Wimbish Passivhaus Development: Performance Evaluation

2014 Assessment with Technical Appendix

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Synopsis

This paper reports on an assessment of the performance of the Hastoe Housing Association's Wimbish Passivhaus development during calendar year 2014.

It may be read as an update to the Technology Strategy Board (now Innovate UK) funded Building Performance Evaluation study that covered the period from 1st April 2011 to 30th September 2013. (An executive summary and a case study may be found on http://wimbishpassivhaus.com/datasheets.html.)

This assessment confirms the study findings that the Passivhaus approach delivers homes that are comfortable, healthy, and economic to run. Recommendations are made to reduce the risk of future developments suffering from any 'performance gap'.

The continuing monitoring and assessment is valuable to confirm that there are no adverse performance trends, as well as to highlight any defects that might occur so that they can be remedied.

This version of the paper includes the Technical Appendix.

1. Introduction

The TSB Building Performance Evaluation Study verified that the Wimbish Passivhaus development was meeting Hastoe Housing Association's (HHA) primary objective for the dwellings to deliver very low heating bills. Low bills help reduce the impacts of fuel poverty for their tenants, and have the potential to reduce rent arrears.

Figure 1: General View: Houses to right, flats to left

The study proved that the Passivhaus approach delivers. Overall, the homes were performing as designed and provided the occupants, none of whom had particular prior interest in sustainability or energy efficiency, with homes that they found economic to run, healthy to live in and very comfortable and spacious for the size. Some residents stated that their heating bills were only £30 a quarter. This lack of a 'performance gap[1]' is a reflection of the high quality process necessary for Passivhaus development from design to occupation.

Content

This paper covers (for 2014):

- Energy
  - Gas – total and seasonal use
  - Electricity
- Comfort
  - Thermal – winter and summer
  - Humidity – end of the winter
- Air quality – CO_2 readings in winter
- Ventilation – energy use by MVHR in three properties.

[1] For information on this concern see http://www.zerocarbonhub.org/current-projects/performance-gap.

2. Conclusions

The main findings from this 2014 assessment are:

- That the comfort levels and air quality achieved remained good throughout the year
- That the gas consumption and thus the heating bills have remained very low
- The electricity consumption remains ‘normal’, somewhat above the expected low levels in a Passivhaus.
- The ventilation systems seem to be working a bit harder than they ought.

These echo the previous TSB study findings; no deterioration has been identified.

Some recommendations are made to help to ensure that future developments minimise the risk of a performance gap.

The properties should continue to be monitored to confirm continued performance, and to assess the impact of recent servicing of the solar systems and the MVHR.

The monitoring is considered to provide valuable information for Hastoe and for the house-building industry at large.

3. Energy

Annual Gas Consumption

Expectations

Passivhaus design aims for a reduction in space heat demand of around 80% from existing housing stock; reductions from property built to UK Building Regulations remains large. Compliance with the Passivhaus standard requires that space heat demands no more than 15 kWh/(m^2·a)[2] of heat; all 14 units at Wimbish were designed to comply with this requirement.

The design also aims to keep hot water consumption low.

At Wimbish, space heating and hot water are provided by a small gas boiler in each property, supplemented by a solar thermal panel. Gas is not used for any other purpose.

The assessment compares actual gas consumption of each property with the figures calculated in the design.

Findings

Even the worst performing house at Wimbish continues to consume far less gas than typical properties.

Consumption in a property varies from year to year, reflecting the weather. There have been changes in consumption in a couple of properties following a change of tenant.

Overall, except for the cold winter 12/13, average performance is close to the expectations. There is variation between households as one might expect; and we can seek to explain this by the level of occupation and the habits of the household.

If the households were on a cost-effective tariff, then the average gas bill in the flats in 2014 would be £62 and in the houses £130 (including VAT).

[2] For example, for an 80m^2 property, this is only 1,200 kWh of heating in a year (nb hot water demand must be added)

Detail

Figure 2 shows the annual gas consumption of the properties since occupation. It shows how this varies from year-to-year and how it differs from one property to another.

Four bars are shown for each property; the first three reflect that initial occupation was mid-year, and show consumption from July one year to June the next; the fourth bar is for calendar year 2014.

The second year, 2012/13, was the only hard winter experienced, the others being very mild; the chart clearly shows the extra consumption.

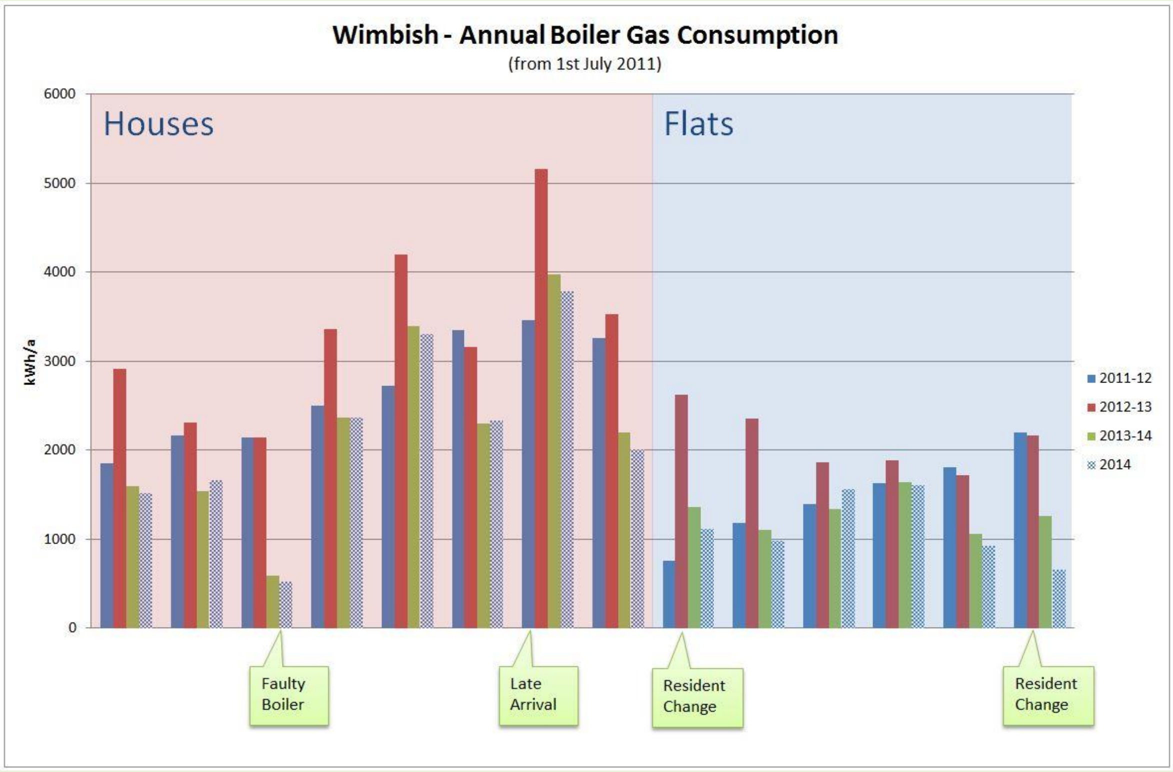

Figure 2: Annual Boiler Gas Consumption

To put this into context, Figure 3 compares these same figures with Ofgem's typical domestic consumption values; it illustrates just how low the Wimbish consumption is.

The chart also illustrates roughly how much the Wimbish residents would be paying for their gas if they were on Ebico's Equigas tariff. During our TSB study this was identified as probably being the most cost-effective option – it should be noted that very low consumers of gas are penalised by most suppliers in having to pay more per kWh delivered than standard customers.

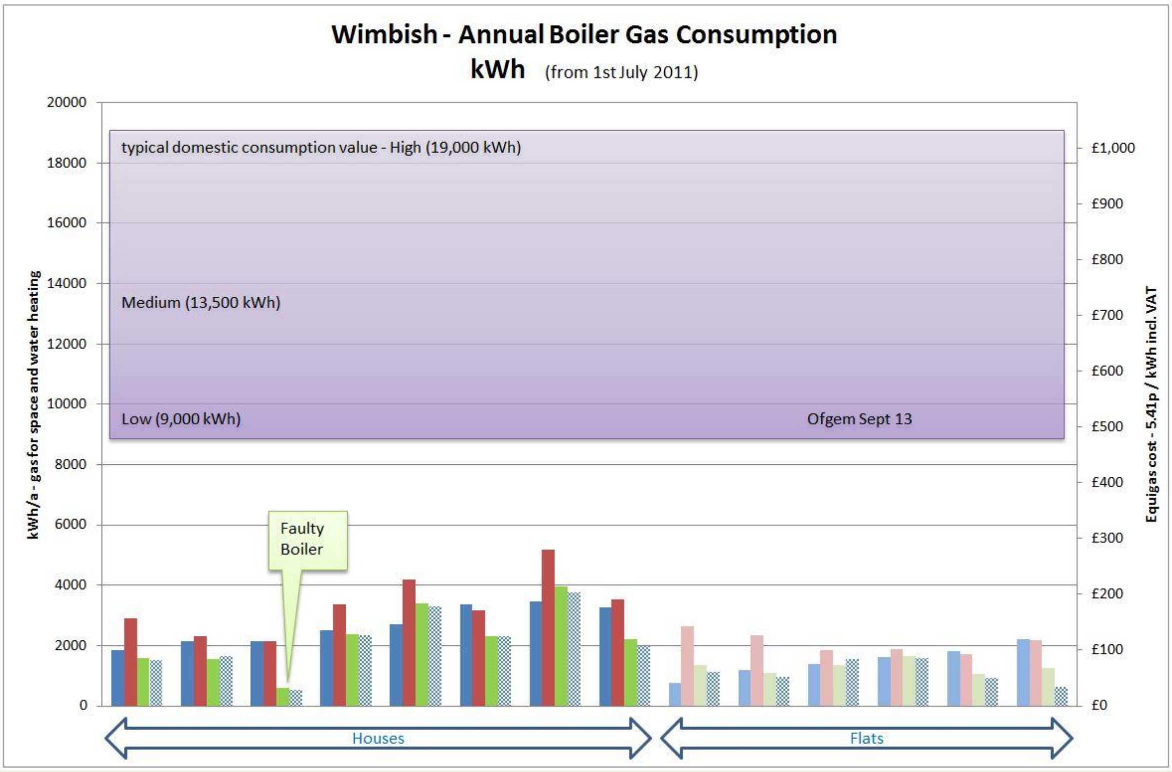

Figure 3: Boiler Gas Compared to typical values

Figure 4 shows the gas consumption normalised by the floor area of the properties. In addition, this shows the expected boiler gas consumption calculated by PHPP, the Passivhaus Planning Package used for design.

Overall, especially if one ignores the data from the cold winter 12/13, the average performance is close to the expectations. There is variation between households as one might expect; and we can seek to explain this by the level of occupation and their habits.

It can be seen in the two flats that have changed hands that the new occupants have been more careful than their predecessors, though in one flat they are perhaps trying too hard to reduce already low gas bills.

