Wimbish Passivhaus Development: Performance Evaluation

10 year Assessment

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Synopsis

This paper assesses the performance of Hastoe Housing Association's Wimbish Certified Passivhaus development for the ten-year period from June 2011.

It builds on the Innovate UK (formerly the Technology Strategy Board) funded Building Performance Evaluation study that covered the period from 1st April 2011 to 30th September 2013, and on assessments in 2016 and 2018. (Reports can be found at http://wimbishpassivhaus.com/datasheets.html.)

This assessment confirms the BPE study findings that the Passivhaus approach delivers homes that are comfortable, healthy, and economic to run over at least 10 years. Recommendations are made to reduce the risk of future developments suffering from any 'performance gap'.

The decade-long monitoring and assessment has been valuable to confirm that there are no adverse performance trends, as well as to identify any defects so they can be remedied.

1. Introduction

The Innovate UK Building Performance Evaluation (BPE) 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. An article in the CIBSE Journal[1] on the Innovate UK programme complimented Wimbish as "one of the few that performed well".

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

The BPE study proved that the Passivhaus approach delivers, and this final 2022 assessment confirms that it continues to deliver the expected performance. Overall, the homes are performing largely as designed and provide the occupants, none of whom had particular prior interest in sustainability or energy efficiency, with homes that they find economic to run, healthy to live in and very comfortable and spacious for the size. Some residents have stated that their heating bills were only £30 a quarter. The lack of a 'performance gap[2]' is a reflection of the high quality process necessary for Passivhaus development from design to occupation.

The February 2022 assessment included an occupant survey using the industry-standard Building Use Studies (BUS) form and occupant interviews; repeat of air-tightness testing in two dwellings; detailed examination of the ventilation system with air flow checks in these dwellings, along with external air flow measurement of other houses; thermal imaging externally and internally; and visual examination of other M&E systems and of the windows and doors.

This publication brings together the findings from the above exercises along with analysis of the monitoring data.

1 See http://www.cibsejournal.com/general/home-truths-innovate-uk-building-performance-evaluation-programme-report/

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

Content

This paper covers:

- Energy Consumption
    - Gas for heating and hot water – total and seasonal use
    - Electricity – total
- Comfort
    - Thermal – winter and summer
    - Humidity – end of the winter
- Air quality – CO_2 readings in winter
- Ventilation
    - Role of the system
    - Energy use by the MVHR
    - Heat recovery
    - Maintenance
- Fabric performance as examined by thermal imaging
- Air-tightness over time
- Occupant Surveys
- Heating and Hot Water Systems
- Review of the Build Approach
- Performance Considerations in a Passivhaus
- Review of the Monitoring Kit

2. Summary

The main findings from this assessment of 10 years of monitoring data[3] plus additional inspection, tests and survey are that the primary objectives of a Passivhaus are being maintained:

- That the comfort levels remain good overall
- That the gas consumption for heating and hot water has remained very low in most properties, far below national averages resulting in low bills
- That the air quality remains good although the ventilation systems are working a bit harder than they ought.

It also finds that electricity consumption remains ‘normal’, somewhat above the expected low levels in a Passivhaus.

These confirm the Innovate UK study findings; no significant[4] deterioration in meeting these objectives has been identified.

The air-tightness test results remain good, though not quite at the level required originally for the Passivhaus certification. The most likely cause of increased leakage is from window and door seals as identified by the thermal imaging.

The occupant surveys confirm a high level of satisfaction overall, although summer comfort and noise suppression from neighbours could have been better.

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

This assessment and 10 years of monitoring has provided valuable information on how these early (in the UK) Passivhaus dwellings are performing; this being of interest to Hastoe and for the house-building industry at large.

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3 The monitoring has continued beyond the 2 year Innovate UK funded period in order to gather valuable additional data. Albeit there is no funding to fix any monitoring faults which might arise, and some metering has been discontinued as the equipment was an inconvenience to the residents.

4 Some properties are not performing as well as we think they should. We can explain discrepancies by household make-up, behaviour or preferences; or by mechanical systems issues.

3. Energy

Annual Gas Consumption

Expectations

For Passivhaus certification a dwelling is usually expected to use no more than 15 kWh per m^2 of floor area each year for space heating and hot water demand also is designed to be kept low. At Wimbish solar thermal systems heat a hot water store, and a gas boiler tops up the temperature when necessary. Heat is taken from the store to warm the incoming air and a towel rail when space heating is needed.

Unfortunately our metering has not been able to differentiate between the different supplies of heat, nor the different uses. In assessing performance the best we have been able to do is to compare the actual gas consumption for each dwelling with that predicted in the design (by the Passivhaus Planning Package – PHPP).

