larch House for towel rail and heater battery, one in Lime House). This was needed because passive house is specifically built around a heating energy standard.
- External weather conditions – using a weather station mounted to Lime House

- Internal conditions of temperature and relative humidity – measured in a number of locations
- Total water use and hot water use – using a water meter on the cold feed, and temperature sensors on cold feed and hot water supply. This was needed because CSH emphasises water use, and the houses are designed to meet CSH Level 5/6.
- Solar photovoltaics (PV) – measuring electricity generation and external insolation (sunshine) via the weather station
- Solar thermal – using the kWh measuring facility of the solar thermal controls, which is cheaper than an additional heat meter as the flow rate is assumed constant and read straight from the flow meter in the solar pump station
- Mechanical ventilation – monitoring internal air quality (CO_2), temperatures in the HRV system, and electrical use of the system
- Air-side heating – individual outlet temperatures are assumed not to vary much over time, so these were measured as a spot check. An interesting issue in Lime House is the conflict between balancing ventilation needs with heating needs. So here CO_2 is measured in the main bedroom, as well as the living room.
- Lighting (also a CSH measure) – measuring electricity use for lighting. External lighting is excluded because it does not affect internal heat gains.

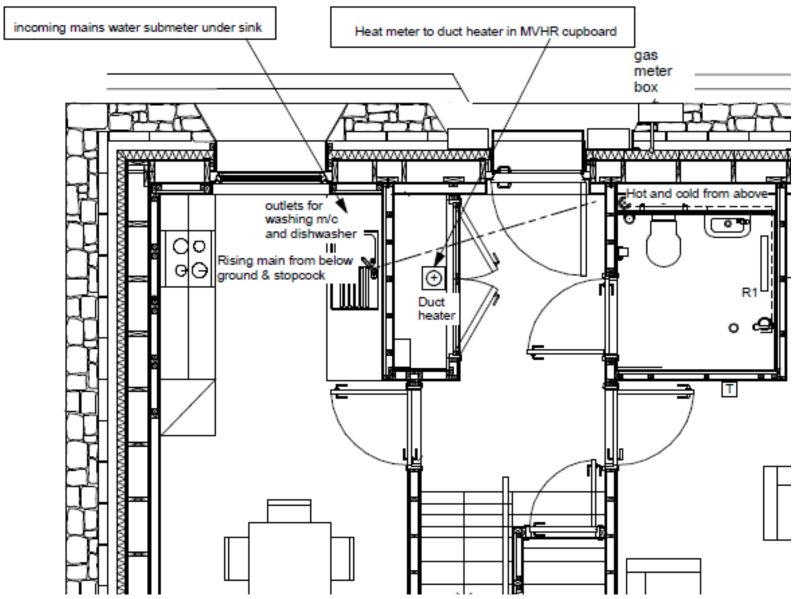
The monitoring system used in Larch House was slightly different from that in Lime House, with an extra heat meter in larger Larch House. Both homes had monitoring equipment for heating and hot water installed by the plumber, while electricity monitoring (including PV and HRV monitoring) and solar hot water system was installed by the electrician.

Larch House	Lime House
• Gas submeter - first floor below boiler • Water meter 1 - incoming main under sink • Water meter 2 - cold feed to hot water cylinder, first floor cupboard • Heat meter 1 - HRV heater battery ground floor • Heat meter 2 - radiators, first floor cylinder cupboard • Three 100A submeters (pulse output): o Total electricity import o Net export o PV generation	• Gas submeter - ground floor HRV cupboard • Water meter 1 - incoming main under sink • Water meter 2 - cold feed to hot water cylinder, first floor cupboard • Heat meter 1 HRV - heater battery ground floor • Three 100A submeters (pulse output) o Total electricity import o Net export o PV generation

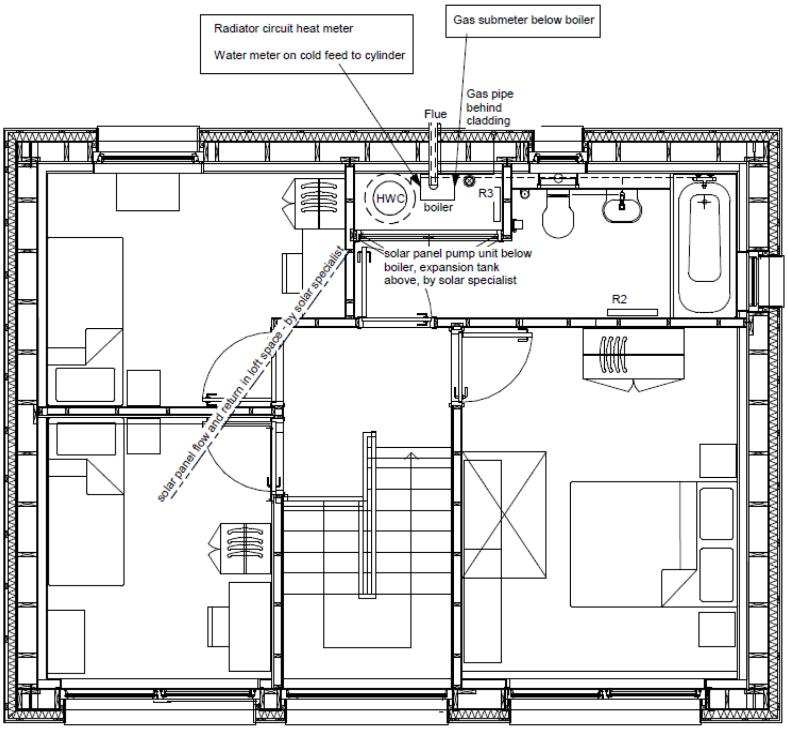
• Consumer unit box to contain DIN rail submeters (pulse output) • Submeters for: o All internal lighting o External lighting o HRV fan unit o HRV Frost heater o Boiler (fused spur) o Solar thermal (fused spur) o Cooker • Resol pulse output to solar control bus connections	• Consumer unit box to contain DIN rail submeters (pulse output) • Submeters for following: o All internal lighting o External lighting o HRV fan unit o HRV Frost heater o Boiler (fused spur) o Solar thermal (fused spur) o Cooker • Resol pulse output to solar control bus connections

Taken together, these meters were thought appropriate to provide a breakdown of energy use in the homes into final uses, and to explore how and why energy is used in different systems over time.