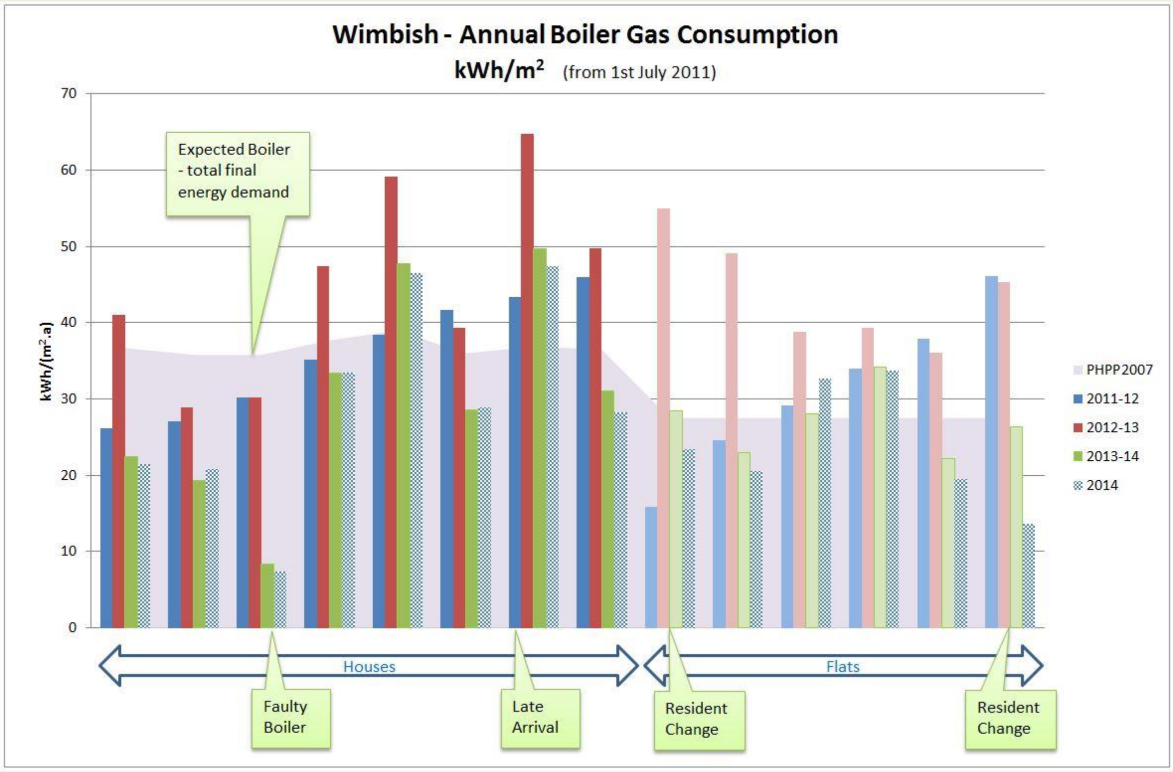

Figure 4: Boiler gas consumption by floor area

Seasonal Gas Consumption

Expectation

In a Passivhaus, the space heating is only required in the coldest months, whereas hot water demand is fairly constant throughout the year. The grey bars in Figure 5 are the sum of these two demands and the yellow bars show the contribution from the solar panels towards meeting this demand.

The boiler is required to make up the difference between demand and the solar contribution.

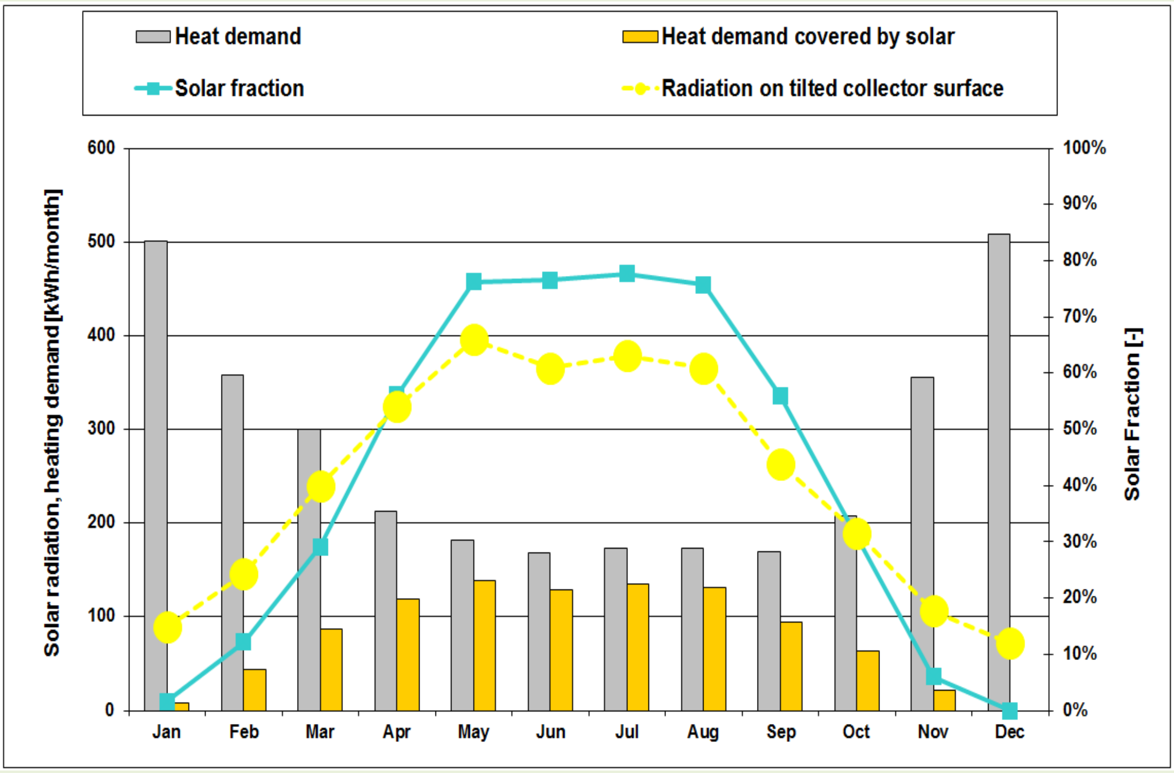

Figure 5: Heat Demand and Solar Contribution (PHPP as designed – but re-implemented in PHPP8.5)

Thus, if the properties are performing as designed, we might expect to see high gas use in December and January, falling to very little from April through to September, certainly no more than 30 kWh per month. Indeed, in some properties, summer gas use was expected to be zero.

Findings

However, as can be seen in Figure 6, around half of the properties for which we have data, have summer gas consumption well above the expected values.

Site visits to review the provision of hot water have been made autumn 2014 and it will be interesting to see whether there is an improvement in 2015.

A recommendation from this is for future design to consider the impact on systems and their performance if occupancy levels differ from the Passivhaus norms. At Wimbish it would probably have been desirable to have larger solar panels on the houses.

Detail

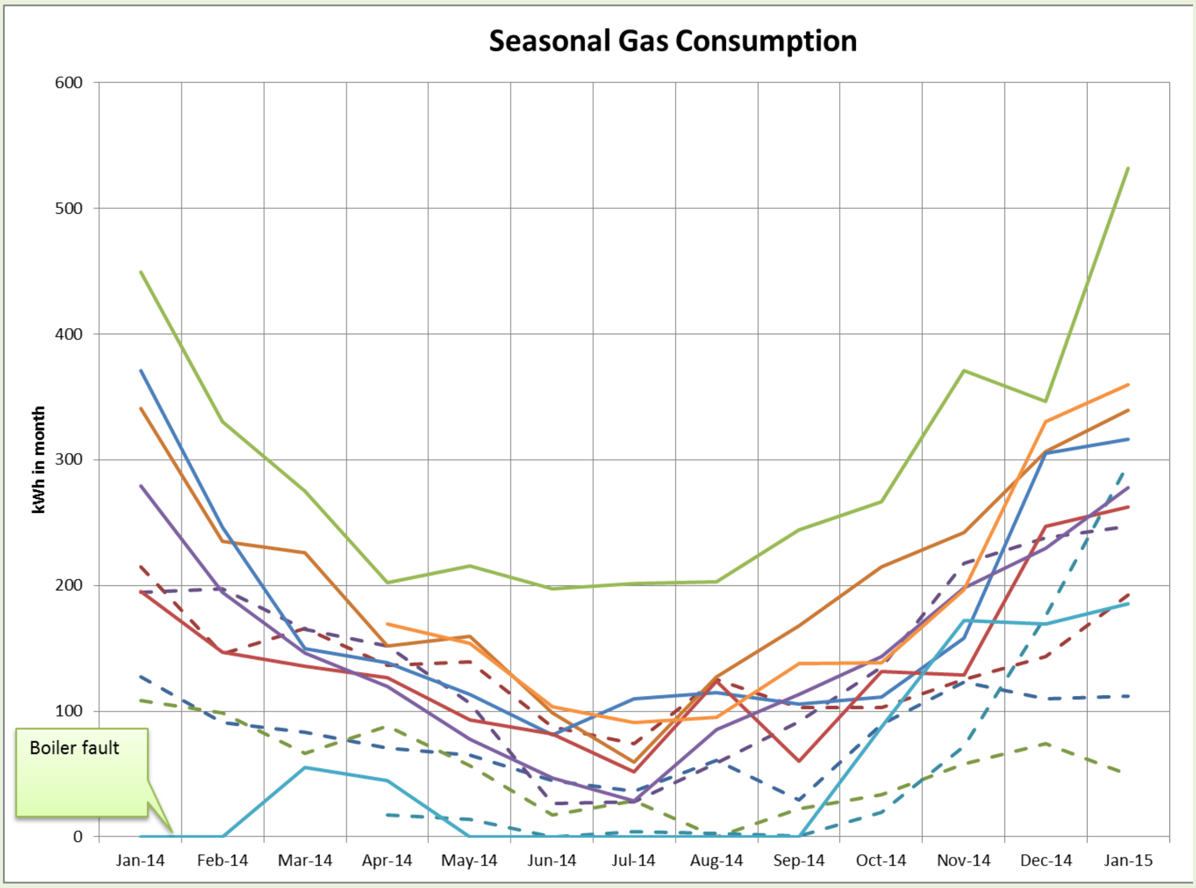

Figure 6: Logged Monthly Gas Consumption[3] (houses solid lines, flats dashed)

This unexpected gas use in summer may be down to one or more of the following:

1. Unanticipated (and unlikely) use of space heating
2. Reduced, or no, contribution from the solar panels.
3. Household sizes are larger, and/or the residents bathe more, than the assumptions in PHPP.

3 Gas metering for 2 plots has not functioned, and in a further two only since end March.

Annual Electricity Consumption

Expectations

The Passivhaus standard does not include an explicit target for electricity use, but we can establish an allowable figure for electricity for each property – about 27 $kWh/(m^2 \cdot a)$ for the houses and 31 $kWh/(m^2 \cdot a)$ for the flats.

By comparison, if we divide the Ofgem medium typical domestic consumption value by the average UK property size, we get a figure of 40 $kWh/(m^2 \cdot a)$.