Findings

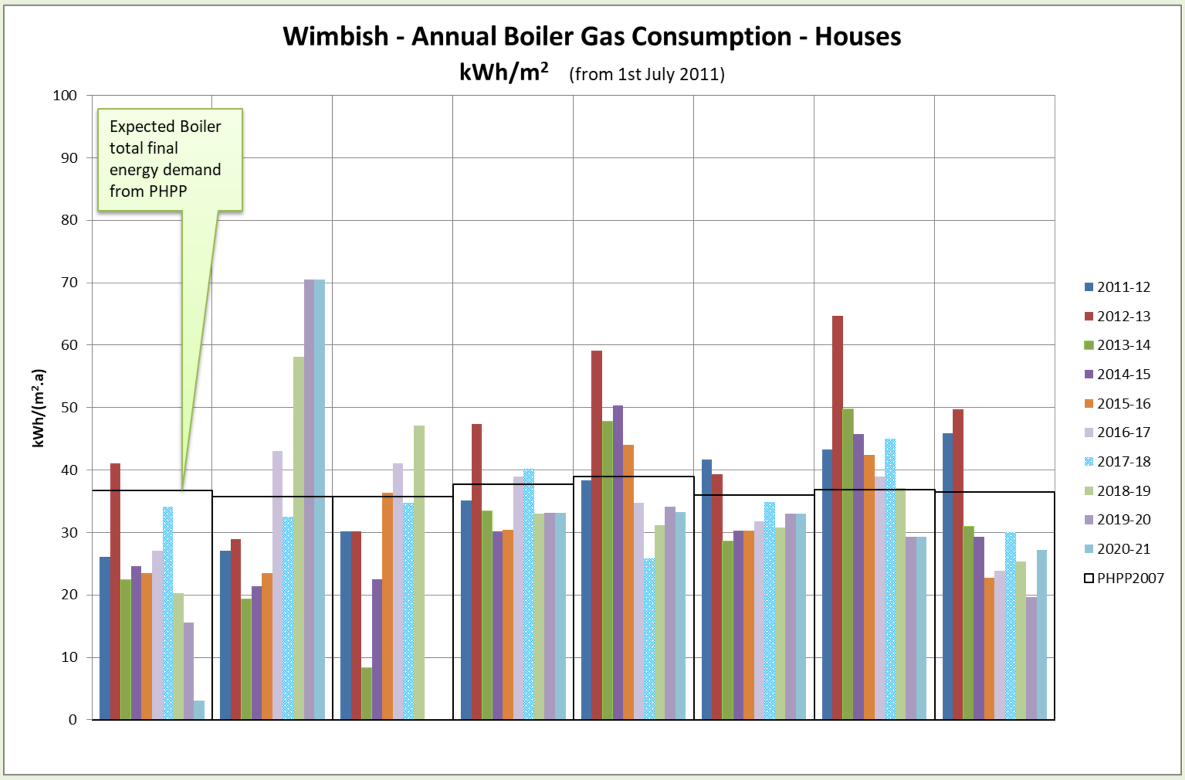

Figure 2: Boiler gas consumption by floor area – 10 years of data for each of the 8 houses

Firstly, note that Ofgem quote a Typical Domestic Consumption Value of 12,000 kWh a year[5], which for the houses would be above 160 kWh/m^2 showing that even the worst performing properties achieve a huge saving over a typical house.

5 See https://www.ofgem.gov.uk/publications/price-cap-increase-ps693-april

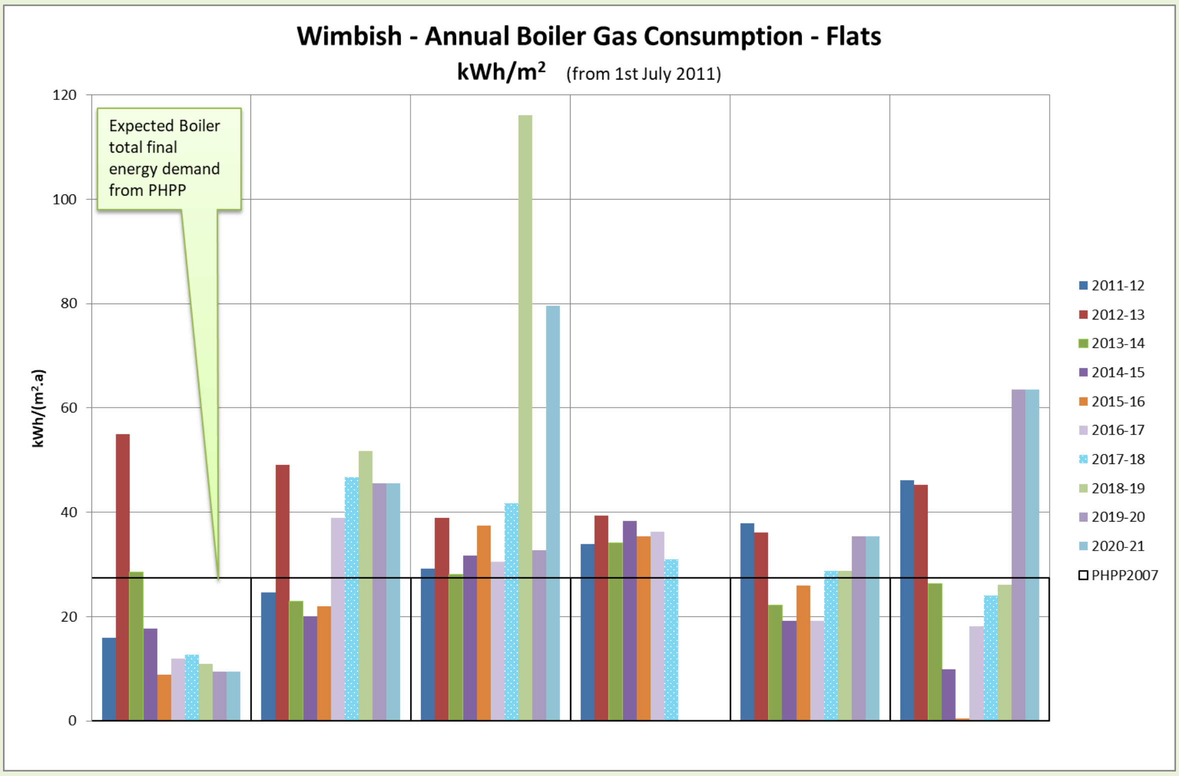

Figure 3: Boiler gas consumption by floor area – 10 years of data[6] for each of the 6 flats

The average consumption in most of the properties over the ten years can be seen to be close to the values expected in the PHPP calculation. Some exceptions were caused by known faults in the heating system, and others are down to household behaviours, for example leaving windows or doors open, or taking long showers. Low values reflect low occupancy, and some of the discontinuities in the data reflect a change of resident.