The meters for Larch House are shown on the floor plans below.



Larch House ground floor plan showing locations of meters.



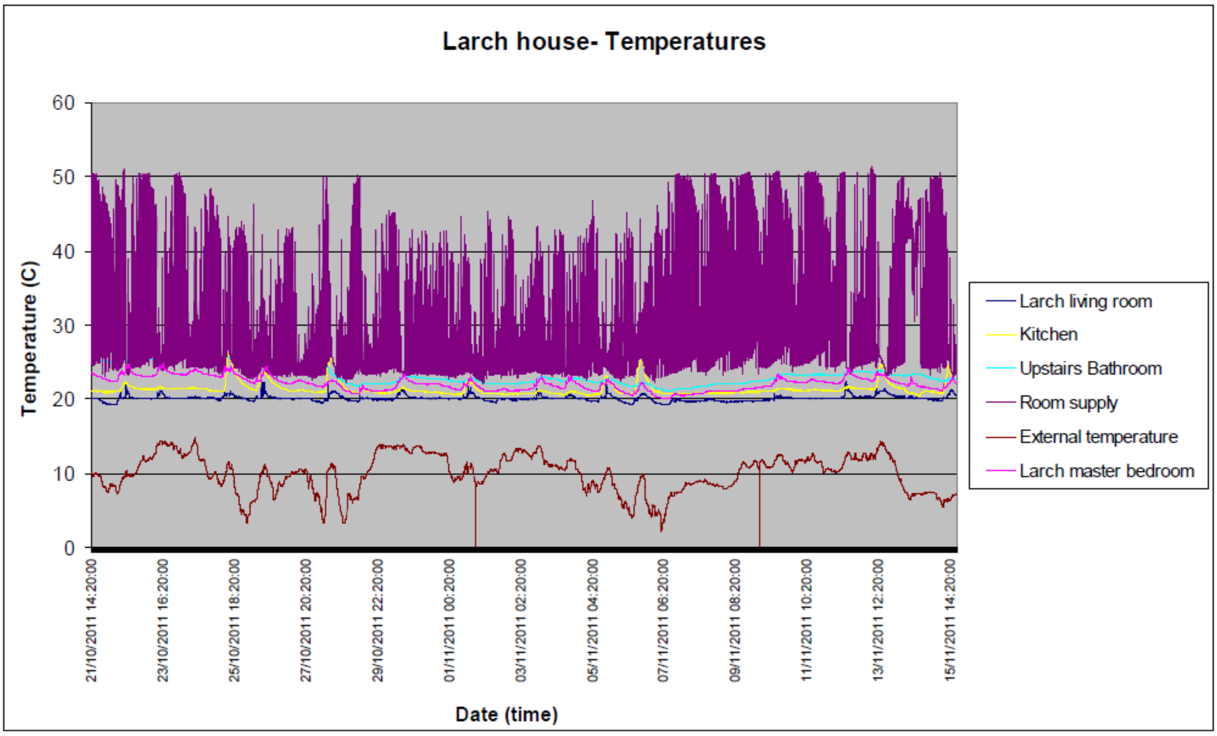
Larch House first floor plan showing locations of meters.

Early Monitoring Results

Bere did preliminary analysis of the monitoring data in December 2011. This focused initially on data from October to November 2011, and indicated that some of the temperature sensors were installed in inappropriate locations. Some readings in Lime House were over 40°C, for example, and this was later found to be because they were in direct winter sunlight.

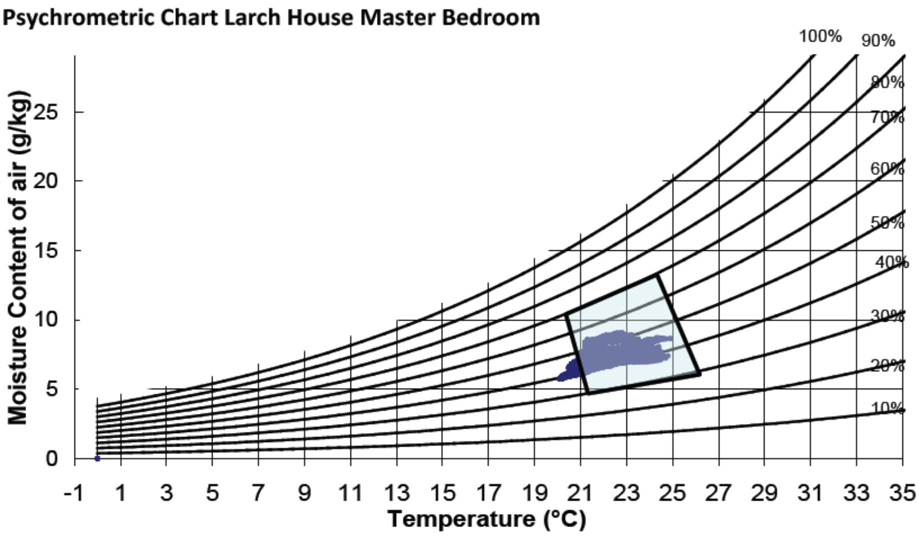
This problem did not occur in the Larch House because the blind controller was of the incorrect specification (noted above). This meant that blinds were closing in winter when solar gains were needed, so that the sensors were not directly affected by low winter sun as they were in Lime House, which does not have blinds.

As a result, Bere visited the site and adjusted the sensors, recording both the old and new locations. The original temperature readings for Larch House are shown below. There was a one-day spike in minimum supply temperature on November 14 may point to an issue with the frost protection heater. This probably warrants further scrutiny.