Findings

In general, the electricity consumption in the houses may be described as 'normal', and not the reduced level hoped for in a Passivhaus. In the flats consumption is less, a reflection of lower numbers of occupants.

Extra heat gains from electricity use will tend to reduce gas bills for heating in winter, and raise the risk of overheating in summer.

Ideally a Passivhaus developer would provide energy efficient appliances. Designs might also seek to encourage energy saving behaviours, and handover to the residents should also include tips on reducing their electricity bills.

This reinforces a recommendation that designers should consider the sensitivity of their design to variations in factors such as level of occupation and use of appliances.

Detail

The annual electricity consumption chart (Figure 7) shows that on average the houses consume a little above the Ofgem medium value, and the flats well below – largely a result of lower level of occupation.

There is a distribution of consumption across the houses and the flats, rather more in the flats – again reflecting occupation levels. In most properties, there is little year-on-year variation in consumption, the exception being 2 flats that changed tenants.

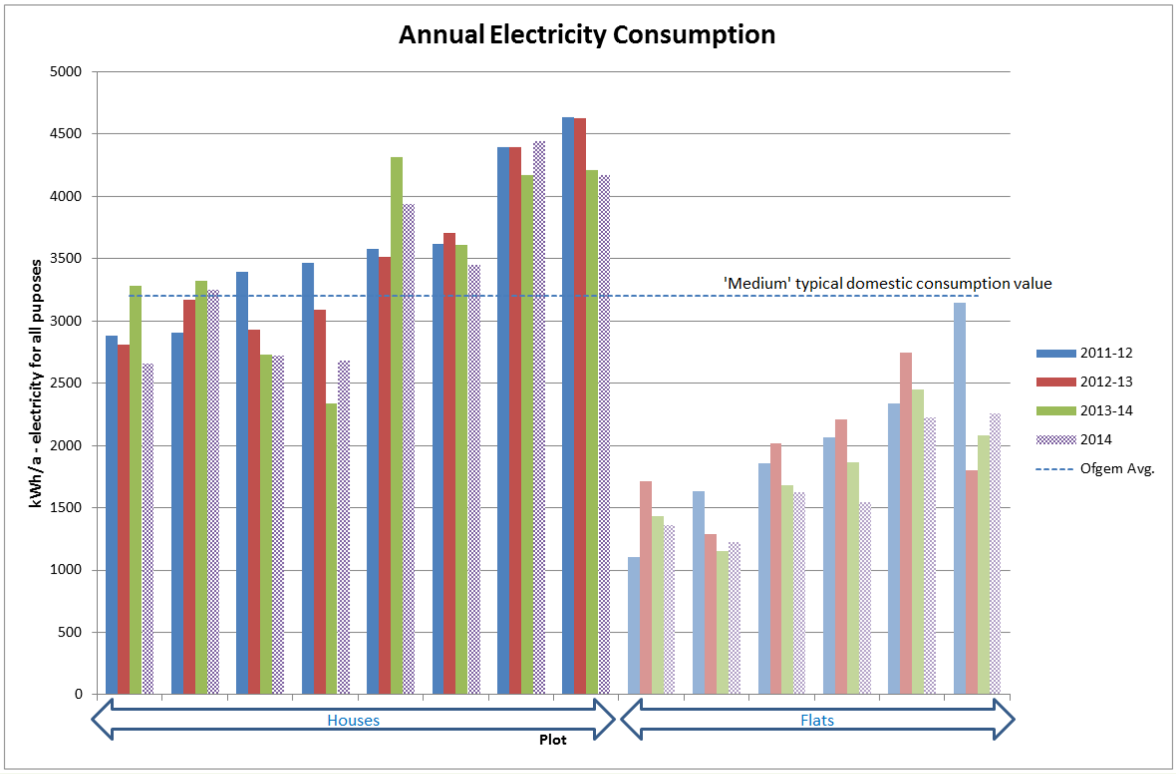

Figure 7: Annual Household Electricity Consumption

Plotted against floor area, and in comparison with the PHPP ‘allowance’ (Figure 8), it can be seen that none of the houses, and only two of the flats, are exceeding expectations.

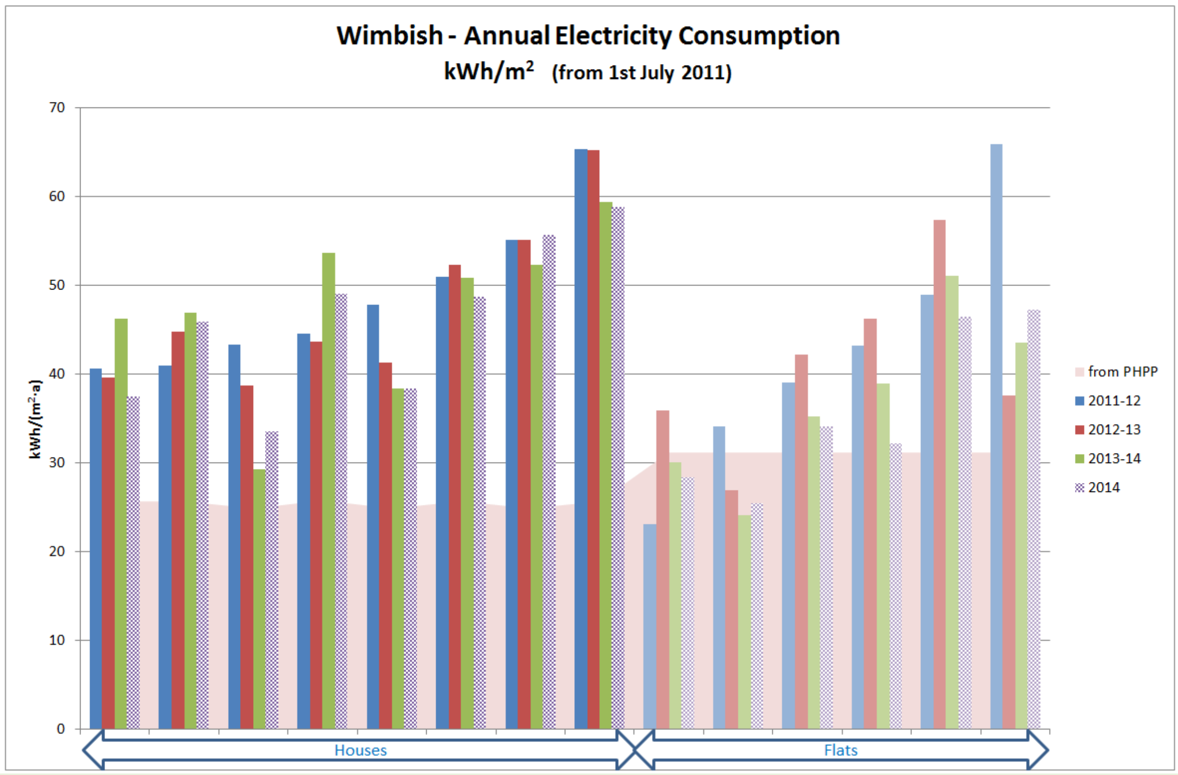

Figure 8: Electricity by Floor Area

This ‘normal’ electricity consumption may be attributed to two factors:

1. Higher levels of occupation than assumed in the design
2. Households bringing their existing, relatively inefficient, appliances with them; and, where new appliances were purchased, the capital cost being a higher priority than efficiency in use.

4. Comfort

Thermal comfort in winter

A Passivhaus should be capable of maintaining a constant temperature of 20 °C in cold weather, however, in practice, the occupants may be happy to let the temperature fall a little when they are out, or asleep.

Figure 9 shows, for February 2014, the range of values for 80% of the time[4], and the median value, for each sensor:

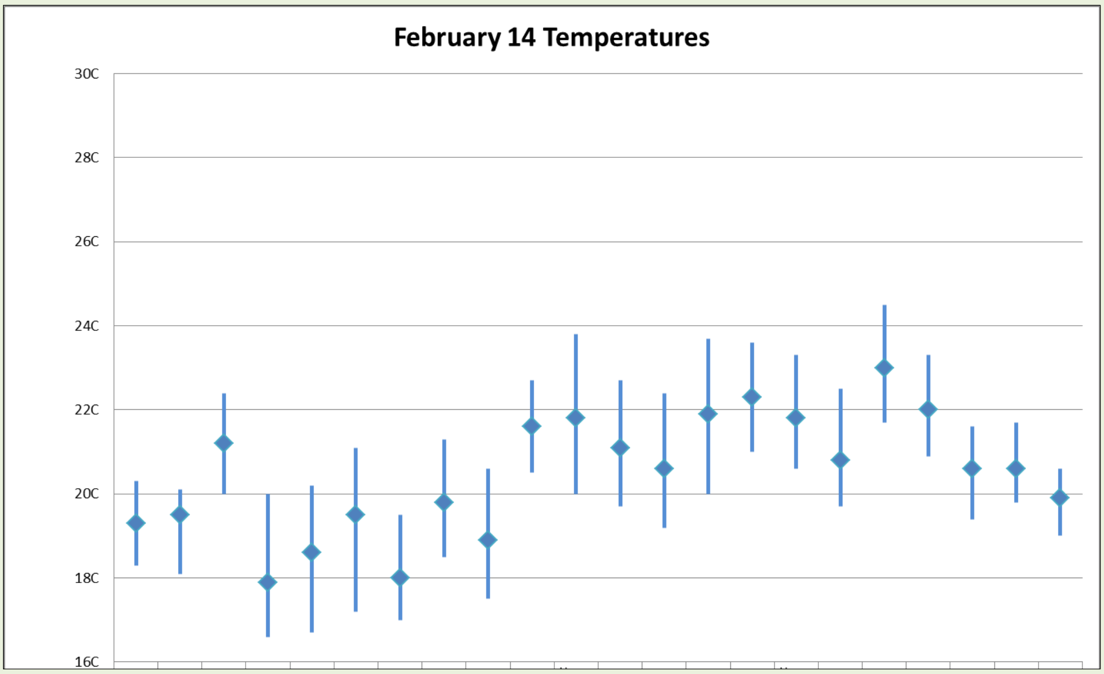

Figure 9: Winter Temperatures (Flats to the left – 8 sensors; remainder sensors in the houses)

The flats are generally a bit cooler than the houses; this is thought to relate to the level and hours of occupancy rather than any inherent difference in the structure.

Overall the temperatures in February are excellent, though it should be noted that it was a relatively mild February.

[4] Omitting top and last decile

Thermal comfort in summer

There is concern that new homes, especially thermally efficient ones, can overheat in summer when it is difficult to dissipate excess heat.

The aim of Passivhaus design is to ensure that 25 °C is not exceeded more than 10% of the (annual) occupied hours.

Although 2014 was a warm year overall, it did not have an extended period of hot days that would thoroughly test the dwellings and their occupants. July was the warmest month; Figure 10 shows that most properties average below 26 °C for the month.

