Simple and cheap heating systems for individual Passive Houses

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1 Introduction

Many of our projects are single-family Passive Houses on urban or rural sites where there is no district heating. These houses need a heating system that uses the energy available at the site, either natural gas or electricity. We would like the heating systems to be cheap, easy to install and maintain by local tradespeople, and efficient and well-controlled.

We developed simple and economic approaches using either a gas boiler or a heat pump and a water-filled heating system. The heating systems are designed to address the issue that conventional heat sources are too powerful for the heat load of a single Passive House.

Temperatures have been monitored using equipment from openenergymonitor.org/emon/ using wireless sensors (±0.5 °C) in rooms 1.2-1.8m above floor level. Water temperatures are measured by surface fixed sensors which read 1-2 °C lower than water temperature.

2 Radiator systems

Radiators form a well understood and reasonably low cost heating system. During the design of the Lancaster co-housing scheme [Yeats 2014] we needed to reduce costs, and with the agreement of the client we omitted radiators from bedrooms and cloakrooms. This left one main radiator in the main living area and a towel rail in the bathroom. Monitoring showed that the bedrooms are warmer in use than heat loss calculations usually predict, even with doors closed, thanks to internal heat gains. A Building User Survey carried out for this project showed that occupants were very happy with the thermal comfort in the houses. Since then we have generally used minimal numbers of radiators with good results.

Here we look in more detail at a detached Passive House completed in May 2013 in Clehonger, Herefordshire. This is timber frame on a ground bearing insulated concrete slab. The heating uses a 12 kW natural gas boiler (Worcester 12i), with a main column radiator in the living room and towel rails in bathrooms. Total cost for radiators and valves was around £ 500 (650 €). The heating control is room-compensated type (FR110) with a temperature sensor in the room programmer, used by the boiler to calculate the required flow temperature according to the difference between actual and desired temperature.

We monitored conditions in the house with a number of temperature and humidity sensors, and temperature sensors on heating system pipes. The kitchen temperature is measured at the main heating control, set at 20 °C between 07:00 and 23:00 each day (no overnight heating is conventional in the UK) (Figure 1). The ensuite bathroom has a heated towel rail, with thermostat at occupants chosen setting of 19 °C; the high peaks in temperature are due to showering. The occupants sleep in Bedroom 1 and this is comfortable at 18 to 19 °C. Bedroom 2 is spare and unoccupied, and temperatures are as low as 17 °C.