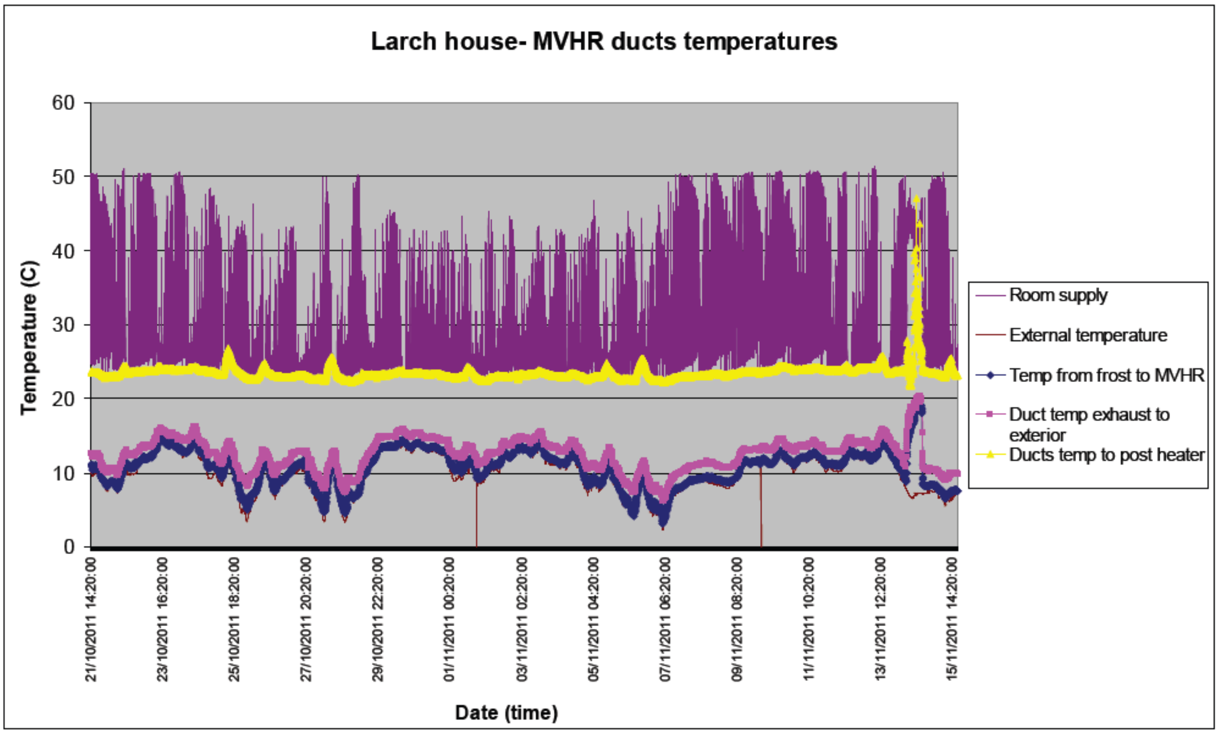
The temperature recorded in all rooms of Larch House stayed in a comfortable band between 19°C and 20°C. However, it was relatively warm in the master bedroom, which raises questions about heating – was the room over-heated, leading to unnecessary energy use?

Bere also plotted moisture content of the air in the bedroom against the air temperature (see Psychrometric Chart below). This suggested that the master bedroom stayed well within the 30-60% band for relative humidity, with temperature between 20 and 25°C. (Ideally it would have been slightly more humid – with RH from 40-60% – but when occupied it is likely that the air would be damper.)



The master bedroom in Larch House in October-November 2011 was recorded at a comfortable 20-25°C.

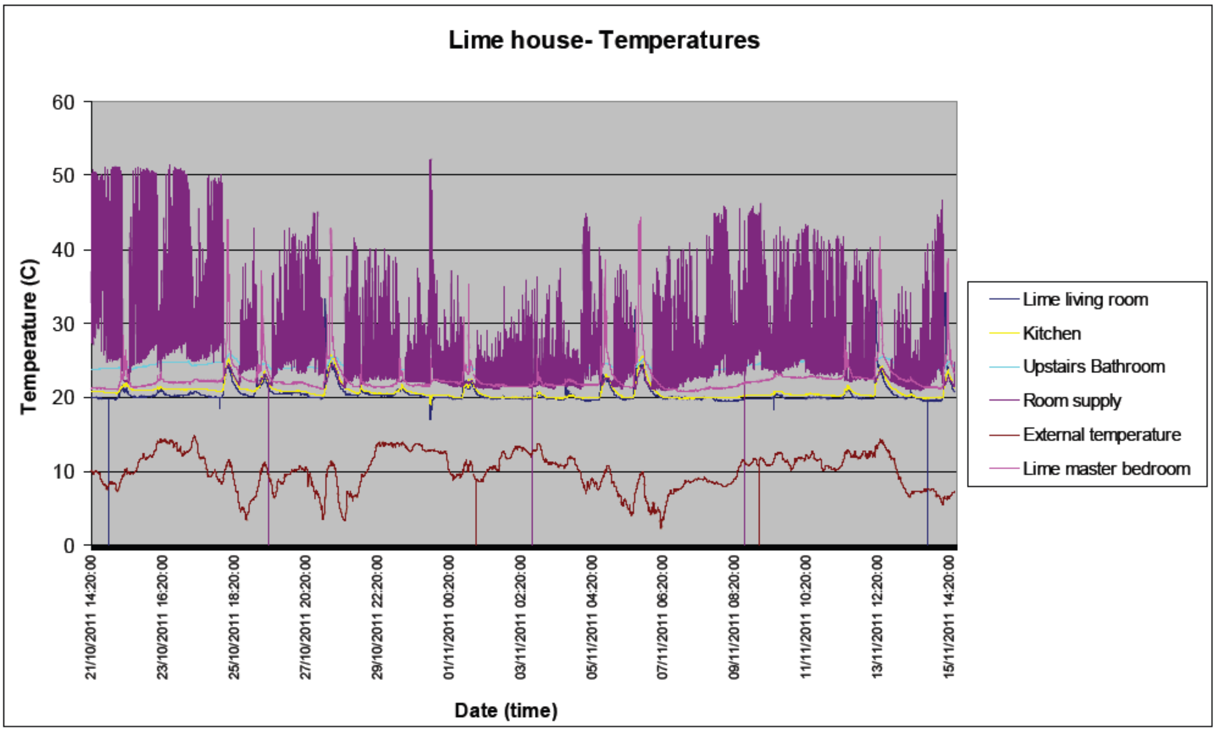
Bere also analysed the data from the sensors in the HRV ducts (below). The incoming air from the frost heater never fell much below 5°C, and this followed the temperature of air leaving the house quite closely – as you would expect. Inevitably, the supply air temperature ranged from around 40°C to 50°C when the air heating was on.