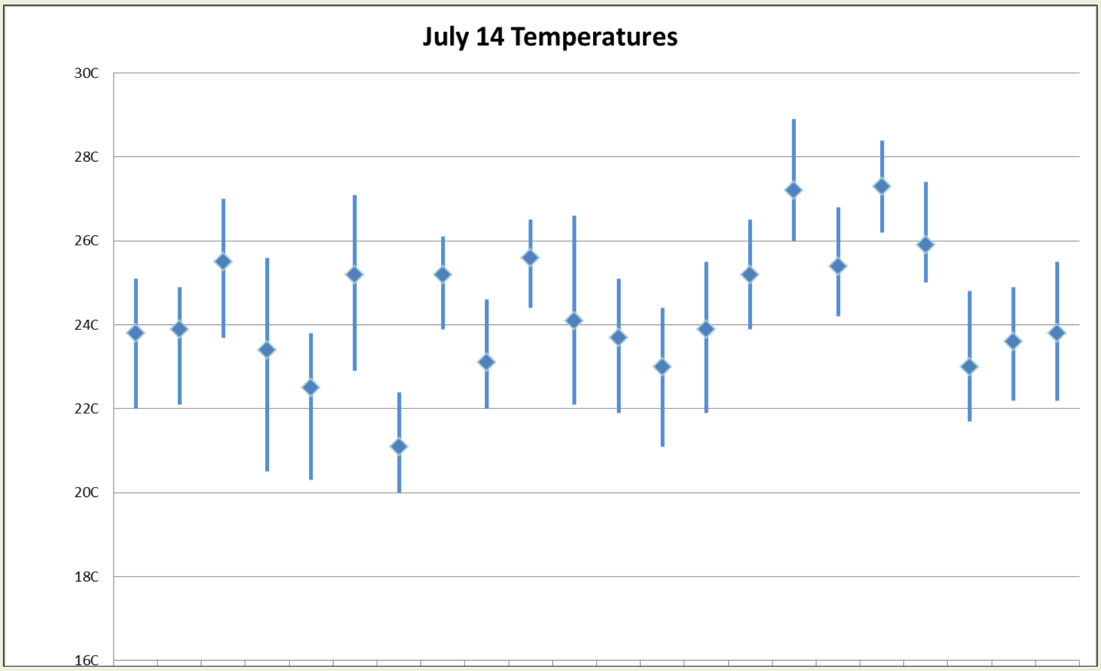

Figure 10: Summer Temperatures (Flats to the left – 8 sensors; remainder sensors in the houses)

Over the whole year, most of the properties are comfortably within the ‘10% of the time’ limit; one flat and two houses being between 12% and 15%. The exception is a 3-bedroom house where the south-facing kitchen and the bedroom were above 25 °C 59% and 47% of the year respectively. This property has the highest occupancy, likes it to be warm, has high electricity use, and a reluctance (historically) to open windows because of insects.

Humidity

The air flows required in a Passivhaus are sufficient to remove the risk of excess relative humidity (RH) and consequent condensation and mould, so long as the MVHR system has been constructed, commissioned, maintained and operated correctly. Our TSB study analysis found that values have stayed well below upper thresholds.

There is also a possibility that, by the end of the winter, a mechanically ventilated property might become overly dry, with risk of respiratory difficulties for the occupants.

The standard heat exchanger in the MVHR unit can be replaced by one that also recovers humidity. A trial in winter 2013/14 of such an 'enthalpy exchanger' has been conducted in the two houses that have MVHR monitoring in place.

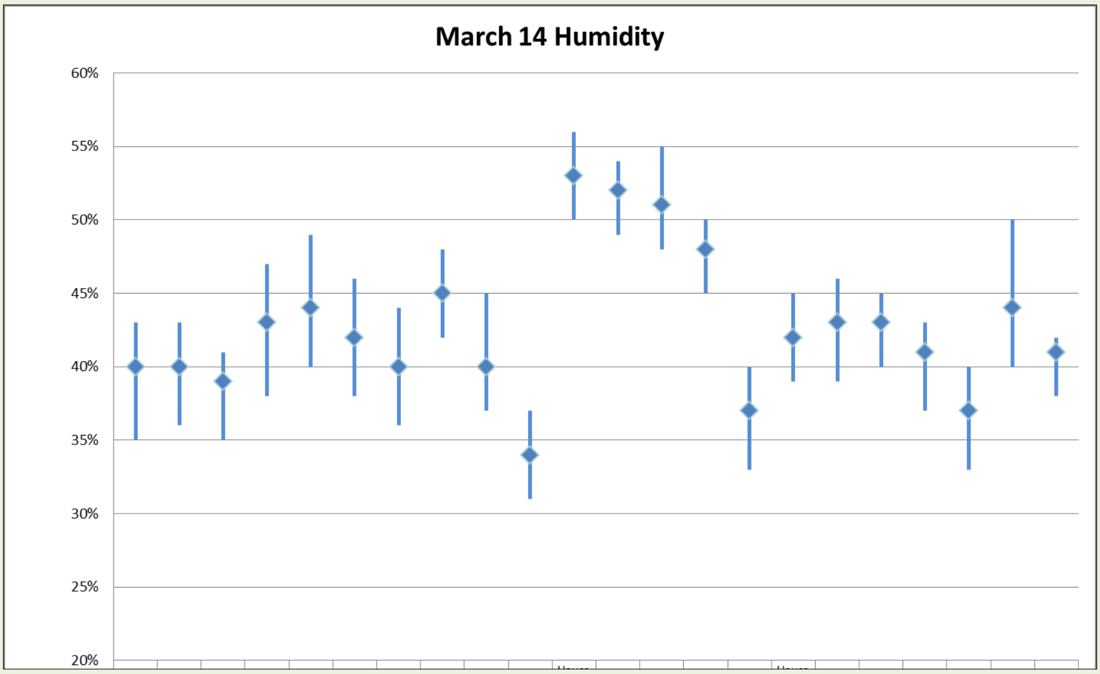

Figure 11: Humidity Distribution End Winter (Flats to the left – 8 sensors; remainder sensors in the houses)

The above chart shows that for each sensor the values are within a narrow band.

The four sensors with the highest RH values are all in one 2-bed house, the one with the enthalpy exchanger. The 3-bed house with the same exchanger does not show the same increase.

Overall the RH levels are perfectly acceptable.

5. Air quality

Carbon dioxide levels are commonly used as a proxy for the air quality in a property. In an occupied room with poor ventilation, the CO_2 levels can quickly rise from an ambient 400ppm to 2,000ppm and above, where concentration levels diminish and fuzzy-headedness starts. While absolute thresholds are difficult to justify, value excursions above 1,500 should be infrequent, and it is desirable to keep peaks to no more than 1,200ppm[5].

The TSB study found that readings at Wimbish were generally in the acceptable range, although air quality was impacted when the filter needed changing. This 2014 assessment confirms that the air quality remains acceptable.

During the summer months, when occupants are more likely to open windows, the air quality is less of an issue; thus looking at data in March is likely to be indicative of the worst figures[6].

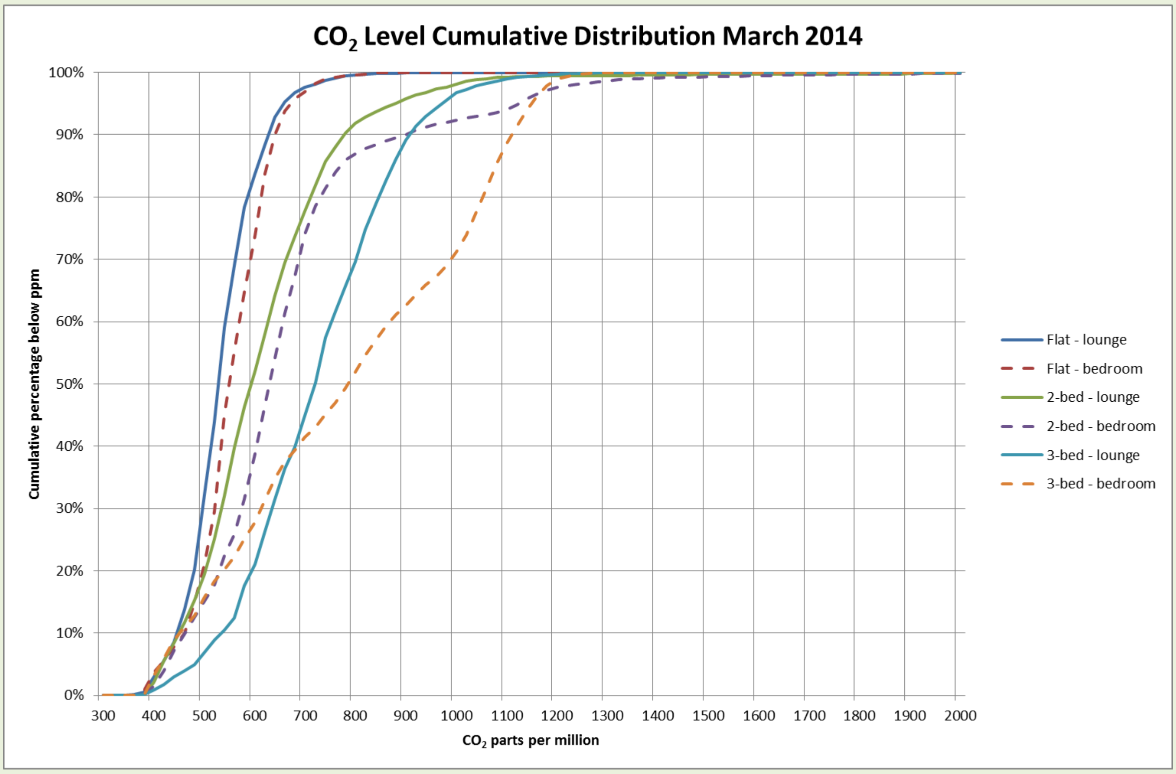

Figure 12: Distribution of Carbon Dioxide readings

CO_2 levels are good, only very rarely above 1,200 ppm.

The MVHR was commissioned to the Hastoe-expected occupation levels for the property types. This probably explains why the under-occupied flat performs best, followed by the 2-bed house, then the over-occupied 3-bed house.

5 On the other hand, keeping CO_2 levels below 800ppm could be indicative of too high an air exchange rate [the greater the air flow the more energy used by the fans, the greater the heat loss by the system, the faster the moisture loss, and the faster the filters block up].

6 This analysis is for the whole month. Looking at ‘occupied hours’ for each room might be more meaningful (but ‘occupation’ is not explicitly monitored).

6. Ventilation

The ventilation system must maintain air quality (section 5) and contribute to maintaining comfort (section 4). It must do these efficiently:

1. In the energy used to run the fans
2. In the level of heat recovery maintained
3. And the effort/cost in maintaining the filters.

Our TSB study found that under normal operating conditions the fan electricity consumption and specific fan power (SFP) were close to the product specification in the monitored flat and 2-bed house, but that the fans were working a bit harder in the 3-bed house, increasing the SPF by about 1/3 – however, in all three cases the systems remained within the Passivhaus allowable limit.

Monitoring the energy used by the fans each day provides a useful indicator of the status of the filters.