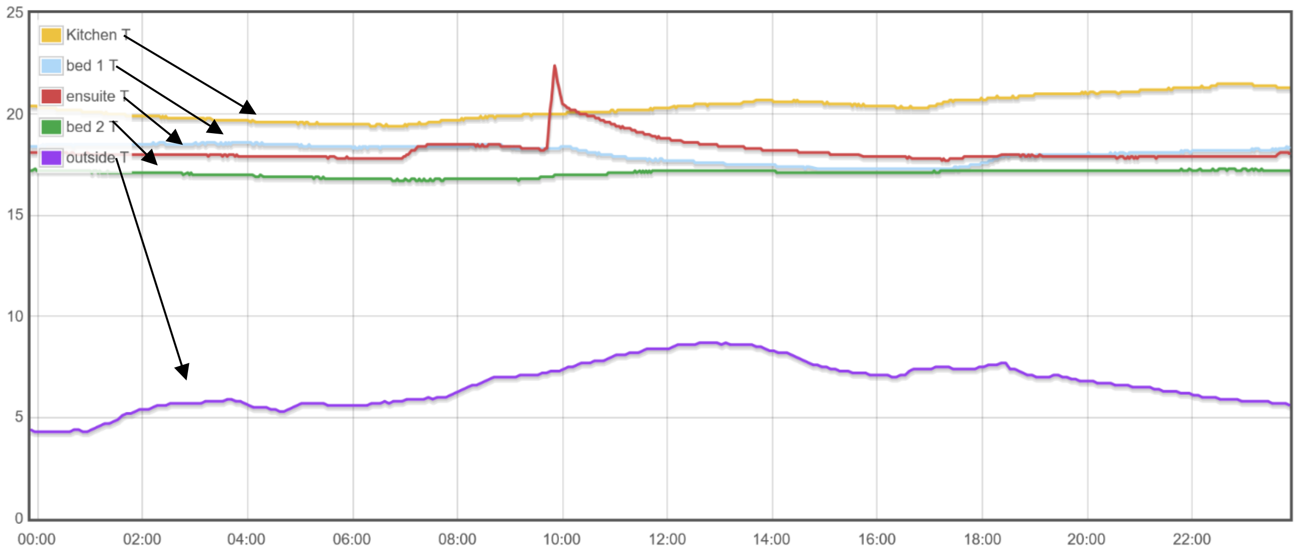

Figure 1: Winter temperatures in Clehonger Passive House over 24 hours

2.1 Design of self-buffering heating system

The 12 kW boiler in this house can reduce output to a minimum of 3 kW, but the design heating demand is only 1 kW. If we have a 1 kW radiator there are 2 kW of extra heat to absorb. With a small heating system the temperature of the water can rise rapidly and cause the boiler to shut off as an emergency measure. The traditional solution is a buffer vessel, say 200 L of water. This requires more space and adds complication and cost to the system. Instead, we looked to see if the system itself could form a buffer if the radiators were large enough.

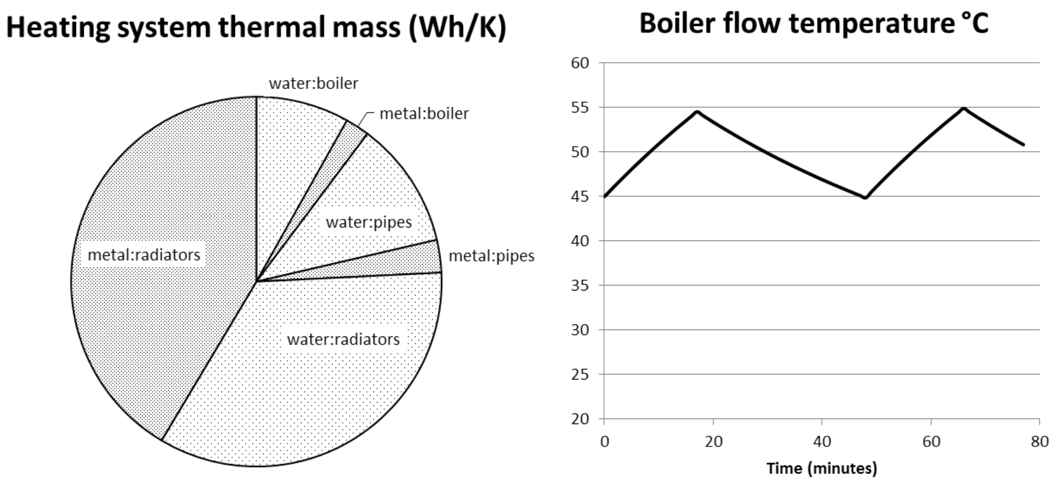

Figure 2: Calculated heating system thermal mass and temperature response with oversized radiators

We know that the boiler will be fine with < 1 K temperature rise per minute, and also will only be at risk of high temperature lock-out if running > 70 °C. So we selected a water temperature so that the radiator water volume and thermal mass combine to limit the temperature rise of the heating water (Figure 2). We deliberately used a high water content radiator, and sized for maximum heat demand at an average temperature of 52 °C so that it would be large enough to provide the buffering we wanted. To ensure that the volume is always available for buffering there is no thermostatic radiator valve (TRV) – output control is by the room compensating controller. This would not work so well with a large number of radiators, each with a TRV – we find in this case the bedroom TRVs are normally closed.

2.2 Results

Looking at the monitored results we see the boiler typically fires for 10 minutes, and the flow temperature rises by 10 K (Figure 3). This cycle repeats every 30 to 60 minutes, depending on room temperature. The heating does not run for 24 hours – typically solar gains in the day mean the boiler turns off in the afternoon and restarts after sunset, stopping when there is heat gain from cooking in the kitchen. Note peaks at 60–70 °C are for heating the hot water (this temperature is not running through the radiator – our sensor is at the boiler).