Air leaving the house varied in the band from 7°C to 20°C apart from a short period on the 14th November, when the sensor recorded 45°C. It is not clear why the temperature of air leaving the house jumped so high on that day.

Location of sensors

Initially some of the temperature sensors were located on the floor. However, all were moved to the same 2m height above floor level, and away from any possible solar gain. Bere also moved one of the two sensors in Lime House's kitchen/living room into the downstairs bathroom, which was not previously fitted with a sensor.

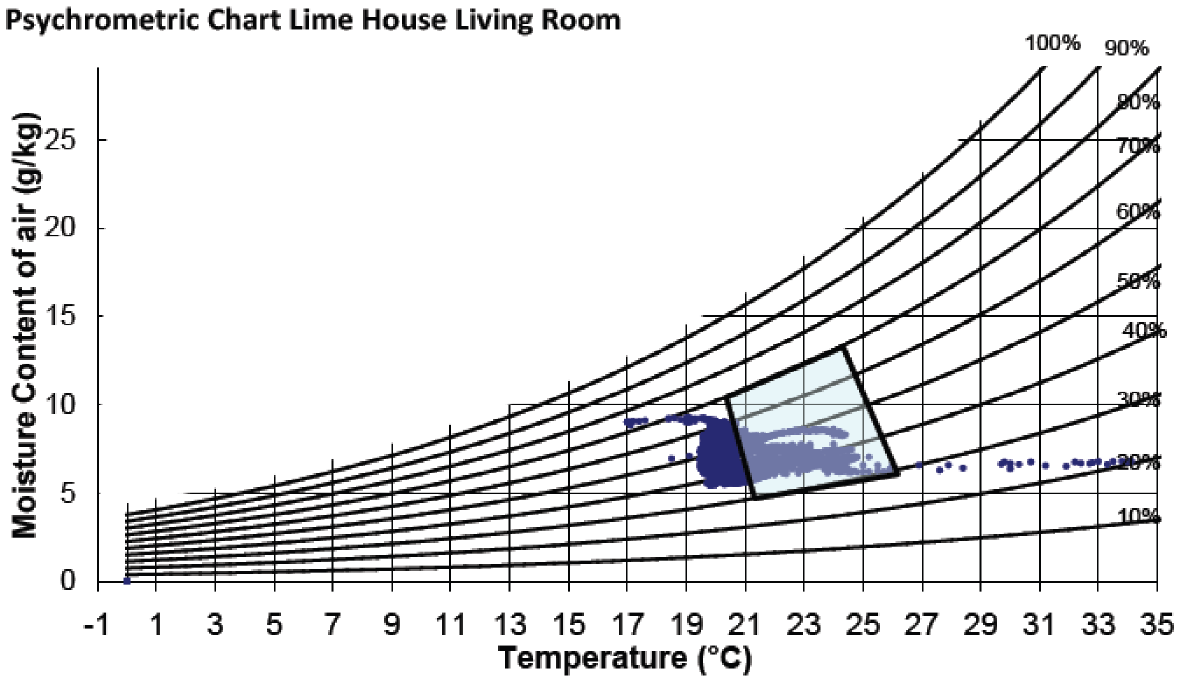


As in Larch House, the master bedroom in Lime House got surprisingly warm – sometimes over 40°C – according to the sensors. However, this was partly due to sensors being located inappropriately under sunlight.

The sensors in air-side heating show that the heating in Lime House worked similarly to that in Larch House, but usually with lower supply air temperature and perhaps shorter periods of heating than Larch House.

The psychrometric chart below suggests that the living room in Lime House was usually in the comfortable 19C-25°C range, but sometimes became very hot and occasionally quite cold. This may have been caused by the un-capped BT duct which was discovered in January 2012 (mentioned above), and might have had an impact on temperatures particularly in the strong, cold winds typical of this upland location.

Relative humidity was usually in the 30%-60% range (ideally it would have been 40-60% RH), but again there were occasional periods of dry or damp air – linked to extreme temperatures.



Bere's work also identified a temperature gradient between upstairs and downstairs rooms. The difference between the floors was typically 1.5 ℃, warmer upstairs. Bere came up with four possible explanations for the temperature difference between floors:

1. The volume of the air supply on the upper floor might be too high, delivering too much heat. However the ventilation system was carefully designed and balanced, so this was deemed unlikely.

2. The unnoccupied buildings were not benefitting from internal heat gains on the ground floor typically from occupants, refrigerators and other kitchen and living room appliances.

Since the room thermostat is located on the ground floor, if additional internal heat gains are produced on the ground floor, the thermostat on the ground floor will be satisfied for longer periods on a typical winter day, and will call for less heat throughout the house. If the upper floor does not normally have the same quantity of internal heat gains as the ground floor, it will be cooler upstairs.

3. Inadequate pipe lagging in the upper floor airing cupboards was resulting in increased internal heat gain on the upper floor. In a very well-insulated building, heat losses from airing cupboard pipework is more significant than in a less well insulated house.