In the past, residents have told researchers that their annual gas bills have been around £120. Over ten years the average annual consumption in the houses has been 2,520 kWh – the Ofgem cap from April 2022 is equivalent to 7p per kWh, thus the bills might rise to £176. Actually, and unfortunately, households with low consumptions are penalised since the standing charge can become a major element of the bill. Bills might average around the £280 pa mark – though this is still way below the Ofgem figure of £840.

Seasonal Gas Consumption

In a Passivhaus, the space heating is only required in the coldest months, whereas hot water demand is fairly consistent throughout the year. At Wimbish the solar thermal systems are sized to supply sufficient hot water in the summer months. The boiler is required to make up the difference between demand and the solar contribution, which should primarily be in the winter months.

Thus we might expect to see higher gas use in December and January falling to very little from April through to September.

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

[6] Some data is not available for these figures because residents had their meter changed and/or the metering failed.

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

1. Unanticipated (and unlikely) use of space heating[7]
2. Reduced, or zero, contribution from the solar panels.
3. Household sizes are larger, and/or the residents bathe more, than the assumptions in PHPP
4. Excess heat losses from the thermal store and pipework.

Annual Electricity Consumption

Expectations

The Passivhaus standard does not include an explicit target for electricity use, but we can establish an allowable figure in PHPP[8] for electricity for these particular properties – about 1,900 kWh/a for the houses and 1,500 kWh/a for the flats.

By comparison, the Ofgem typical domestic consumption value is 2,900 kWh/a.

Passivhaus design expects best practice: low energy lighting and energy efficient appliances, and that these are used considerately to minimise consumption. This saving is reduced somewhat by the energy consumption of the ventilation system.

Findings

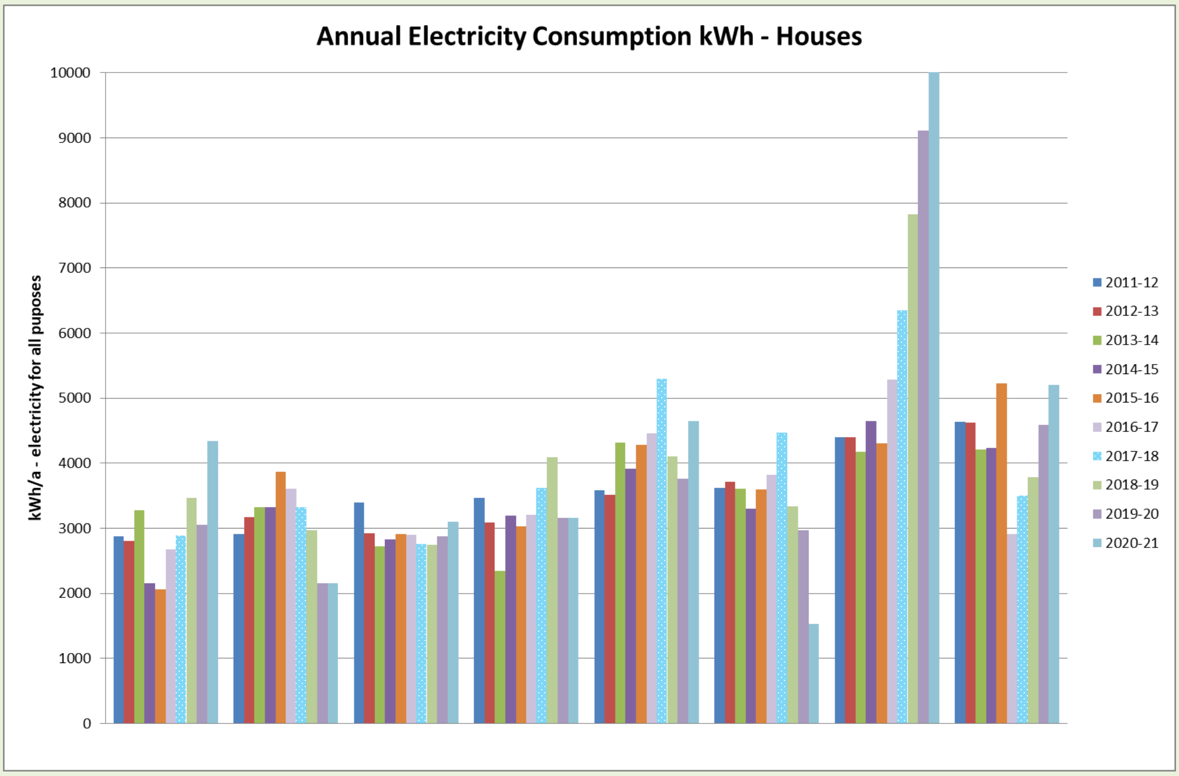

Figure 4: Annual Electricity Consumption - 10 years of data for each of the 8 Houses

7 Some ‘accidental’ summer heating has been detected, however heat usage was insignificant

8 By deducting the gas usage from the primary energy target of 120 kWh/(m^2·a).

The electricity consumption in the houses (with one exception) may be described as 'normal', rather than the reduced level hoped for in a Passivhaus. In the flats consumption is less, a reflection of lower numbers of occupants.