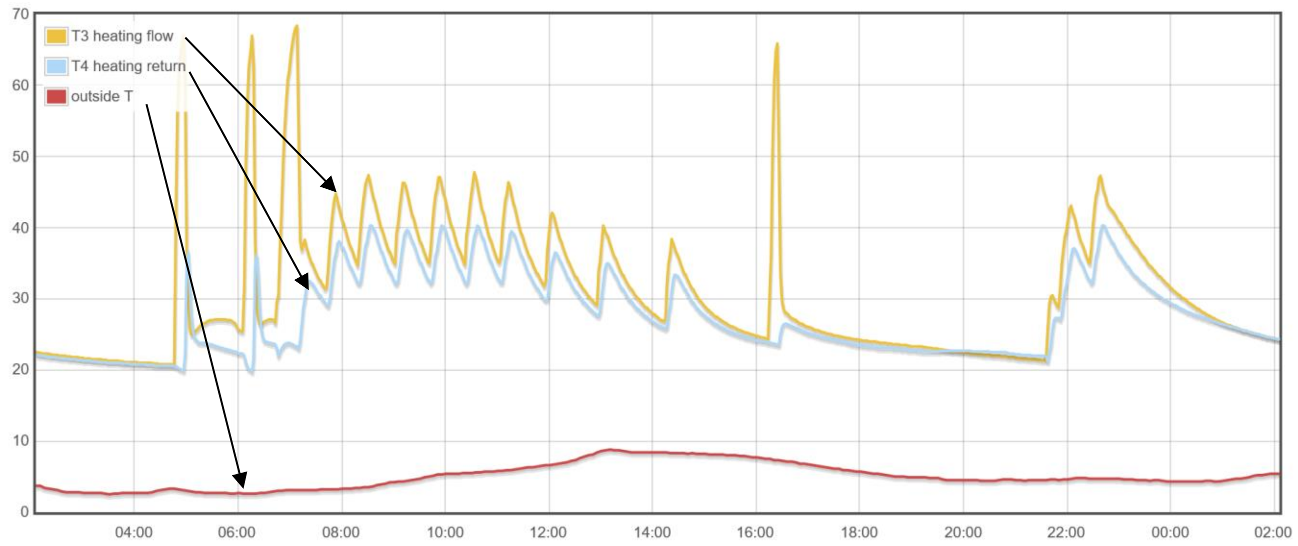

Figure 3: Heating system flow and return temperatures during a January day

Although the monitoring shows the system is working well, the return temperature to the boiler is higher than we expected. This may be due to water passing through the towel rails and not cooling down due to the insulation of towels. Here we did not use valves with preset flowrates on the towel rails, but it would be good to do so in order to limit this flowrate.

3 Underfloor heating

Underfloor heating is not necessary for comfort in a Passive House, and is a relatively expensive system of heating, but sometimes clients decide they want to pay for it anyway. Also at the low temperatures of floor heating a heat pump operates at peak efficiency.

Early experience of underfloor heating in low-energy houses could be poor, with issues of overheating. Conventional systems were able to provide 70 W/m^2, in a Passive House this is far too much. The slow response of the floor temperature to inputs from a room thermostat leads to too much heat being put into the floor. Weather compensation is a traditional method of dealing with this, but we see in Passive Houses that the influence of solar and internal heat gains is so large that external temperature is no longer a good predictor of heat load.

A Passive House of similar construction in Taliesin in Wales is heated by a 4 kW “Kensa Single Compact” ground source heat pump, with heat input directly to the ground floor slab only (plus bathroom towel rail) (Figure 4). The system was designed by John Cantor. The house has two floors so the heat output required from the floor will be around 20 W/m^2.

Figure 4: Laying the underfloor pipework in Taliesin Passive House (left); finished house (right)

The thermal surface resistance for heat flow from the floor to the room is 0.1 m^{2}K/W, so for a heat load of 20 W/m^2 the floor will only be 2 K above room temperature. We modelled the temperatures within a floor, here with boundary temperatures 24 °C for the pipe and 20 °C for the room, with resultant heat flow of 25 W/m^2 (Figure 5).