4. Heat might be flowing from the ground floor to the first floor. During preliminary testing all internal doors were left open.

Bere decided to look into each of these possible explanations on a future visit. They also decided to explore how resilient the homes would be in the event of a power cut – are occupants better off or worse off in a passive house than an ordinary home?

Second visit

Bere Architects returned to the site a second time, and scrutinised the monitoring data for the period from mid-November 2011 to mid-January 2012. (This was after the temperature sensors were moved out of sunpaths.) They also carried out three experiments:

- Turning off the mechanical ventilation for 30 hours in Larch House, and
- Closing all internal doors
- Adding insulation to the airing cupboard pipes.

The first key finding from these experiments, as shown in the graphs below, was that with the heat recovery unit and boiler turned off in the Larch House, the temperature dropped no more than 1.5 ℃ over 30 hours. The small temperature drop while the system was not running indicates that the house maintains a perfectly comfortable temperature even under unexpected events (such as power cuts).

The second key finding was that CO_2 levels in Larch House doubled from around 800 parts per million to 1600ppm over 30 hours. This suggested that in a draft-free and highly-insulated house, the risks related to increased CO_2 levels in the case of power failure (with the windows shut) are fairly low, considering the CO_2 levels after over 30 hours were still below some reported levels in schools (sometimes up to 2500ppm).

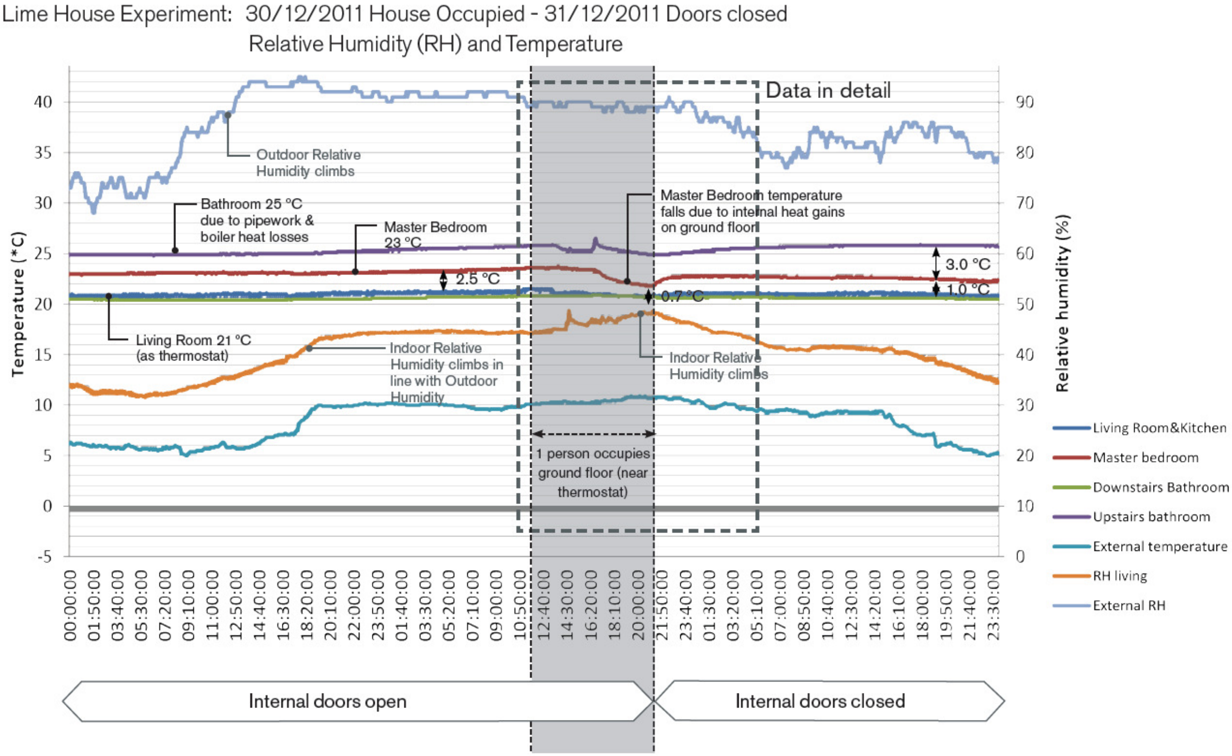
However, the Larch House was only minimally occupied – just two people, and they did not stay overnight. It is likely that CO_2 would have risen further had there been four or more people, and if they had stayed overnight. We should also remember than CO_2 is a proxy for other airborne pollutants. The result tells us (unsurprisingly) that there is limited flushing of pollutants when the HRV is switched off.

This means that occupants of these homes should ensure they open windows if the HRV goes off when they are doing activities that might lead to air pollution: painting, varnishing nails, gluing model planes, etc. They may also need to be aware of new furnishings that can off-gas hazardous chemicals, including formaldehyde glues.

The third key finding was that occupying the house on the ground floor almost eliminated the temperature gradient between ground and first floor. Even without appliances, two people in the living room made enough of a difference to even out the temperature on ground and first floor.