Property	Nominal Fan Watts	Image	Equivalent daily 'pulses' (each pulse being 0.1 kWh)
2-bed House	29	Figure 13	7
3-bed House	54	Figure 14	13
Flat	25	Figure 15	6

The reduction in daily consumption in July 14 seen in Figure 13 is suggestive of a filter change, and the short term reduction in September of the residents taking a holiday.

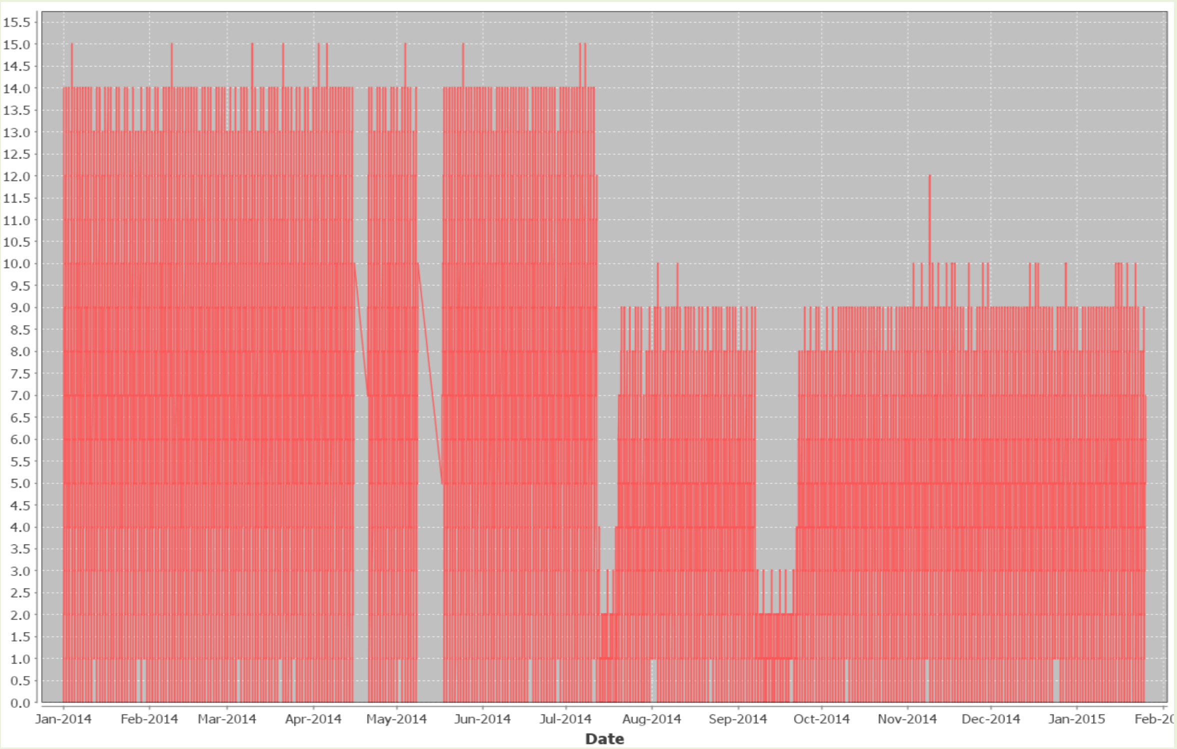

Figure 13: 2-bed House MVHR Electricity Consumption

The filters catch pollen and other particulates in the incoming and outgoing airflows before they reach the heat exchanger and the fans, thereby protecting these components from clogging up. The filters on the incoming air also reduce the quantity of dust build-up in the ducts (otherwise they would need periodic cleaning) and ensure good air quality for the residents.

Over time the filters will become blocked, to maintain the airflows the fans will start to work harder, and noise levels will increase. Eventually the fans will reach maximum speed, and the air flow will then become compromised, affecting air quality, and the ability to deliver heat. Running at full load may reduce the life of the fans. Filters should be replaced when the fans start to work harder.

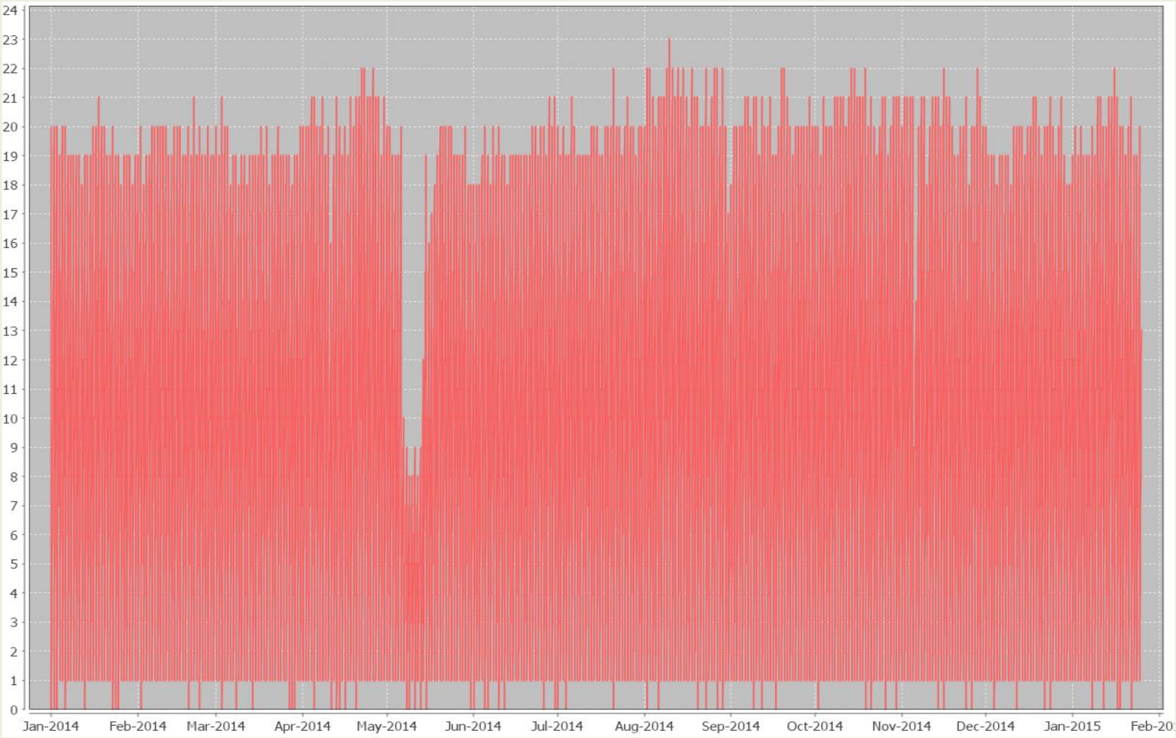

Figure 14: 3-bed House MVHR Electricity Consumption

These three figures do not show evidence of the filter changes as clearly as similar charts produced for the TSB Study; they do show that daily electricity consumption in the houses[7] is well above the nominal level, implying that the filters need changing, although we understood that they have been changed. The issue is complicated in that both the houses employed the enthalpy heat exchanger as a trial for part of the year. It was expected that these might increase the fan load; however the end of the trial is not evident in these figures.

7 As the same MVHR units are employed in all the properties, those in the flats are running at the low end of their range, this gives them a lot more headroom before any adverse effects are evident.

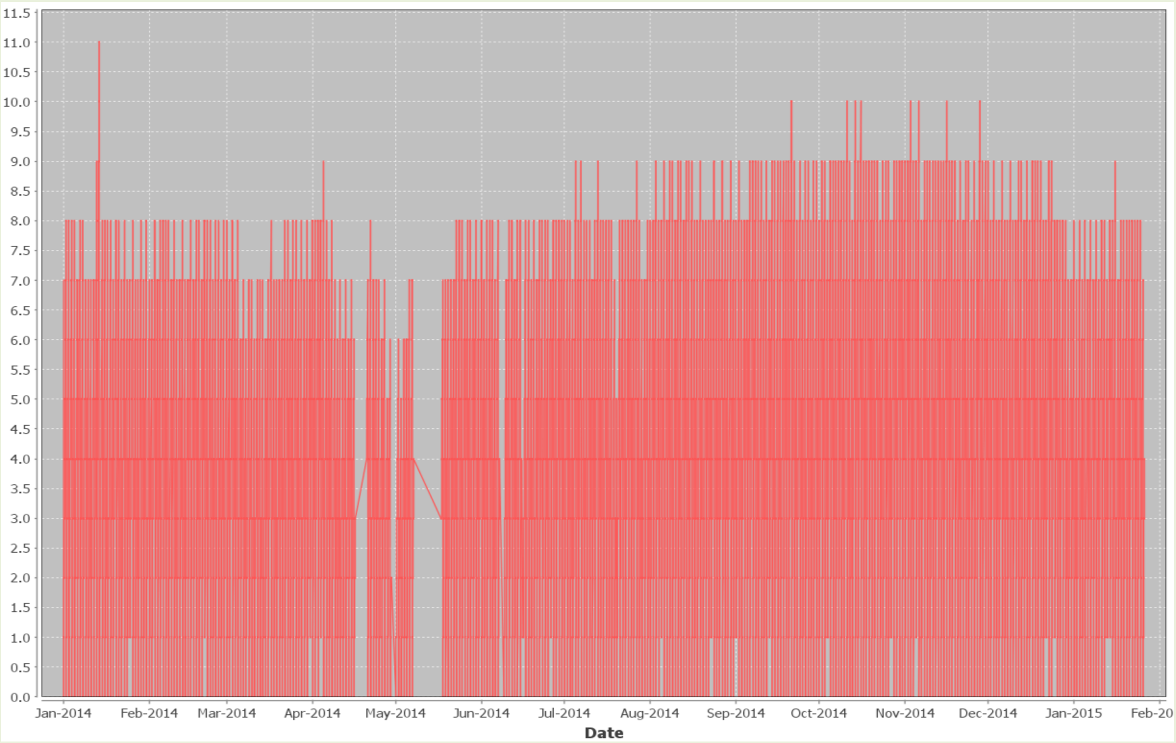

Figure 15: Flat MVHR Electricity Consumption

Property	TSB Study: Nominal consumption kWh/a	TSB Study: Actual year to 5/7/13 kWh/a	2014 kWh/a
Flat	219	223	291
2-bed House	254	353	405
3-bed House	473	634	715

The increase in consumption in 2014 is a concern; it may just be confirmation that the filters really should have been changed sooner, or it may be symptomatic of some other malaise. Either way the households will have had slightly higher electricity bills as a result, and there might have been some impact on the air quality.

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WimbishPassivhaus

A. Appendix – Performance considerations in a Passivhaus

Passivhaus design is holistic and seeks to consider a wide range of factors that may have a bearing on performance. As background to the charts and discussion in this paper some of the issues are briefly discussed here.

A Passivhaus is expected to require very little heat input; at Wimbish, with solar systems to meet a large part of the hot water demand in summer, gas consumption by the boilers is very low. Passivhaus design also aims to keep electricity use down by provision of energy efficient lighting and, if possible, by providing efficient appliances. It is assumed that occupants will be sensible in their use of appliances (perhaps as a result of handover advice). Thus primary energy demand is kept low, along with the resultant carbon emissions. This is calculated from an assumed level of occupation, derived from the considerably more generous German standards for space per person than the figures applied for UK social housing (and indeed any UK housing) [8].