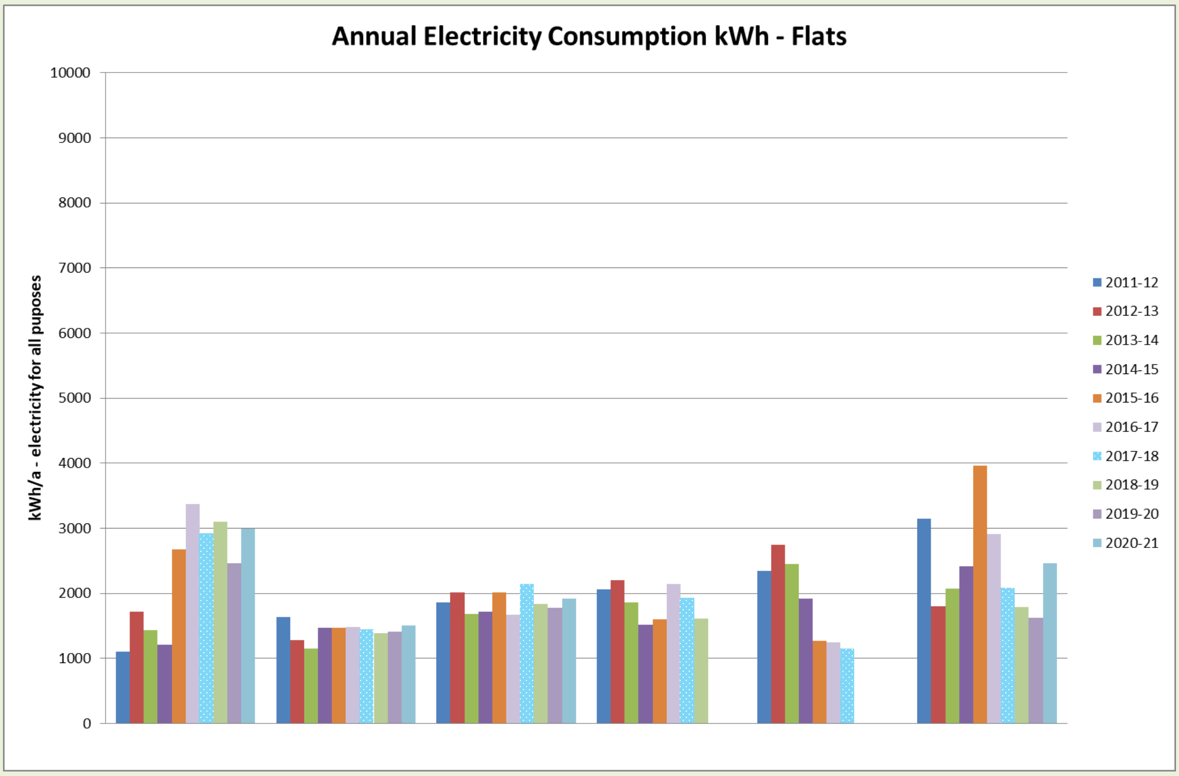

Figure 5: Annual Electricity Consumption - 10 years of data for each of the Flats

Extra heat gains from above-expected 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[9]. 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.

9 Hastoe were not able to do this

Detail

The annual electricity consumption charts (Figure 4 and Figure 5) show that on average the houses consume a little above the Ofgem typical value, and the flats well below – largely a result of lower level of occupation.

There is a distribution of consumption across the houses and across the flats. In most properties, there is little year-on-year variation in consumption, the exception being properties where there was a change of resident.

This ‘normal’ electricity consumption may be attributed to three 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.
3. Behaviours not aligned with the Passivhaus ethos. This may be because with very low gas bills, spending extra on electricity has been of little concern.

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. On the other hand some households choose to maintain a higher temperature, recognising that it costs them little extra to do so.

Previous assessment reports have included charts of winter temperatures showing that the residents found it straightforward to keep warm.

Since then, reduced access to the monitoring kit has meant that comprehensive data has only been available for 4 of the houses (and none of the flats). In addition, we cannot be confident that the calibration hasn't drifted and therefore updated charts are not justified.

The occupant survey carried out in February 2022 confirms a high level of satisfaction with winter comfort.

Thermal comfort in summer

As above, the charts have not been updated from previous assessments because of lack of confidence in the data accuracy.

There is concern that new homes, especially well insulated 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.

Previous analysis of 2014 to 2017 found that though they were warm years overall, they did not have an extended period of hot days that would thoroughly test the dwellings and their occupants. July was generally the warmest month, most properties average below 26°C for the month, though some are warmer than many people would find comfortable. That some households are able to keep cooler shows that it is possible.

The occupant survey carried out in February 2022 shows some dissatisfaction with summer comfort.

It is acknowledged (see section 11 Build approach) that if the development were to be undertaken now that more attention would be given to the overheating risk and that the approach may be different.

Humidity

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[10], so long as the MVHR system has been constructed, commissioned, maintained and operated correctly. Our Innovate UK study analysis found that values have stayed well below upper RH thresholds.

Overall the RH levels are perfectly acceptable, and the properties are not becoming overly-dry.

[10] In addition, high levels of insulation and avoidance of thermal bridges prevent cold spots.

5. Air quality

In all occupied buildings maintaining good air quality is vital. Fresh air is needed for the residents' health and pollutants must be removed.

Carbon dioxide levels are commonly used as a proxy for the air quality in a property. If the air flows are sufficient to maintain CO_2 values to an appropriate level then it is likely that sufficient fresh air is being made available[11], and that smells, for example from cooking, and other pollutants are being removed. In pandemic times this would include removal of virus aerosols – highlighting the importance of good ventilation.

