Larch house and Lime house – review of systems design and implementation

This report reviews the design of building services at Larch and Lime houses, Ebbw Vale, and the on-site systems assessment carried out on 23rd June 2011. The two houses are similar so are described together, with differences identified at relevant points.

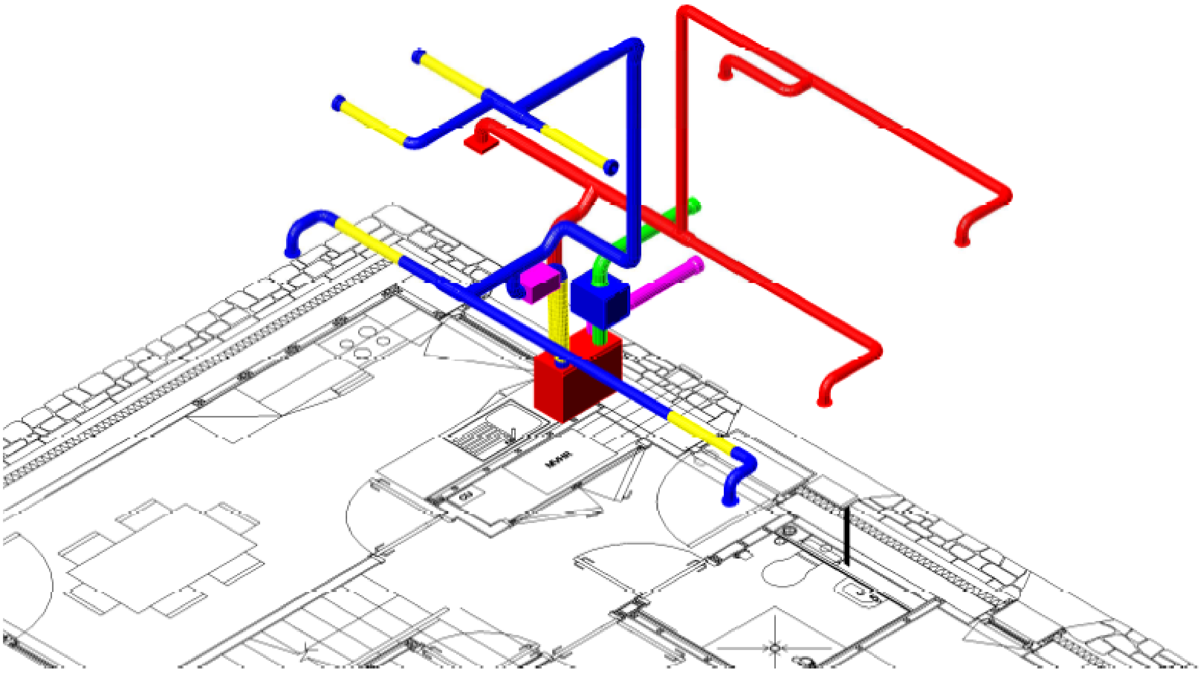
Heat Recovery Ventilation & heating

The heat recovery ventilation systems provide supply and extract ventilation. They also provide space heating. Both systems use a Paul Focus 200 MVHR unit and a VEAB hot water heating coil. The 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 area. Extract air returns to the MVHR. Terminals are Lindab steel terminals and extract valves, plus a filtered kitchen extract grille, with flow rates adjustable at the terminal.

Ductwork used is Lindab spiral wound galvanised metal ductwork. Insulation of heated ducts is mineral fibre+foil, insulation of ducts between MVHR and the exterior of the house is Armaflex. Electric pre-heating protects the heat exchanger against frost using a Paul ISO unit with G4 prefilter and PTC electric element under control of an electronic thermostat to raise supply air to the MVHR to a set point of -1°C.

Larch house

The MVHR unit is located in a cloaks cupboard by the front door. Intake and exhaust terminals face onto the street.



Ducts run in a limited zone between joists to kitchen dining shower room and living areas and rise in the airing cupboard to run in lowered bathroom and landing ceilings. Bedroom supply terminals are wall mounted and the ceiling is higher in bedrooms.