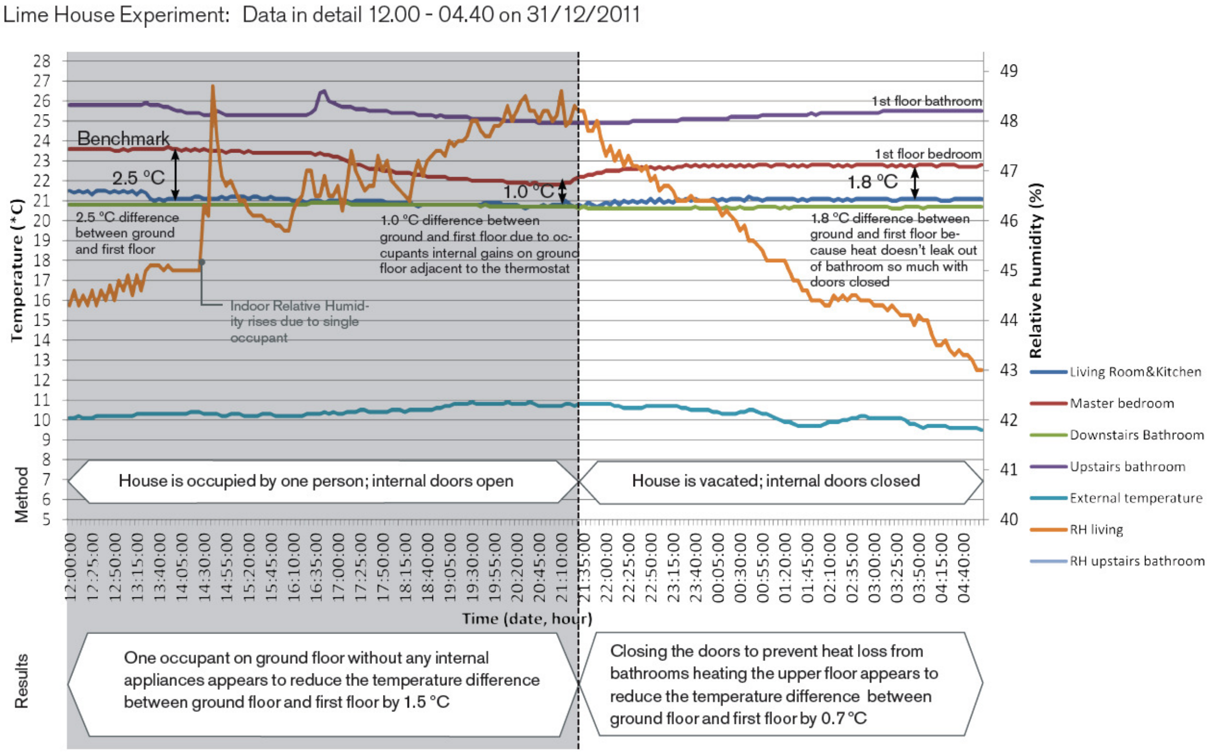
Similarly, when internal doors were closed, the temperature differences between upstairs and downstairs decreased, because less heat escaped from the bathrooms to other rooms.

The air had been slightly dry at the beginning of the experiments, when the houses were unoccupied: RH was 32% however, with two adults using the house, giving off vapour (breathing, sweat, etc), and using bathroom and kitchen, the RH increased to 42-43%. The fact that the relative humidity increased to normal levels indicates that the house should perform as expected when occupied.

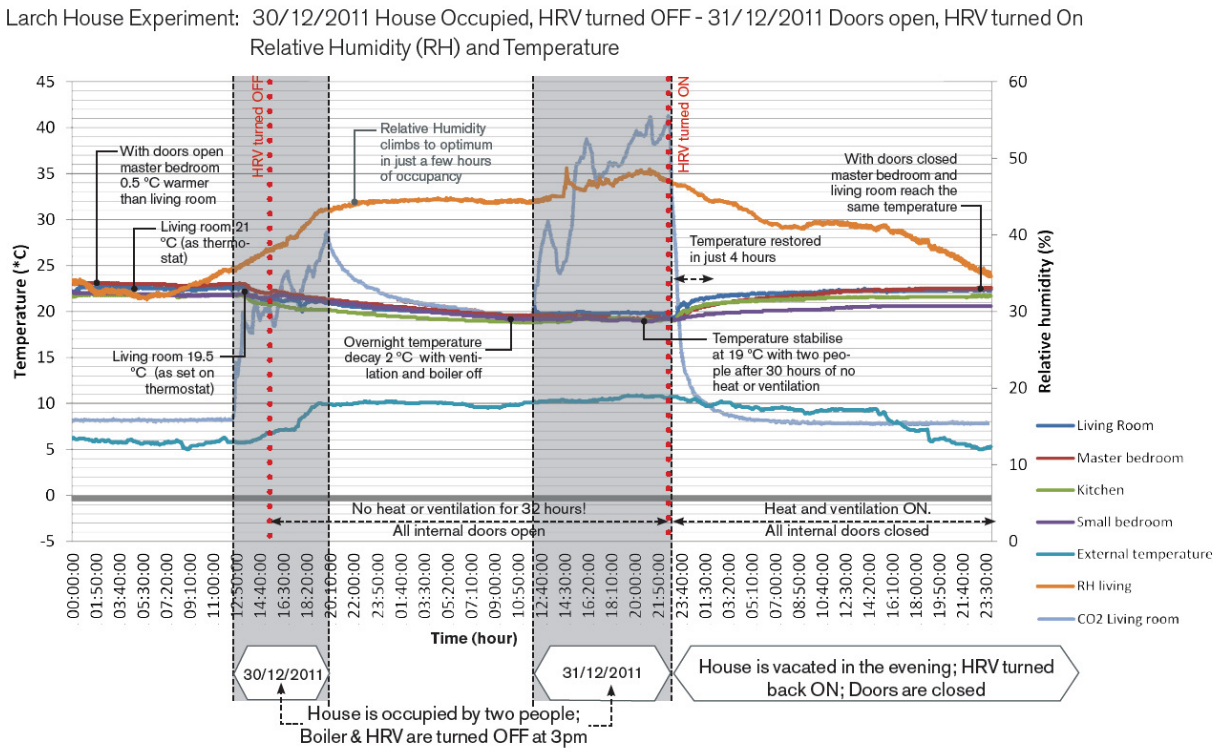


Experiments in Lime House found that occupying the living room evened out the temperature difference between upstairs bedrooms and downstairs, although the upstairs bathroom remained warm. It also helped to raise relative humidity, which makes the house more comfortable.

Analysing the data more closely found that closing internal doors reduced the temperature difference between ground and first floor from about 2.5°C to 1.8°C (see graph below).