In an occupied room with poor ventilation, the CO_2 levels can quickly rise from an ambient 400ppm to 2,000ppm and above, where occupants' concentration levels diminish and fuzzy-headedness starts. While absolute thresholds are difficult to quantify, value excursions above 1,500ppm should be infrequent, and it is desirable to keep peaks to no more than 1,200ppm[12].

The Innovate UK study found that readings at Wimbish were generally in the acceptable range, although air quality could be impacted a little when the filter needed changing. The 2018 assessment confirmed 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 the assessment looked at data in March, this likely to be indicative of the worst figures. CO_2 levels were good, only very rarely above 1,200 ppm. No long term trends in air quality have been detected.

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

The data for the period since 2018 does not provide a meaningful update on earlier assessments. We have no data for the 3-bed house; the only comprehensive data being for the 2-bed, and this property was irregularly occupied.

11 Note that at commissioning the system was set to meet both Passivhaus and Building Regulations Part F requirements.

12 On the other hand, keeping peak 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. Ventilation

The ventilation system must maintain air quality (section 5) and contribute to maintaining comfort (section 4). In addition the pandemic has highlighted the importance of good ventilation to reduce airborne virus aerosols.

The system must fulfil its role and be effective and efficient:

1. In running at minimum cost; that is the energy used to run the fans
2. In the level of heat recovery achieved – that is minimising heat losses
3. And the effort/cost in maintaining the filters and the system as a whole to deliver adequate fresh air and remove pollutants.

Role of the ventilation system

A Passivhaus is designed to not only be thermally efficient, but also to be air-tight[13]. Minimising leaks through the fabric avoids heat loss, and reduces the risk of moisture in air leaking from the building condensing in and damaging the fabric.

Having largely eliminated draughty leaks, one must then add assured ventilation to remove pollutants, including excess moisture, for the benefit of the occupants, and of the fabric. At the same time fresh air is to be supplied. To be ‘assured’ in a domestic environment this ventilation should be mechanically driven, that is by fans. These may run continuously, or be demand driven (by sensors, or perhaps less dependably, by the occupants). Mechanical ventilation systems can be centralised, or be distributed through the buildings.

Much of the time a simple extract system might suffice, but in winter it is wasteful to lose all the heat in the exhaust air, and a heat recovery unit helps the dwelling be energy efficient. Thus UK Passivhaus, Wimbish included, are generally fitted with a mechanical ventilation system with heat recovery, or MVHR. The MVHR is the essential lungs of the Passivhaus – without it functioning effectively the building would suffer from poor air quality, high humidity and probably condensation.

Fan energy use

Our Innovate UK 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. However, the fans were working a bit harder in the 3-bed house, increasing the fan electricity consumption by about 1/3. Despite this, 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.

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. If the filters are not replaced then eventually the fans will reach maximum speed, and the air flow will then become compromised and probably unbalanced, affecting air quality

[13] Tested to be less leaky than 0.6 air changes per hour at 50 pascals (see section 8.)

and humidity levels, and the ability to deliver heat[14]. Running at full load may reduce the life of the fan bearings. Filters should be replaced no later than when the fans start to work harder.

Table 1: MVHR unit annual electricity consumption

Property	Innovate UK Study: Nominal consumption kWh/a	Innovate UK Study: year to 5/7/13 kWh/a	2014 kWh/a	2015 kWh/a	2016 kWh/a	2017 kWh/a	2020 kWh/a
Flat	219	223	291	363	525	498	318
2-bed House	254	353	405	465	415	385	355
3-bed House	473	634	715	777	793	Not available	Not available

Note that early in the study 100 kWh of electricity might have cost around £15; in April 2022 it is more like £28.

The increase in fan electricity consumption 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 higher electricity bills as a result, and there might have been some impact on the air quality and on noise from the unit.

More recently the consumption in the measured flat and 2-bed house has reduced and been closer to expectations; this is probably the result of the improved servicing regime. Unfortunately we do not have data for the worst case 3-bed house (resident broadband change led to loss of connection).

Heat recovery

The best quality MVHR units are tested to achieve around 90% heat recovery; that is only 10% of the heat in the outgoing air is lost (and needs to be replaced by the heating system). Units certified by the Passivhaus Institute achieve this level of performance. In practice, for a unit installed inside the property, there will be losses to the ducts[15] between the intake and exhaust vents and the unit which increase the overall losses close to 15%.

For the Innovate UK study in-duct temperature sensors were installed in three properties to enable the heat recovery performance to be assessed. Earlier assessments report that the expected level of performance was being delivered in winter months, so long as the filters were in good condition. Applying this performance to the commissioned air flows an assessment of the value of the heat recovered was also made. However, it is not thought appropriate to cost-justify an MVHR system in this manner since a low energy house requires assured ventilation (see Role of the ventilation system).

System maintenance

The maintenance is largely the timely replacement of filters, both at the unit and at the kitchen extract. Hastoe have retained service engineers to carry this out for the tenanted properties, with shared owners being responsible in their homes. Since a set of filters cost about £50 the replacement should only be done when necessary. However, other than in the three properties where monitoring records

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[14] Space heating is delivered by a small heater warming the incoming air supply; this heating being fed hot water from the thermal store.