If the level of occupation, both numbers and hours, is higher than the design expectation then it is likely that more hot water will be used, as well as an increase in appliance use. Not only will the latter increase electricity consumption, but, at least in winter, the heat gains from these uses may reduce the need for space heating. Lower occupation, more likely in the flats, can have the reverse effect.

That most households brought their existing appliances with them, and purchase new with cost price as the primary consideration, means that most appliances are not the most efficient on the market. This too raises electricity use and may impact heat demand.

A Passivhaus is designed such that it is capable of maintaining a constant temperature of 20 °C. In practice, households are likely to find some variation of temperature pleasing. Inherent in the high level of thermal insulation of a Passivhaus is that very little heat can be lost through the fabric, and left alone with the ventilation off, a house will only cool very slowly even in the coldest weather. The ventilation system however, even with well-performing heat recovery, will cool the property if the lost heat is not replaced[9]. Thus, if the occupants are out during the day, and the heating system is 'timed-off' or the thermostat has been turned down, a Passivhaus can lose a few degrees of heat[10]. Of course, if the household chooses to open windows, then heat loss can be faster.

Turning the thermostat up above 20 °C will increase heat demand and gas consumption. Some properties have been logged as being warmer – this may be a thermostat adjustment, or may be the result of high heat gains from other activities, either way this can be household choice.

2014 was the warmest year on record, and included above average temperatures in the winter months; this will have reduced heating demand (the analyses have not been adjusted in any way for the weather).

Previous analyses (during the TSB study) have confirmed that these considerations apply at Wimbish; but it is outside the scope of this quick assessment to consider these again. Readers of this paper should, however, bear them in mind.

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8 Note that more recent guidance on Passivhaus design (PHPP v8) gives greater emphasis to ensuring performance at the expected level of occupation – which in the UK is likely to be higher than PHPP estimates.

9 If air quality is not a consideration, as it is unlikely to be when the occupants are not present, then losses can be reduced by turning the ventilation down to a minimum.

10 It is important not to lose too much, since the heating system is not sized to heat the property rapidly.

B. Technical Appendix

This appendix explores some of the issues in more technical detail; it is aimed at Passivhaus Designers and other interested parties.

Some content is repeated from earlier in this document, to save having to look back.

Monitoring gas consumption

Although our monitoring equipment provides a large quantity of valuable data, it has unfortunately not proved adequate neither to separate the space heating demand from that for hot water, nor to differentiate the supply from the boiler from that from the solar panel, with sufficient accuracy to be meaningful.

Thus we compare the expected gas consumption in each property (using figures from the Passivhaus Planning Package – PHPP2007 Boiler worksheet) with the actual consumption.

If a property uses what we consider to be an excess of gas (though their bills will remain small) it does not automatically mean that the fabric is deficient. It could be that the household likes lots of baths, or that the solar panel has a fault. Looking at the data in conjunction with water usage, and across the seasons, can help in understanding why a property uses excess gas.

Seasonal gas consumption

The space heating in a Passivhaus is only required in the coldest months, and demand diminishes rapidly as the weather warms. Hot water demand is fairly constant throughout the year. The grey bars in Figure 16 are the sum of these demands for a 3-bedroom house.

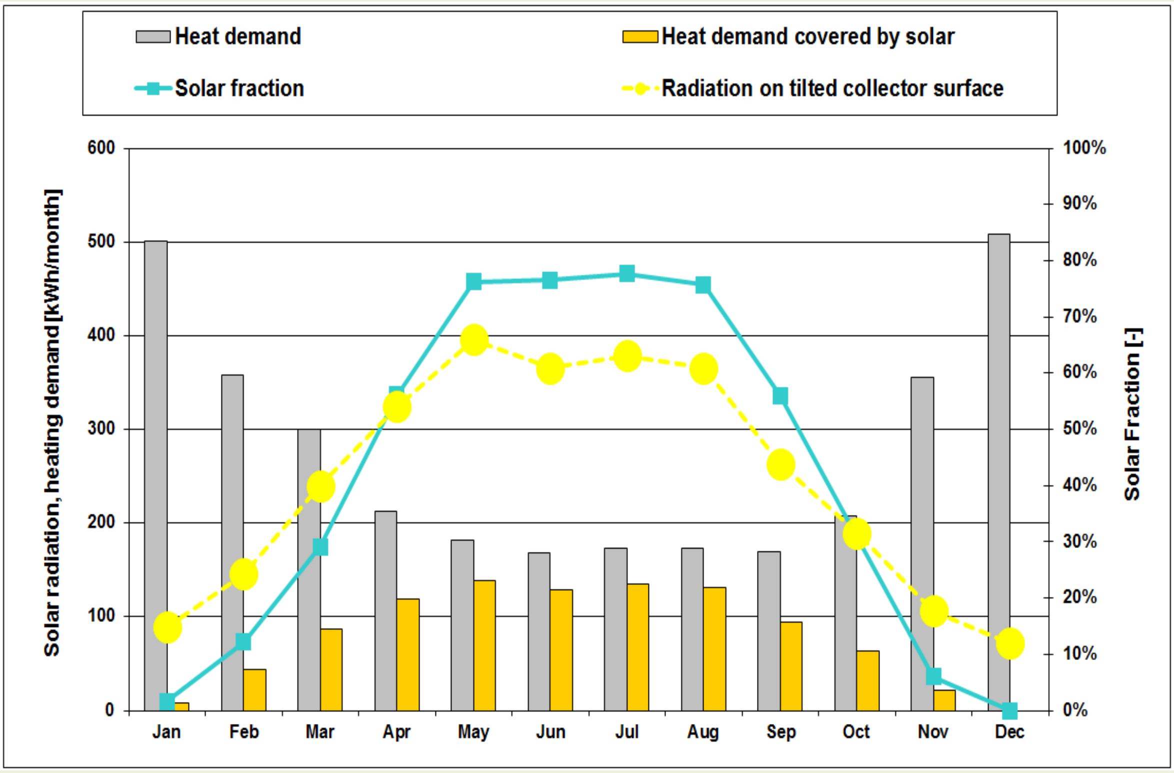

Figure 16: Heat Demand and Solar Contribution (PHPP as designed – but re-implemented in PHPP8.5)

The solar panels were sized to meet the summer demand, though since they were standardised across the 14 properties they fall a little short of meeting the demand for the larger houses (this figure is for a 3-bed house). The boiler is required to make up the difference between demand and the solar contribution, thus while some properties were expected to make no calls on the boiler during the summer, others might require some gas.

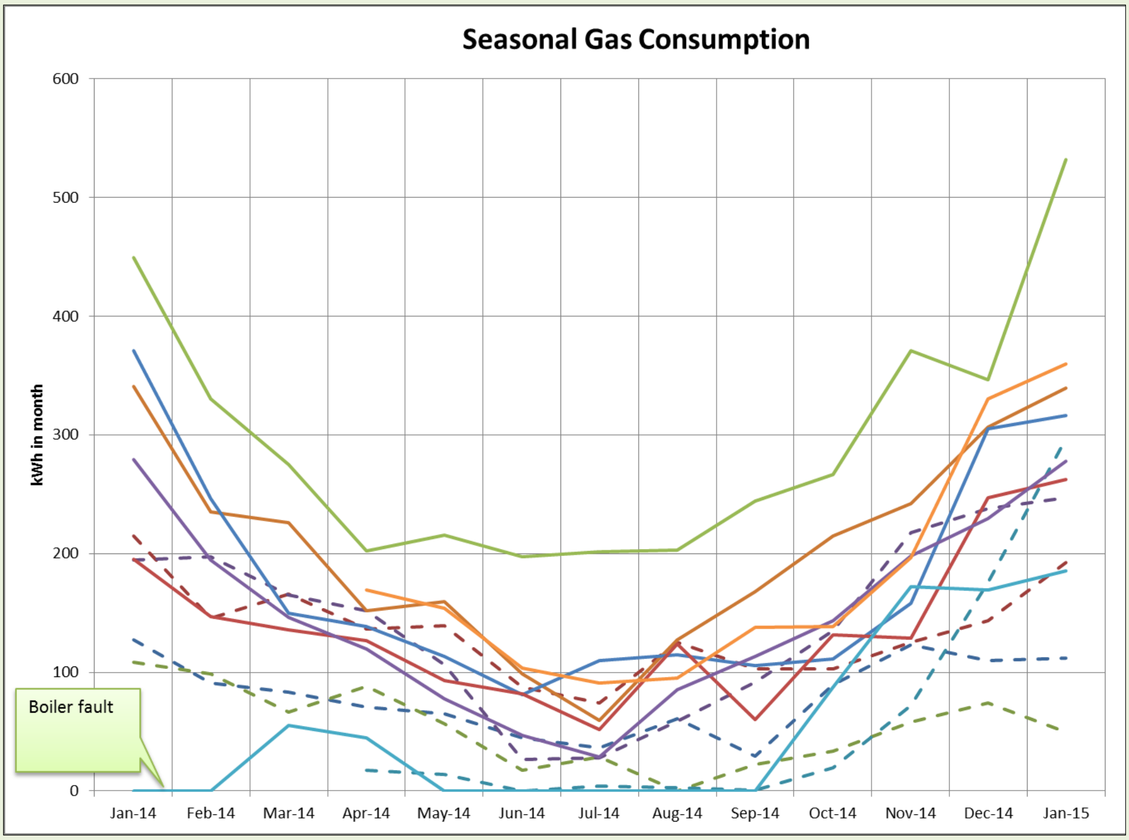

Figure 17: Logged Monthly Gas Consumption[11]

Figure 17 shows the logged monthly gas consumption and that some used rather more than predicted. This unexpected gas use may be down to one or more of the following:

1. Unanticipated use of space heating[12] – though the mild weather in 2014 makes this highly unlikely, and in any event the quantities would be very small
2. Reduced, or no, contribution from the solar panels. This could be because the panels are faulty, or because the settings are such that the boiler heats the water before the solar gets a chance, reducing the contribution it can make. Site visits to review the provision of hot water have been made autumn 2014 and it will be interesting to see whether there is an improvement in 2015.
3. Household sizes are larger, and/or the residents bathe more[13], than the assumptions in PHPP.

11 Gas metering for 2 plots has not functioned; and in two others the metering was repaired at the end of March.

12 The TSB Study detected some unnecessary summer heating – this might have been caused by leaving the thermostat by an open window.

13 In the TSB study however, a questionnaire on bathing habits, and assessment against water consumption, failed to detect any significantly increase in bathing.

If we ask PHPP to recalculate assuming 5 people[14] living in the house, and to use its calculated internal heat gain, then we see significant changes in the heat demand (Figure 18). Hot water demand has roughly doubled across the year; space heating demand has fallen, because there are more gains from appliance use and from heat losses from pipework. The boiler will be needed to do more work across the year.