The detailed snapshot of energy use, showing the occupied period, shows that RH in the living room falls quite quickly after the occupant left - from 48% down to 43% in six hours, even with internal doors closed



In Larch House, where the HRV was turned off, temperature only declined 2°C with the internal doors open

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. Even with the HRV switched off, both houses retain heat effectively, losing only around 2°C in 30 hours.

4. CO2 levels remain acceptable even if the ventilation system goes off for 30 hours (although other contaminants may mean windows have to be opened).

5. Relative humidity is on the low side (sometimes around 30%) when the houses are unoccupied, but this increases to the comfortable 40-60% range when the houses are occupied.

6. At present upstairs rooms run around 2.5°C warmer than the downstairs rooms

7. Closing doors between rooms reduces the higher first-floor temperatures to around 1°C.

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. 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. 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. Do the developer / manufacturer produced user manuals help or hinder the correct use of the dwelling? 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

On Thursday 29th March 2012 an occupant walkthrough was arranged for the soon-to-be residents of the Larch and Lime houses as part of Soft Landings Stage 4: 'Initial Aftercare'. The client, housing association United Welsh, had been using them as demonstration homes for over a year so was by this stage quite familiar with the buildings. However, the two families who moved into the houses on 12 April had only visited the houses once.

The two families had won a competition allowing them to stay in the homes rent-free for 12 months, but they had not visited then since the competition results were announced. This meant they did not know how to run their new homes.

The walkthrough was an opportunity for the client, architect and m&e consultant to introduce and explain the workings of the houses to the new tenants, and at the same time provide a refresher for members of the maintenance team who would be looking after the houses.

Each family was taken around their own home separately to create a personal, comfortable environment to raise questions, and to allow sufficient time for discussion. As the services strategy and design of for each house is different, it was also felt that a combined introduction to both houses risked causing confusion.

Primary walkthoughs with families included a Liaison Officer from Housing Association and a Maintenance Officer from United Welsh. They started with an introduction to the building, discussing the general design principles and how the building differs from the types of housing that the families had lived in the past.

The visits went on to cover the Passivhaus concept – to see how well occupants understood Passivhaus ideas – in order to tailor the level of technical advice given effectively. This was followed by a room-by-room tour of the house, introducing the control systems for each of the services, with extra time spent on features the families may not have encountered before, for example, the control system for the heat recovery ventilation unit.

Next came an introduction to the TSB BPE project, explaining the goals of the study, introducing the monitoring equipment, and explaining how the results of the findings will be used. Finally there was an introduction to procedures for dealing with any future concerns or technical problems.

Bere had planned to introduce occupants to the user guides for their homes, but these had been mistakenly removed and placed in storage, along with other visitor information, before the tenants arrived. The team explained that the user guides should be permanently installed in the services cupboard, so these will instead be introduced to the two families on the follow up visit.

Technical walkthrough

There was a second walkthrough tour for project partners when the families had left, attended by the architect, mechanical & electrical consultant, maintenance officer from United Welsh, representatives from contracted mechanical & electrical specialist, a decoration general maintenance specialist and a glazing repair specialist.

In summary, this had five objectives:

1. To give an update on the most recent commissioning strategy and how the controls should be set up/adjusted in future
2. To discuss technical problems that had arisen with the equipment and how best to avoid these in future.
3. To explain BPE program, and the importance of informing the team should any changes be made to the way the system is setup.
4. To establish if there are any features of the building where more information is required.
5. To discuss procedures for maintaining the system, such as filter replacement for the heat recovery unit.

BUS Study

Sadly, because the houses have only just been occupied, it has not been possible to carry out a Building Use Survey. The tenants moved in during April 2012, and they will carry out the survey in Phase 2 of the study.

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. 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. Explain any other items not covered above that may be relevant to a building performance study. If action was taken to remedy matters, improve support or feed occupant preferences into future design cycles this should be explained. 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

The team's experience of building the Larch and Lime Houses suggests that, if scaled up, Passivhaus homes can be built affordably, however reasonable costs depend on using normal weather data. Readers should also note that costs will vary somewhat according to local weather conditions.

Success in air tightness for these houses depended on the architects devoting a large amount of time to training site operatives – and to a degree on site supervision – in order to avoid loss of knowledge from design to construction. The time and cost implications of this in the traditional adversarial contractual system are prohibitive and Bere Architects believe that longer-term, architect-led collaborations are necessary in order to control quality and costs.

According to Bere, such collaborations need to be architect-led in order to be focussed on retaining knowledge within the collaboration and to reduce architects' time wasted in re-training operatives. Bere also say this brings a strong focus on quality of delivery, so that Passive House certification is always achieved without unreachable costs.

Occupant comfort

The tenants have only been in the houses for a short time so far, but they are very positive about their experience of the two houses. Two quotes from the families that move in are:

"We absolutely love this house. We can't believe how lucky we are. It's a dream – everything we could wish for and more. We look around the rooms, how warm it is, it's amazing, so well built, so well thought out, the kids love it, it's a dream come true."

"I love my room. It's beautiful. It's mega warm in there and I love playing in it."

Other comments

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

1. Where PH conflicts with Building Regs it is difficult to get contractors to understand why the PH should be adopted.
2. More control is needed on site than usual – without client supplying labour, and keeping the line of responsibility with the main contractor.
3. Collectively, the construction industry needs to improve skills to achieve the demands of Passivhaus construction. This includes increased provision (cost budgeted) for inspection.
4. Main contractors and/or designers need to get sub-contractors on board.
5. More firms should purchase their own air testing equipment and get the full team involved in the airtightness tests.
6. 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.

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

Client and owner, United Welsh, now has a position of leadership in low energy housing in Wales. Larch and Lime houses have now been occupied for just a couple of months, so it is still very early to attempt to draw out clear lessons for the client. However, assuming the occupied performance results are as expected, the findings may indicate that passive house buildings can provide added rental income security, as well as protecting vulnerable tenants, because the tenant is not forced to choose between paying the utility companies and the landlord.