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 MVHR and this is supplied with hot water from the central heating boiler (Rehema Avanta 18s) in the airing cupboard upstairs. The heater battery is on the left 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 boiler also serves towel radiators in shower room and bathroom, and also a small radiator in the airing cupboard for clothes drying. These are heated in parallel with the duct heater under common control of a room thermostat in the living room (Honeywell DT90). The reasons for using radiators in parallel are two-fold. First, the highly glazed nature of the house, though *meeting* the 15kWh/m².a Passivhaus target, has a design peak heating load higher than can be met through the ventilation air, so supplement is needed. Secondly, the output of the air heater is less than 1kW and the minimum output of the boiler 6kW, so the radiators are included in the circuit to provide sufficient thermal mass to control temperature rise in the circuit and prevent the boiler overheating.

This rise in temperature was checked and it was seen 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 whilst 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 however the heating coil installed was smaller than originally specified. As the house was due to open for the Eisteddfod, and the boiler temperature could be adjusted, it was decided to leave the system as built but to fit the 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 appears to be significant duct heat loss, about 10°C in some cases, though no problem maintaining desired room temperatures in winter. It is probably fortunate that it is the bedrooms, with longer duct runs, that suffer the most heat loss.

The heating controls are simply the 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 type of control will avoid the common misinterpretation of a rotary thermostat as a "tap" with the higher setting correlating to more power. Here power is very limited with air distribution heating so the use of constant set point, as opposed to running heating intermittently, is more important than usual. TRVs are fitted to radiators to limit bathroom temperatures as these heaters have excess capacity – this may be absorbed when drying towels or other clothing, but needs to be controlled to avoid overheating at other times.

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

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

Key findings were as follows:

1. Insect screens in the intake louvres were badly blocked:

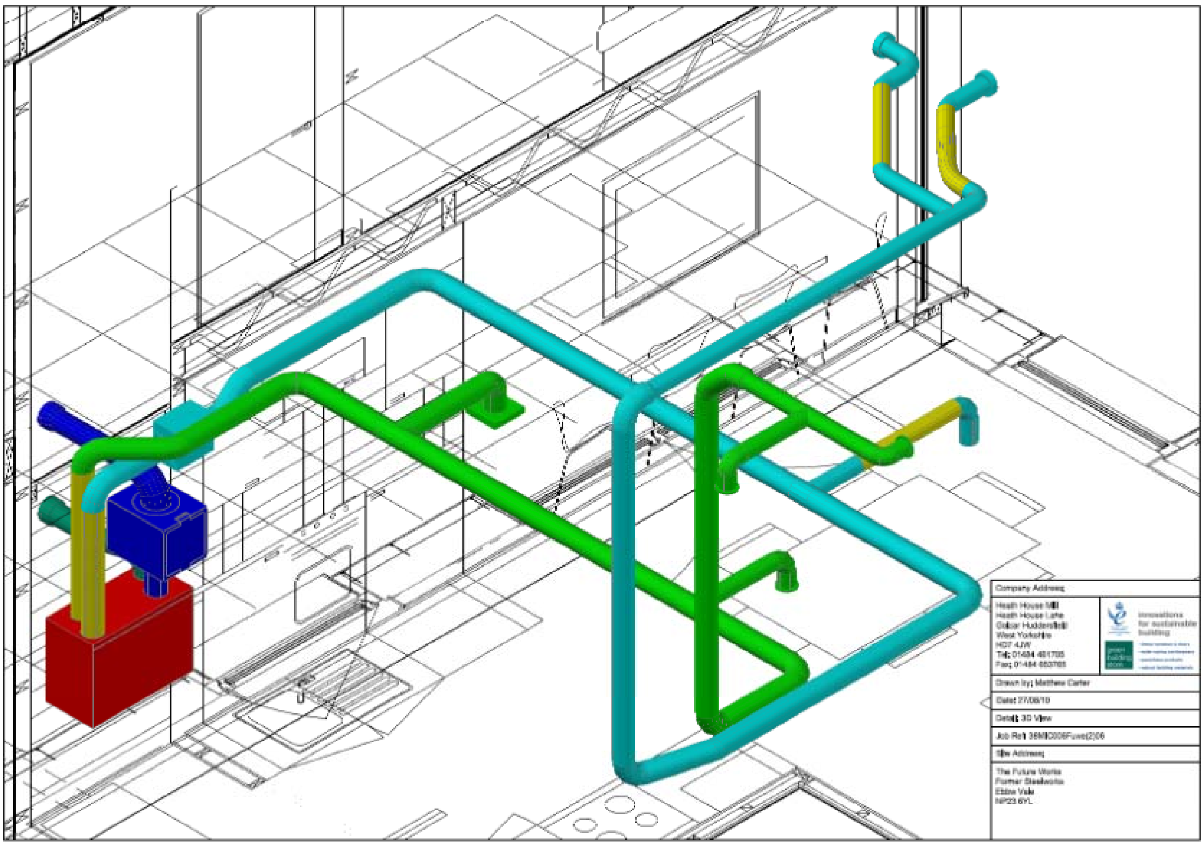
The constant volume fans were running noisily to compensate for the additional pressure loss. The screens were built into the external terminals and could not be accessed for cleaning so the decision was taken to remove them, relying on the easily replaceable pre-filter to remove fluff and insects as this filter will be changed regularly.