Actually, Figure 17 does not show as much extra summer gas use in the 3-bed house as this recalculation would imply, and the highest consuming property is actually a 2-bed house. There is evidently more going on that relates to household habits, and perhaps to the settings of the boiler and solar system, than we have been able to account for in this brief assessment.

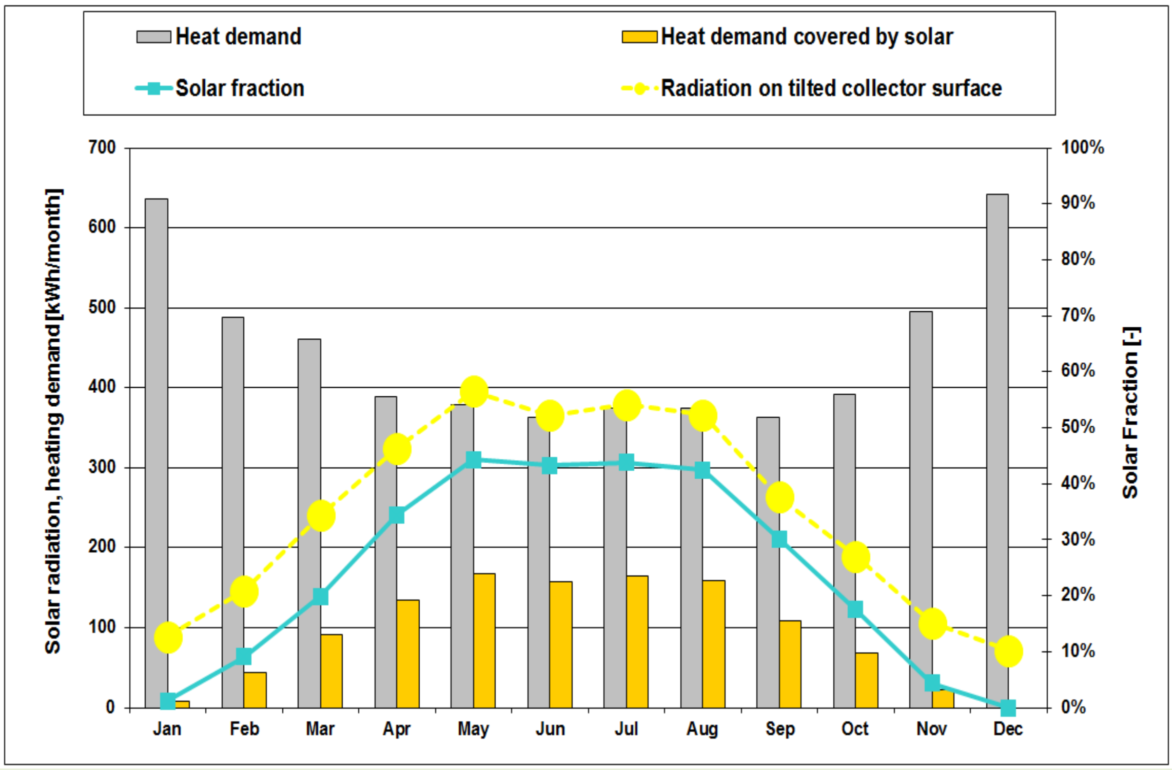

Figure 18: Figure 16 recalculated for 5 people and their internal heat gains

It is hoped that the check of the solar systems (last quarter 2014) will enable them to make a greater contribution in 2015, and thereby reduce gas usage.

A recommendation from this is for future design to consider the impact on systems and their performance if occupancy levels differ from the Passivhaus norms. At Wimbish it would probably have been desirable to have larger solar panels on the houses. In addition, greater attention to the programming of the hot water supply system, and its explanation to the households, would have been beneficial.

Expected Electricity Consumption

The Passivhaus standard does not include an explicit target for electricity use, although it must be accommodated within the total primary energy consumption of less than 120 kWh/(m^2·a). Since we know the expected gas demand, we can establish an allowed figure for electricity for each property – about 27 kWh/(m^2·a) for the houses and 31 kWh/(m^2·a) for the flats.

14 Actually 2 adults and 4 small children

By comparison, if we divide the Ofgem medium typical domestic consumption value by the average national property size we get a rather higher figure of about 40 kWh/(m^2·a). Passivhaus are thus expected to consume only about ¾ of the electricity of a typical house. Having said this, any new house might be expected to have more efficient lighting and appliances and thus consume less than a typical (existing) house.

In general, the household electricity consumption at Wimbish may be described as ‘normal’, and not the reduced level hoped for in a Passivhaus. There are thought to be a number of possible reasons for this:

- Most households brought their existing, relatively inefficient, appliances with them; and where new appliances were purchased the capital cost was a higher priority than efficient use.
- Above average occupation levels leads to higher use
- Because gas bills are so much diminished, the combined utility bill will be well below household’s expectations, meaning that the households pay less attention to their usage and cost of electricity
- In most UK households, there is a lack of connection (in the household’s minds) between behaviour and the resultant impact on bills. For example a household (not at Wimbish) that complains about the cost of having to feed their electricity meter, yet persists in have several large screen plasma TVs and computers on all day.

High electricity use is not just a financial issue, in the summer the heat given off by these appliances can exacerbate the risk of overheating.

Ideally, a Passivhaus developer would provide energy efficient appliances; failing that a scheme to enable households to purchase such appliances without having to bear the sometimes higher up-front cost would be beneficial. Designs might also seek to encourage energy saving behaviours, for example by providing a drying cupboard rather than space for a tumble dryer. Handover to the residents should also include tips on reducing their electricity bills.

Thermal comfort in winter

The requirement in winter is to avoid low temperatures that may lead to hypothermia.

While a Passivhaus should be designed to be capable of maintaining a constant temperature of 20 °C, in practice the occupants may be happy to let the temperature fall some of the time, for example when they are out, or asleep.

When considering thermal performance, averages are often quoted, but they can hide extremes[15] – plotting the cumulative distribution for a period, in the case of Figure 19 for February 2014, provides more detail:

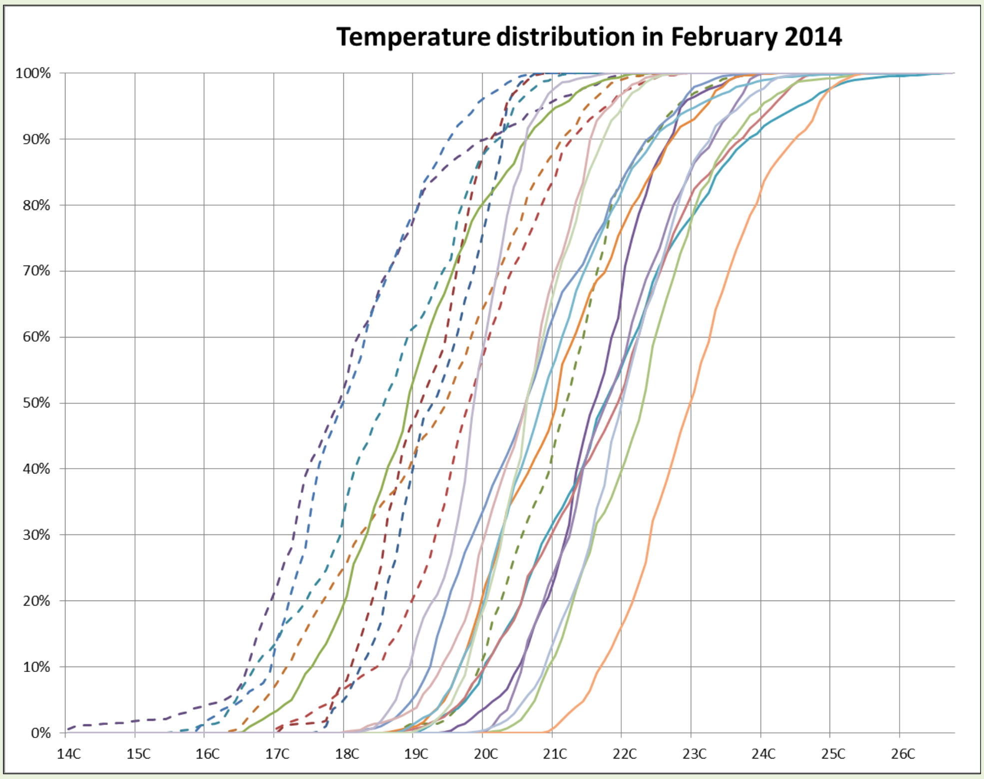

Figure 19: Winter Temperatures (flats dashed lines, houses solid)

Observations:

- Some of sensors logged temperatures above the 20 °C 'target' all of the time, and others only got there a small percentage of the month.
- The great majority of the readings are in the range 17 to 24 °C – showing that the properties remained warm and comfortable
- The calibration of the sensors has been found to drift, and some might be reading a degree or so out.
- Temperatures higher or lower than the 'target', may be occupant preference in adjusting their thermostat
- High temperatures might be the result of high levels of occupation and/or appliance use rather than turning the thermostat up.
- Looking at the 50% at 20 °C point it is interesting to note that of those sensors generally cooler, all but one is in a flat, and only one of those warmer is a flat. That the flats are cooler than the houses is thought to relate to the level and hours of occupancy rather than any inherent difference in the structure.

15 Very cold half the time, and very hot the other half, will give an average 'good'.

Overall the temperatures in February are excellent, though it should be noted that it was a relatively mild February.

Thermal comfort in summer

In summer the requirement is to keep temperatures down, to avoid the household suffering thermal stress.

There is concern[16] that new, thermally efficient, homes can overheat when it is difficult to dissipate excess heat.

The aim of Passivhaus design is to minimise this risk, with a metric of ensuring that 25 °C is not exceeded more than 10% of the (annual) occupied hours.

The Wimbish design met this criterion using the Passivhaus Planning Package (PHPP2007) current at the time, however migrating to the current tool[17] suggests that a little less glazing or more shading may have been desirable in order to meet the criterion.

Our TSB study analyses found:

- In practice, the 10% threshold had been exceeded by a significant margin in some of the properties.
- However, even in heat waves, the interior temperatures had not exceeded 30 °C, suggesting that in the hottest weather the dwelling's insulation has a beneficial effect.
- Occupant behaviour can have a large impact on the internal temperature during hot weather. Mediterranean practices of battening down the hatches during the day to avoid heat ingress, and throwing open windows when it is cooler at night, can avoid excesses. Avoiding heat generating activities such as using a tumble dryer, or a large plasma TV, helps too.
- Household opinions on their summer comfort varied widely, and seemed to relate to whether or not they perceived that they knew what to do to keep cool (rather more than actually how hot their homes were)

Although 2014 was a warm year overall, it did not have an extended period of hot days that would thoroughly test the dwellings and their occupants, thus although it provided a good test of over-heating in general, it did not provide a thorough test of what might happen in a heat wave.

[16] For example by the Zero Carbon Hub, see http://www.zerocarbonhub.org/current-projects/tackling-overheating-buildings.

[17] The current tool (v8.5) has improved algorithms for the overheating calculation.

Figure 20 shows the distribution of values logged by each sensor for the whole of 2014 (ignoring the hall sensor in Flat 1 that malfunctioned part of the time).