As for the new occupants, Bere Architects say they are available to answer any questions or concerns about your new home. They say they want everyone to get the greatest benefits and satisfaction from living in the houses.

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.

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.

Messages for other designers

Bere Architects have had several problems on different passive house projects with front door tolerances. Getting the balance right between a threshold that passes as level access, while at the same time is completely draught-free, is far from easy. Doors that are not fitted with sufficient skill and care often end up sticking at the threshold. This means that door installation requires specialist skills and careful attention.

In social housing as in the general housing market, Bere recommend the Lime House approach of around 20% glazing ratio on the south elevation rather than the larger windows of Larch House. This brought considerable cost savings both on glazing costs and external blinds. It also simplified controls and ease-of-use. Although the larger windows and blinds gave the greatest sense of light and space, they proved a little unforgiving if blinds are not used thoughtfully.

Bere also say that pushing beyond the norm of minimum standards is always a challenge and involves hard work and long hours. However, their experience is that as these advanced working methods quickly become the norm it becomes easier, and the results become greatly more rewarding in terms of satisfaction. They also add that the clients who want these kinds of buildings are “without exception, delightfully enjoyable to work with – the cream of clients in our view”.

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. 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.

3. Glazing of around 20% of the south facade, without external shading, is more cost-effective and ultimately more robust than higher glazing ratios.

10 Appendices

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

References

This report drew information from:

Andrew Farr (2011) Commissioning and Revisit Report, August 2011

Bere Architects (2011) RICS Award Update August 2011

Bere Architects (2011) Infra-Red Thermography Report

Bere Architects (2011) Site Visit: 15 December 2011

Bere Architects (2011) Thermal Bridging and Performance Analysis Report

(No author) (2011) Monitoring Installation Layout 27.09.11

Justin Bere (2011) Cost effective solutions to social housing – comparing the differences between certification by annual heat demand and by peak load, Paper presented to Passiv Haus Institute Cost-effectiveness WORKING GROUP VIII

Nick Devlin (2011) Lime House EPC

WSA’s (2011) Co-Heating Test Report

PHPP Verification Pages

Passive House Verification

Photo or Drawing

Building:	Hwylus Haus	
Location and Climate:	Ebbw Vale	Wales - Ebbw Vale (MN)
Street:		
Postcode/City:		
Country:	Wales/United Kingdom	
Building Type:	Detached residential house	
Home Owner(s) / Client(s):	Blaenau Gwent County Borough Council	
Street:	Steelworks Road	
Postcode/City:	NP23 6YL Ebbw Vale	
Architect:	bere:architects	
Street:	73 Poets Road	
Postcode/City:	N5 2SH London	
Mechanical System:	Alan Clarke and Peter Warm	
Street:		
Postcode/City:		

Year of Construction:	2010				
Number of Dwelling Units:	1		Interior Temperature:	20.0	°C
Enclosed Volume V_e:	434.4	m³	Internal Heat Gains:	2.1	W/m²
Number of Occupants:	2.5				

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area: 86.7 m²

	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	13	kWh/(m²a)	15 kWh/(m²a)	Yes
Pressurization Test Result:	0.2	h^{-1}	0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	83	kWh/(m²a)	120 kWh/(m²a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	48	kWh/(m²a)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	60	kWh/(m²a)		
Heating Load:	11	W/m²		
Frequency of Overheating:	6	%	over 25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m²a)	15 kWh/(m²a)	
Cooling Load:	2	W/m²		

We confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The calculations with PHPP are attached to this application.

Issued on:

signed:

Passive House Verification

Photo or Drawing

Building:	2 bed Welsh Passivhaus	
Location and Climate:	Ebbw Vale	Wales - Ebbw Vale (MN)
Street:		
Postcode/City:		
Country:	Wales/United Kingdom	
Building Type:	Detached residential house	
Home Owner(s) / Client(s):	Blaenau Gwent County Borough Council	
Street:	Steelworks Road	
Postcode/City:	NP23 6YL Ebbw Vale	
Architect:	bere:architects	
Street:	73 Poets Road	
Postcode/City:	N5 2SH London	
Mechanical System:	Alan Clarke and Peter Warm	
Street:		
Postcode/City:		

Year of Construction:	2010				
Number of Dwelling Units:	1		Interior Temperature:	20.0	°C
Enclosed Volume V_e:	325.2	m^3	Internal Heat Gains:	2.1	W/m^2
Number of Occupants:	2.0				

Specific Demands with Reference to the Treated Floor Area

Treated Floor Area: 69.1 m^2

	Applied:	Monthly Method	PH Certificate:	Fulfilled?
Specific Space Heat Demand:	17	kWh/(m²a)	15 kWh/(m²a)	No
Pressurization Test Result:	0.6	h^{-1}	0.6 h^{-1}	Yes
Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household Electricity):	87	kWh/(m²a)	120 kWh/(m²a)	Yes
Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity):	49	kWh/(m²a)		
Specific Primary Energy Demand Energy Conservation by Solar Electricity:	75	kWh/(m²a)		
Heating Load:	10	W/m^2		
Frequency of Overheating:	6	%	over 25 °C	
Specific Useful Cooling Energy Demand:		kWh/(m²a)	15 kWh/(m²a)	
Cooling Load:	2	W/m^2		

We confirm that the values given herein have been determined following the PHPP methodology and based on the characteristic values of the building. The calculations with PHPP are attached to this application.

Issued on:

signed:

Photos

Photo: Bere Architects

The Larch House south façade is highly glazed with external shading to reduce overheating.

Lime House (right) has smaller windows on the south side, and is rendered. Both houses have solar water heaters and a PV array on the roof. (Photo: Tim Crocker)

The two families just about to move into their new homes, in April 2012.

Larch house, Wales' first Code Level 6 house, and its first passive house, when it was still open for visitors

End