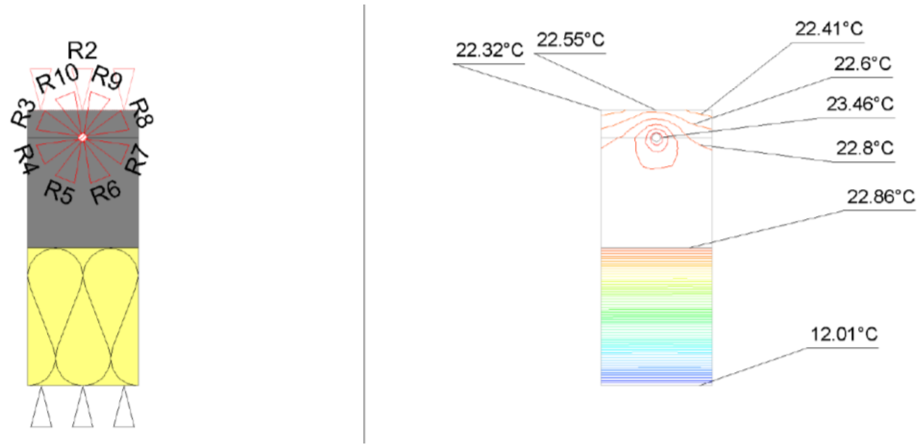

Figure 5: PSI-therm 2-D model of underfloor heating pipe in concrete slab (R2 defines room boundary condition, R3–R10 to pipe section approximated as an octagon)

According to this model for 20 W/m^2 load the room temperature will be 20.8 °C. With an average of just 24 °C only a small water temperature drop can be achieved between flow and return, at most 4 K, since the slab is at least 22 °C the return cannot be lower.

The slab is 250 mm thick and hence thermally massive. If the heat pump is turned off the slab will still be at an average of about 22.8 °C and continue to heat the room. However, if the room temperature increases due to solar gain, for instance, the temperature difference between slab and room reduces, and at a room temperature of 22.8 °C, there will be no more heat transfer from the floor to room. Conversely, if the doors are left open, and the room temperature drops to say 18 °C, we now have a higher temperature difference and increased heating power from the floor.

3.1 Results

Monitoring shows that room temperatures are very stable (Figure 6). The heat pump is controlled on/off by a room temperature thermostat, but can also be turned off by a return water high limit thermostat (in the heat pump) which is set at 22.5 °C. This is needed to limit the average temperature of the slab and prevent it from getting too high. On a cold day the room temperature control may be too slow to respond to the heat being put into the floor, but we know a return temperature of 22.5 °C corresponds to a floor temperature able to meet the maximum heat load. If the room temperature is still below the set point after the return has cooled below 0.6 K hysteresis then the heat pump starts again.