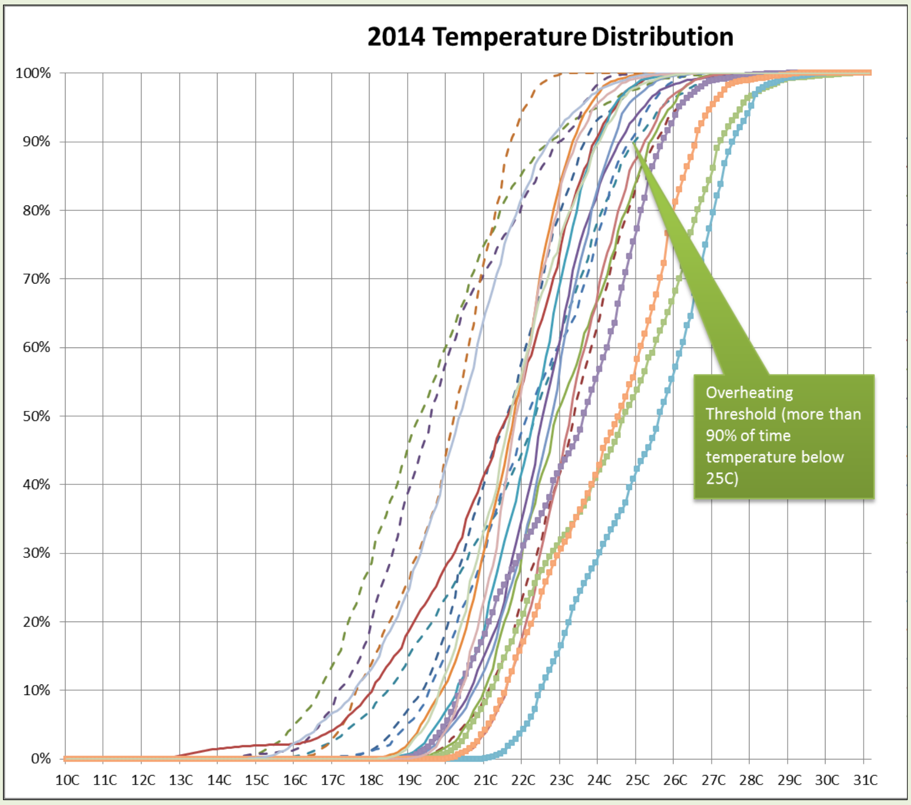

Figure 20: 2014 Temperature Distributions (flats dashed lines, houses solid – sensors with markers in the 3-bed house)

The four warmest rooms are all in one 3-bed house, with the kitchen the warmest, being over 25 °C 59% of the year. There are considered to be a number of reasons for the warmth in this house:

- The household says that they like it
- The property has the highest occupation of all the properties
- They have joint highest electricity consumption
- They are reluctant to open windows in summer, having young children
- The kitchen is south-facing and the full width of the house, catching maximum solar gain, though shaded by the Brise Soleil

Three other rooms monitored fail the criterion as well, but by a lesser degree. Two of these are in two-bedroom houses, where the sole sensor is in the lounge. While it is possible that the kitchens are warmer (both rooms are south-facing), generally the effect of the MVHR is to even temperatures around the properties at any one time.

The warmest month of the year was July, and Figure 21 shows the distribution of readings for the month.

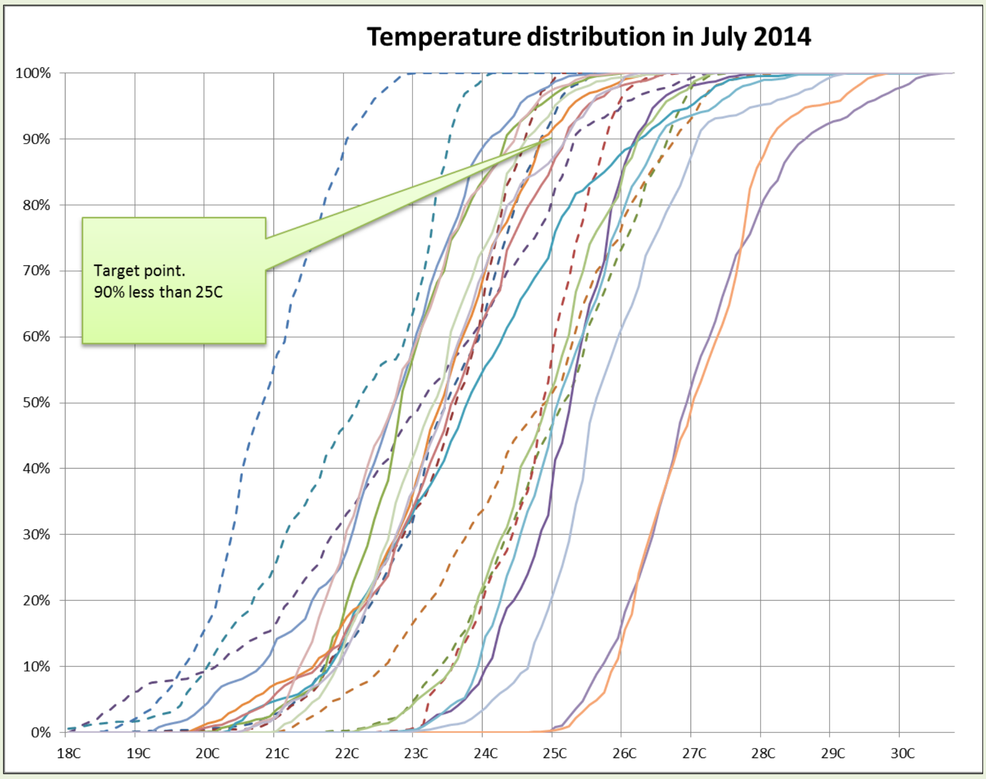

Figure 21: Summer Temperatures – July 2014 (flats dashed lines, houses solid)

Although the figure shows the Passivhaus criterion, it is not truly meant to be used like this, being an annual target, not one for a single month.

The three hottest sets of readings are again from the 3-bed house with high occupation, where the kitchen and the bedroom were above 25 °C virtually all month.

Some of the sensors did record consistently lower temperatures. Again the flats are generally cooler than the houses; occupancy is likely to be a factor, along with the greater thermal mass in the flats.

The large variation in temperature between the properties is puzzling. That some remain relatively cool implies that it can be done.

Humidity

In a similar manner to temperature the relative humidity should be neither too high nor too low.

The air flows required in a Passivhaus are designed to be sufficient to remove the risk of excess relative humidity (RH) and consequent condensation and mould; this is dependent on the MVHR system having been constructed, commissioned, maintained and operated correctly. Our TSB study analysis found that, following an initial drying-out period when there was high humidity, values have stayed well below upper thresholds[18].

There is a tendency for mechanically ventilated properties to lose moisture during the winter. This is because an MVHR removes moisture from the property along with other pollutants (the outgoing air being warmer and having a higher moisture content than the replacement air), and unless this moisture is replaced by other means[19] the result will be a gradual reduction in the humidity level.

18 Thresholds can be defined in various manners, but values consistently above 65% RH may cause issues.

19 For example, evaporation from clothes drying, transpiration from plants, or moisture from cooking.

There is a chance that a property will become overly dry by the end of the winter (for example below 20% RH), with risk of respiratory difficulties for the occupants.

This is unlikely to be as much an issue in maritime southern England as it is in central Europe, where the winter air is colder and thus drier, but checks should still be made. Our TSB study analysis found that there was a reduction in the humidity level through the winter, which recovered in the spring when windows were opened. The lowest values were not at risky levels, however the median levels in 2013 were a little lower than in 2012 (falling to approximately 35% from 40%) and there was a question whether continued drying out of the fabric of the buildings might result in even lower values in 2014 and subsequent years.

A technical solution to this risk is to replace the standard heat exchanger in the MVHR unit with one that also recovers humidity. A trial in winter 2013/14 of such an enthalpy exchanger has been conducted in the two houses (2-bed and 3-bed) which have MVHR monitoring in place.

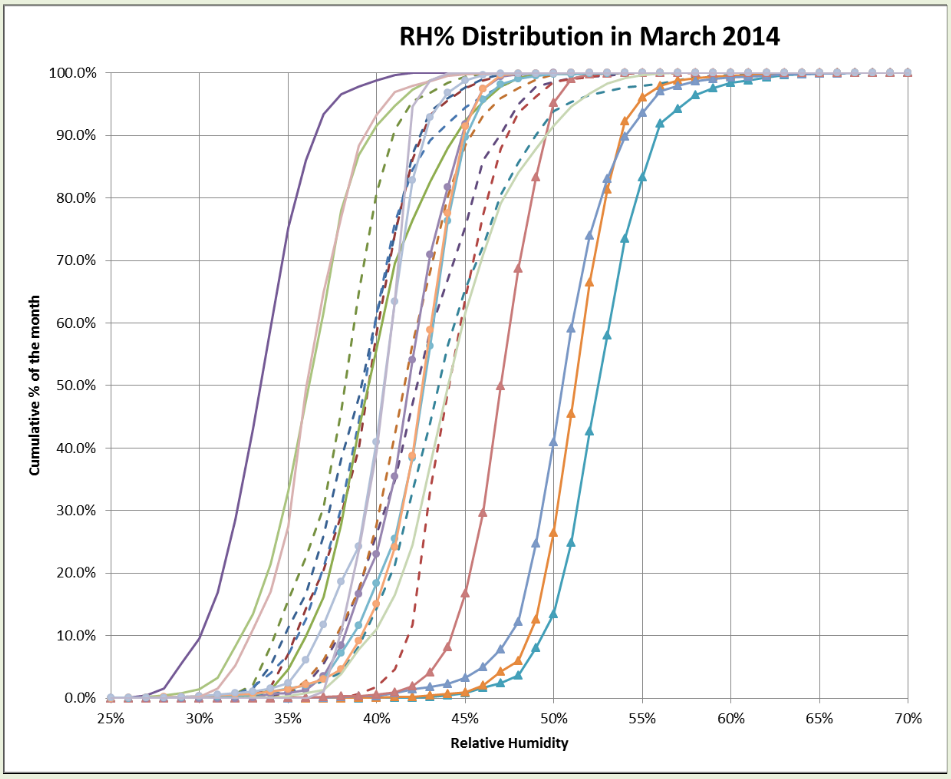

Figure 22: Humidity Distribution End Winter (flats dashed lines, houses solid – triangle markers in the fully monitored 2-bed house)

The chart for March 2014 (Figure 22) shows that for each sensor the values for 80% of the time are within a narrow band, though there are quite large differences between sensors. This is likely to be caused by variations in household practices that add moisture to the air.

The four sensors with the highest RH values are all in the 2-bed house, with one of the enthalpy exchangers; the 3-bed house does not show the same increase.

Overall, the RH levels are perfectly acceptable. Very few readings are at the upper threshold, and few below 30%. The median value, ignoring the experimental 2-bed house, is around 40%. This reversion to 2012 values is likely to be a result of the mild 2013-14 winter.

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