[15] The ducts contain cold air and must be well insulated.

the electricity use by the fans the need is not obvious until it becomes a serious need. Monitoring shows when energy use is rising (the fans needing to work harder to maintain air flows when the filters become blocked) – see Fan Energy Use above; it might help for daily figures to be visible to the householder, or for the unit to raise an alarm when a pre-set threshold was reached.

Hastoe's service arrangement works on a twice-a-year basis; while this should be about right for the houses, the lower flow rates in the flats mean that it could probably be less frequent there. A 'serious need' is indicated by increasing noise from the unit as the fans complain that they cannot maintain the air flows. If the air flows are compromised then so will be the air quality in the dwellings, and it could prove difficult to deliver sufficient heat via the air supply.

The routine servicing is dependent on being able to find a mutually convenient time for the householder to grant access to the service engineer. On occasions this has led to a delay of a few weeks, and the monitoring has observed a modest reduction in air quality.

A secondary aspect of the service is to ensure the air flow at supply and extract vents internally and at the exhaust and intake externally are free from any impediment. Externally the grills can become blocked by insects, and a small bottle brush may be required. Internally the vents sometimes need to be removed for cleaning, since the vent gap is the control on the air flow care is required to ensure that on replacement the gap remains as before. The service engineers have sought to check the air flows, but there is doubt whether the balance between the rooms has been appropriately maintained to comply with both Passivhaus and Building Regulations requirements (which differ slightly).

Air flows tested in one of the houses in February 2022 showed a significant difference between the sum of the room extracts and the air being exhausted from the building. This suggests that the ducts leak. There was concern at the original commissioning in 2011 (see below). However it seems to be worse now and ought to be investigated. Checks were also conducted externally on three other houses concluding that the air flows were not what they ought to be and that the systems should be checked again once the filters were known to be clean.

Conclusions

For an effective ventilation system the design, procurement, installation, commissioning, maintenance and operation must all be done well.

A confidential technical annex to the Innovate UK Wimbish Study report commented on each of the above six aspects. Although the air quality (see section 5) and other factors have remained good the procurement and installation were not quite as good as they could have been. The result being that the commissioner had to set the fans at higher setting than expected in order to overcome the pressure losses and deliver the designed air flows; he also found it difficult to balance the systems in a couple of the dwellings, and in one house there was a larger than desirable difference between the sum of the extract flows and the exhaust – implying that air was being drawn through a leak in the ductwork.

With one exception, the Wimbish households have largely used the MVHR as the design intended, and as explained to them during the extended handover process. Some found the controls over-complex, and simply left the system on the default setting of speed 2 – which has worked fine. Others have been more savvy and used the boost to remove cooking smells or moisture from bathing, and a low setting when away on holiday. The exception is a flat where the tenant was adamant that he would prefer to have the MVHR off and leave windows ajar. This has generally been the coolest flat, yet his gas bills are comparable with others; the property is not one of those monitored in detail, so we are unable to comment on the impact on air quality, though it is unlikely to be good. If he wished to be warmer he would probably have to use an electric heater as most heat is designed to be delivered by the (non-existent) air supply, this would raise his bills significantly – the lesson is to use the MVHR!

In conclusion, the MVHR systems are doing what is expected of them, though with a bit more energy cost than expected, and with care required to keep the filters clean. A decadal service is recommended.

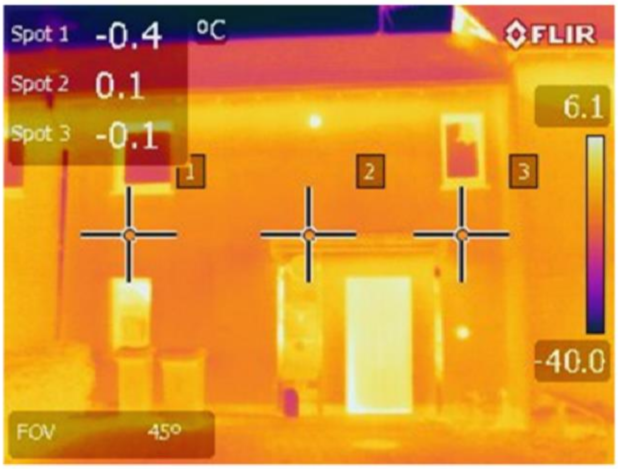
7. Fabric – Thermal Imaging

The Innovate UK Study reported the following conclusions[16] in regard to the fabric as inspected by thermal imaging:

> Firstly none of the issues identified are likely to be of significant impact on the performance of the buildings. As a result, additional diagnosis was not warranted.
>
> The main wall fabric exhibited minimal anomalies. BSRIA identified a possible issue above the brise soleil. However, I believe this is more likely to reflect the difference between areas shaded by the large overhang, and those areas more open to the diffuse daylight. Radiation impacting on the latter area possibly being supplemented by reflection off the brise soleil. It should be noted that the colour variation of the buildings' render made inter-building comparison difficult.
>
> Anomalies found at gable ends might indicate some heat leakage from the lofts (possibly a design feature to aid ventilation). However, this would then indicate that the lofts were warmer than ambient temperature, and perhaps there is greater heat loss from the occupied rooms into the loft than expected.
>
> Some (minor) heat losses were found by the windows and doors. There are a number of possible reasons:
>
> - Damaged seals
> - Settlement of the window/door meaning that the seals would not be as effective
> - Poor design detail, either of the window itself, or of the surrounding fabric
> - Poor construction – with either imperfect insulation, or deficient taping
>
> Finally, some design details, such as of the spy hole and of the loft hatch, could be improved in future.

The 2022 revisit found many of the same issues, some exhibiting further deterioration, as shown in the following extracts from the visit thermal imaging report.