2. Measurements of flow rate and power consumption were taken with dirty and clean filters. These showed equal flow rates and 5% increase in power consumption, 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/hr (3-person average) and 0.33Wh/m³ for 120m³/hr (4-person average) This 120m³/hr figure compares with PHI test figure of 0.36Wh/m³ and Appendix Q test figure of 0.27Wh/ m³, though note that the PHI test should include the frost heater installation and Appendix Q does not. Neither test would explicitly include the air heater (approx 20Pa).
4. Thanks to carpet installation 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 impact on infiltration heat loss.

Note throughout the ventilation report flowrate 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

Lime house

Here the MVHR unit is located in the understairs cupboard off the kitchen and the external terminals are on the garden side of the house. Again a heater battery in the ductwork heats the supply air.

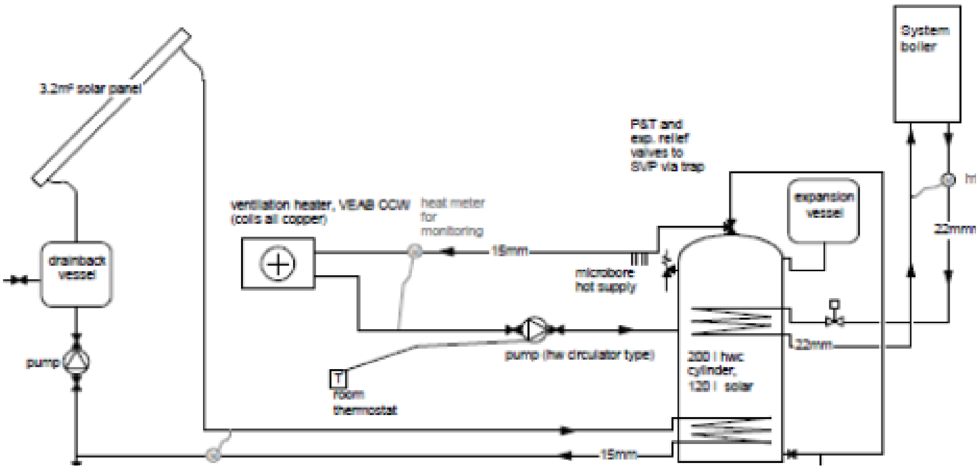


Ducts have to run in the first floor to get around the staircase before rising in the airing cupboard to serve bedrooms and bathroom via a lowered ceiling void as in Larch house.

The frost heater is on the right, the silver ducting on the left is silencers on supply and extract, and the heater battery is suspended from the ceiling. The control thermostat for the frost heater is on the wall on the left and the main MVHR controls on the right, with boost ventilation controls in the kitchen and outside the bathroom. These switch the MVHR to the highest flowrate for 15 mins.