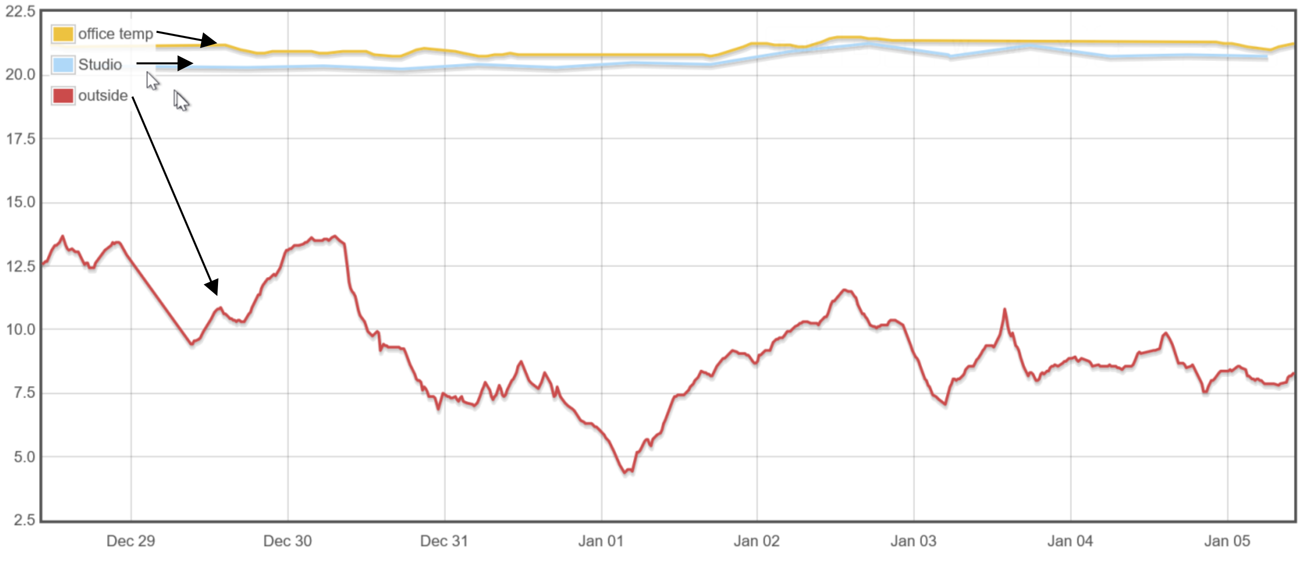

Figure 6: Room temperatures over a week

The initial spike in the graph in Figure 7 at 07:00 is where the heat pump heats domestic hot water, then the heat pump heats the floor. Here, the flow temperature rises slowly from 25 to 27 °C over a number of hours, with return temperature about 4 K lower. The heat pump does not cycle on and off, despite having a fixed output 3 times the design heat load of the house, and generally provides sufficient heating with 1 or 2 cycles per 24 hours.

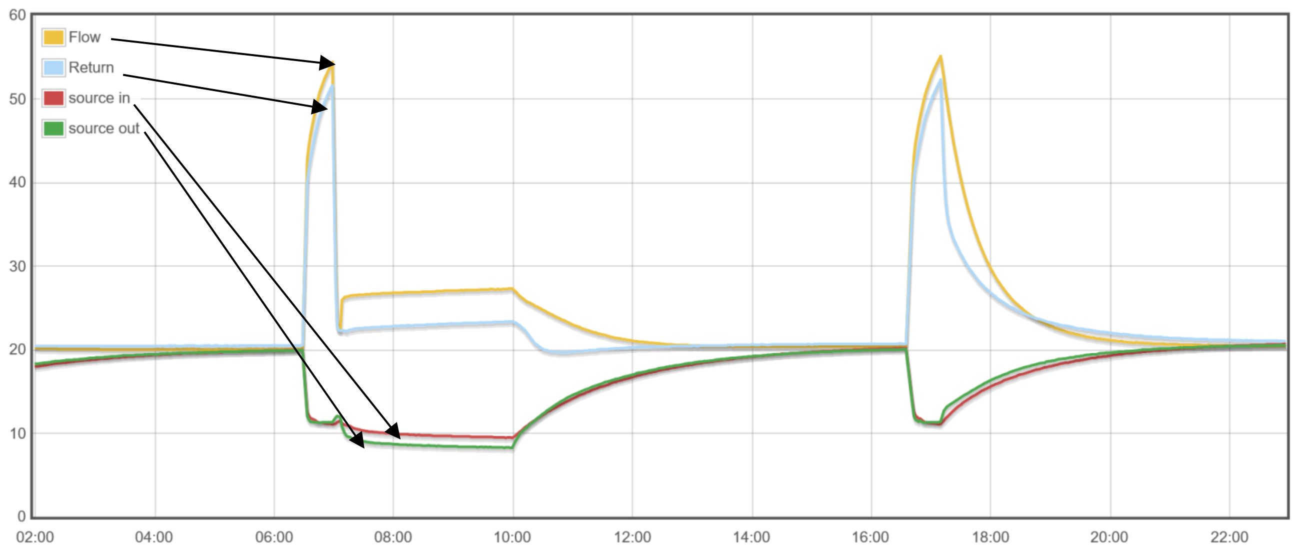

Figure 7: System flow and return temperatures

In the design, we had allowed for zoned control to be added with room thermostats and actuators on the heating manifold, but this proved unnecessary, saving the client about £ 1000 on the cost of the heating system.

4 Conclusions

- The heat loads in a Passive House are very low.
- The heat flow between rooms in a building is the same as less well insulated houses.
- We do not need to heat all rooms, so can use a simpler heating system.
- Buffering through the mass of a radiator system or floor heating enables a standard size heat source to be matched to the much lower heat load of a Passive House.
- Radiator and underfloor heating systems are standard items and easy to obtain at competitive prices.
- Use manufacturer's standard controls and schematics to avoid confusion and mistakes, both at installation and over the lifetime of the system.
- For a Passive House, the same components can be used, but in a simplified form and at lower cost than usual.

5 Acknowledgements

Taliesen Heat pump system & monitoring: John Cantor (www.heatpumps.co.uk)

6 References

[Yeats 2014] Yeats, A.: Lancaster Co-housing Project, Proceedings of 18th International Passive House Conference, Passive House Institute, Darmstadt, 2014.