16 Note that the list of possible reasons for the heat lost is a generic list. The thermal imaging was not able to determine the extent to which any of these applied.



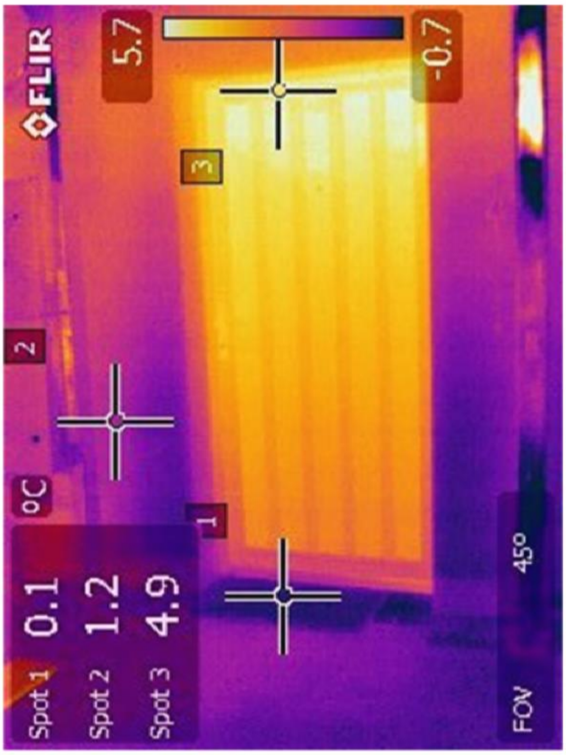
2. EXTERNAL INFRA-RED PHOTOGRAPHS

11 February 2022 was clear, sunny and relatively still, with local ground frost and temperatures close to freezing. The bright sunshine limited external infra-red photography to the North side.

Figure 2 shows the North facade of one of the 2-bedroom houses. The three blocks at the bottom left are a hedge and two dustbins. It shows a largely good thermal envelope, with some inevitable thermal bridging around the perimeter of the windows. *The kitchen window (lower left, shows hotter owing to a reflection).* The front door, although to a high specification for the time, is very much the weakest spot.

***FIGURE 2: North façade of a 2-bedroom house**. The bright strip along the upper part of the wall is not a thermal bridge, but results from the shading by the eaves overhang of radiant heat losses to the clear sky (still below -40 C here). The bright triangle (top right) shows low morning sun shining onto the ridge of its neighbour. The dot to the right of the front door is the outlet from the MVHR unit. The central dot near the top is the boiler flue.*

Figures 3 and 4 show more detail around the front door. Figure 4 confirms considerable air infiltration, particularly at the cill. This substantiates comments by residents about draughts from the front doors.



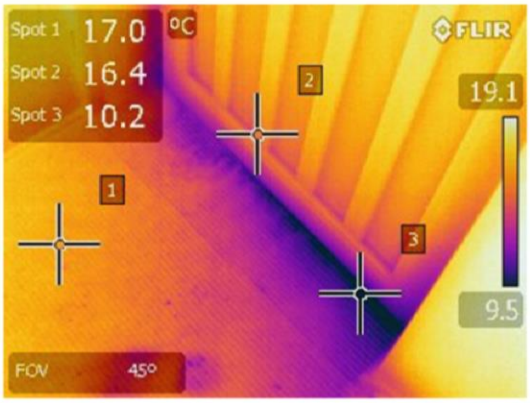


FIGURE 3 (left): Outside front door
Not only is the door at a much higher temperature than the adjacent wall, but it is warmer at the top than the bottom. This is partly because the glass porch roof above provides a shield from radiation losses to the clear sky.

FIGURE 4 (above): Internal view of the same door
This shows cooling by air infiltration at the cill, where the weatherstrip had been torn, owing to opening, closing, grit and foot traffic. Smaller amounts of infiltration were found around the perimeter of the door, with the section between the lock and the floor being particularly leaky.

Figure 5 illustrates similar (though generally less severe) heat loss and air leakage around the back door of the kitchen/dining area, again confirming comments by occupants. Here the seal at the bottom of the door was displaced (figure 6) and the bottom window frame gasket detached and folded over in two places (figure 7 shows one of them).

FIGURE 5 (left) *Back door and adjacent opening window.*

FIGURE 6 (above) *Back door cill with detached weatherstrip, bowing outwards in the middle.*

FIGURE 7 (right) *one of two folds in the draught seal of the window to the left of the back door*

The other regularly-used windows and doors here had similar problems with their bottom seals. The door seals will have been damaged grit and foot traffic. The window casements may also have settled, increasing the drag on the seals and sometimes folding them over and/or pulling them out of the aluminium extrusions they slot into.

8. Air-tightness

For Passivhaus compliance a building must be tested to achieve an air leakage of less than 0.6 air changes per hour. This minimises heat losses from air leaking through the fabric of the building, as well as reducing the risk of moisture condensing within the wall en-route.

The following table shows the air test results at build completion, the additional tests in the 2-bed properties after the lounge window was changed, tests of 5 properties near the end of the Innovate UK study in 2013, and of 2 properties in 2022.