For this house, which was certified on the 10W/m².a criterion rather than 15kWh/m².a, ie it is a Passivhaus because it can be heated via the ventilation air, BRE decided that solely air heating should be used. To avoid the mismatch between boiler output and air heater power some sort of thermal store was required, however it is known from previous experience that a standard thermal store (as distinct from a cylinder containing the actual hot water used at the taps) tend to be poor at utilising solar thermal requiring gas boiler boost during the summer. Also this type of store needs to be at significantly higher than desired 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, and cylinder heat loss is increased.

Noting that the air heater battery uses copper tube (not steel as in radiators) it was decided to use the domestic hot water directly in the air heater, so that the hot water cylinder can be operated in the usual way, with stratification to optimise the solar thermal performance. A twin coil cylinder is used, with upper coil heated by the boiler and lower coil by the solar panel:



Here the coil temperatures proved more critical, as we require 100% air heating from water at standard dhw storage temperatures of around 55°C. The larger capacity heater battery was fitted and this provides air at 49°C for water flow and return temperatures at the heater of 53°C/46°C and cylinder set point of 55°C.

Note that a change was made to the design as originally drawn as the thermostatic mixer valve fitted to the top of the cylinder prevented circulation of the hot water through the heater.

Again heating controls are a room thermostat with on/off button. Boiler controls are fitted but set to continuous dhw with cylinder temperature controlled via a boiler-connected temperature sensor. A standard high limit thermostat is included on the power supply to the 2-port valve, and the valve is controlled by the boiler to permit run-on as required.

At 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 will be drawn through downstairs rooms, providing more fresh air when bedrooms are unoccupied. Though a good arrangement for fresh air supply this proved less good for heating: during the first winter of operation room temperatures were typically 2°C higher upstairs than downstairs, so the ventilation was re-adjusted to provide 60% downstairs and 40% upstairs. It was noted that this required the living room terminal set to maximum opening.

This issue seems to be an unavoidable aspect of air-heating – we shall be interested to see how it works out in practice when the house is occupied and internal gains are added to the mix. For future design using air heating we recommend very careful consideration of the heat supply from the ventilation based on ventilation rates, duct heat loss, and room heat loss, plus desired room temperatures and consideration of buoyancy driven circulation between floors too. This doesn't look simple!

With off-coil temperature of 49°C supply air temperatures were measured at the terminals as follows:

Room	**Supply air °C**	**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°C) This indicates a significantly higher heating input downstairs than upstairs, which will hopefully redress the temperature imbalance experienced previously when the total heat input to upstairs was around 10% higher than downstairs.

Again the ventilation system was examined and re-commissioned by Green Building store as detailed in their report. Findings were essentially as for the Larch house. One characteristic found with the constant volume fans used is that they do not go down to very low flow volumes, with minimum around 70m³/hr (19 l/s). Here the fan speeds were set at 90m³/hr for speed 1 and 120m³/hr for speed2, so that for 3-person occupancy speed 1 would be the usual operating mode and for 4 person occupancy speed 2 would be used.

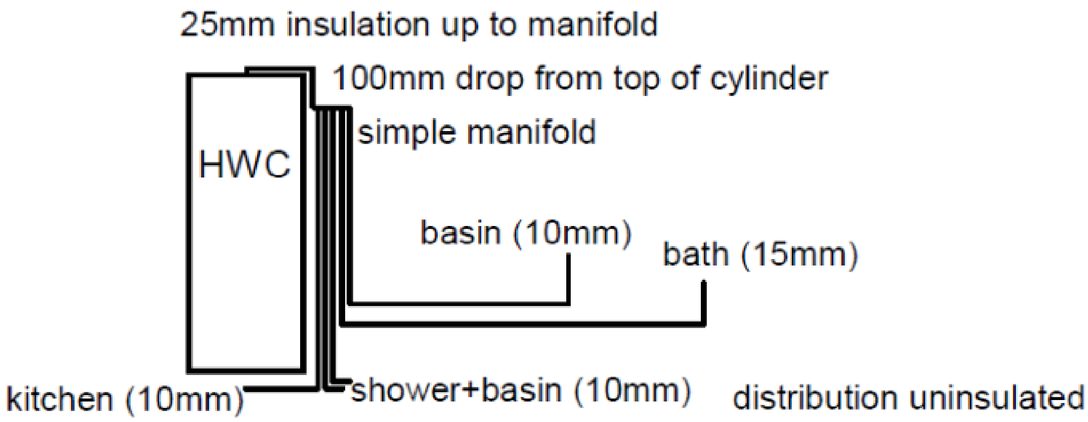
Flow rates were also checked with heating both on and off. This was found to make no significant difference.

Filters were noticeably less dirty than in Larch house – building work in progress on an adjacent site across the road may be the cause of this.

Hot water and solar thermal

Each house uses a Filsol solar thermal collector, specified as they are the only Welsh manufacturer. The Larch house has a total of 4m² and Lime 3.3m², to suit the size and expected occupancy of the houses. The hot water cylinders are unvented copper cylinders specified with higher than normal levels of insulation at 100mm thick. This required a basic cylinder diameter of 400mm to give 600mm overall to fit in the airing cupboards. Capacity 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. Flow rates are limited by restrictors for code for sustainable homes compliance 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 for faster bath filling considering that waiting for hot water is not important.



The same distribution type is used in both houses. Cold water distribution is normal, using 15mm pipework.

Note that CSH levels 5 and 6 were to be met using water efficiency measures only – household rainwater collection seems nonsensical in an area where the utility has a surplus of water. Also the concentration on minimising use of water also minimises the use of energy for heating water – by far the largest energy use in water systems.

The Larch house solar thermal system was designed to use a pressurised system but it was intended to use a drainback system in Lime house to compare operation and reliability of the alternative approach. However the installers felt there was not room for the drainback tank in the airing cupboard and fitted it in the loft of Lime house. This is inaccessible and not frost free so not a viable location and the installer converted the system to pressurised.

The systems have not always worked well and a solar specialist, Llanisolar was commissioned to examine the systems. Their findings are covered in a separate report, though note the house names Larch and Lime were inadvertently swapped.

The principal finding was that the switch from drainback to pressurised in Lime house was not carried out with the correct pump station, leading to loss of heat from cylinder to panels – this cannot happen with a drain back system but in a pressurised one a non-return valve is needed. 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 at the time of installation of the monitoring equipment (17th Oct 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 not the return, and had to be refitted to the correct pipes in both houses.

Also at the October visit the Larch house system was seen to have ceased working, with the pump no longer running.

Metering and monitoring

The monitoring aims to cover a number of aspects of these buildings, connected with both Passivhaus and code for sustainable homes standards, detailed as follows, with all meters and temperature sensors being linked to a datalogger to record measurements at 5min intervals for remote upload:

Total energy use for gas and electricity in each house (requires additional export meter to monitor actual household usage before PV input considered)

Passivhaus specifically is a heating energy standard so we will measure heating energy use (requires heat meter to separate from hot water; in Larch house two are used for towel rail and heater battery, Lime only requires one)

Also it is necessary to measure external conditions to make sense of this, for which a weather station is used mounted to Lime house, and internal conditions of temperature and relative humidity in a number of locations.

CSH water use - houses are designed to meet CSH5/6 water use based on efficiency: measure total water use and hot water use via a water meter on cold feed. Temperatures of cold feed and hot water supply are also measured.

Solar PV: PV generation measured, external insolation measured via the weather station

Solar thermal: here the kWh measuring facility of the solar thermal controls was used – this is cheaper than an additional heat meter as the flowrate is assumed constant and read from the flow meter in the solar pump station.

Mechanical ventilation: measure internal air quality - CO_2 - also temperatures in MVHR system, and electrical use of the system

Heating via air a la Passivhaus – this is a distinct technology in addition to MVHR. Individual outlet temperatures may be assumed not to vary much over time, so these were measured at spot check. What is particularly interesting in the case of 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 living room.

Lighting – this is a CSH measure – so we measure electricity use for lighting. External lighting is excluded as not an internal heat gain.