Table 2: Air tightness test results over time

n50 ach (1/h)												
BSRIA June 11: Press.	0.55		0.60	0.61	0.26	0.34	0.33	0.39	0.46	0.46	0.53	0.37
BSRIA June 11: Depress.	0.54		0.60	0.65	0.31	0.38	0.39	0.37	0.46	0.56	0.55	0.37
A.T. Dec 12: Press. (adj)[17]						0.53	0.53			0.54	0.62	
A.T. Dec 12: Depress. (adj)						0.68	0.61			0.63	0.62	
BSRIA Mar 13: Press		1.14		1.32			0.51		0.60			0.75
BSRIA Mar 13: Depress		1.09		1.20			0.70		0.64			0.88
Feb 2022: Pressurize							0.93				0.87	
Feb 2022: Depress							1.01				1.06	

The air infiltration has increased, and is now some 50% more than the Passivhaus standard and the original pressure test results ten years ago. Although still very good in relation to current UK regulations (let alone practice!), this is concerning, given the imperative to reduce heating loads and that the sizing of Passivhaus heating systems assumes the Standard's low infiltration rates. The extra infiltration helps to explain comments by some occupants about draughts, low temperatures and occasional supplementary heating.

This extra leakage is thought to come largely from deteriorating door and window seals, particularly at the door thresholds and many of the window cills, and from the double windows failing to close tightly. Damaged seals have also made some doors and windows more difficult to shut and may account for some of the warping reported. Sealing is important to the longevity of low-energy buildings: though some maintenance will always be necessary, ideally seals would be more robust and/or more readily replaceable, even if this necessitated small sacrifices to initial airtightness. After an overhaul, annual inspections would ideally be included in the maintenance regime.

[17] Adjusted to use the same building volume figures as the other tests.

9. Occupant Surveys

Occupant satisfaction has been assessed at intervals during the ten year study by use of Building Use Studies[18] (BUS) occupant surveys.

The first survey was conducted in September 2011, a second in the summer of 2013 and a third in February 2022. The first survey was relatively soon after occupation, and the second was conducted during the hottest weather experienced during the initial Innovate UK study, with the third being part of the wrap-up at the end of ten years of study. The time of year when the surveys were conducted, and who responded, inevitably influenced the responses.

This section is primarily about the feedback received in the most recent survey, with reference to those conducted previously. Residents of all 14 properties were invited to complete the survey, and were reminded to do so several times by Hastoe; despite this we only received 4 responses: 3 from 2-bed mid-terrace houses, and one from a ground floor flat. This meant that the benchmarks were not meaningful, and the responses were treated as case studies[19].

Overall the responses aligned with the other findings of this report, and with the earlier surveys.

Positive responses:

- Heating costs were confirmed to be 'much lower'
- Comfort overall is 'good'
- Air quality overall is good
- Location is excellent

Split/negative responses:

- Winter temperature
- Summer comfort and temperature
- Air stillness and freshness
- Noise
- Appearance

Winter temperature

3 responses were good for comfort in winter, but one was quite poor. The latter explained that '*they had no heating*' using electric oil-filled heaters when necessary, and that they left the back door open so that their dogs could use the garden. [The same residents had given a good response in 2013].

From the site visit it is felt that only simple action is likely to be needed to reinstate their heating (which is primarily by warming the incoming ventilation air). However, more fundamental problems with the boiler or heater element cannot be ruled out. The residents verbally added that they were irregularly in occupation, and thus using the electric heaters suited them.

More generally there was feedback that poor seals at windows and doors led to draughts and heat loss.

18 see https://busmethodology.org.uk or https://www.usablebuildings.co.uk/

19 There is also the possibility that the results could be biased, with responses perhaps coming from households with non-related concerns.

Summer comfort and temperature

Overall summer comfort was somewhat towards the uncomfortable end of the scale, and the response for temperature showing that most respondents felt their property was too hot.

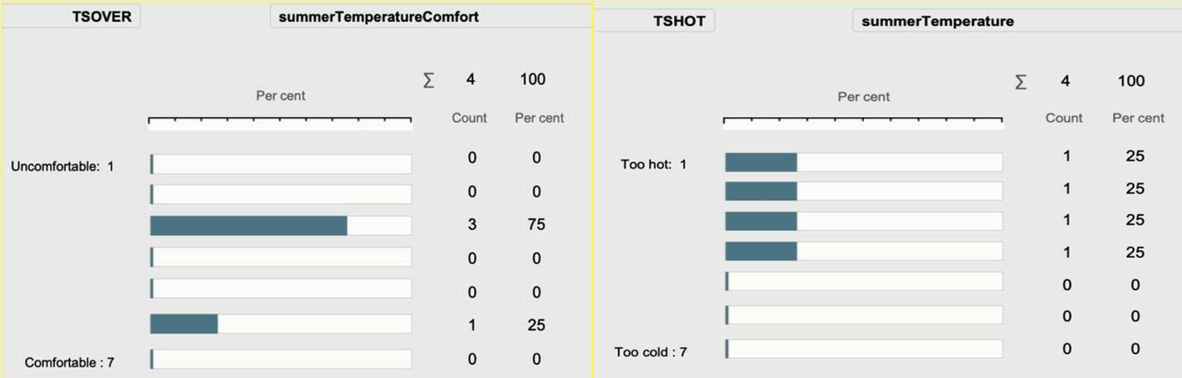


Figure 6: Summer Comfort

The mean scores are close to the values logged in 2013, which were worse than those of 2011.

Comments being '*need a fan in the summer*', '*fans in summer always necessary inc. all night*', '*we open all upstairs windows when it gets too hot*'.

It should be noted that temperature logs have shown that some households have been able to keep cooler than others, and that generally the Wimbish properties are less hot in a heat wave than other properties.

There are a number of possible reasons for these responses:

- Previous assessment was that those residents who felt in control of the approach to manage the overheating risk felt more comfortable (even though they might have similar temperatures)
- That advice given a decade ago hasn't become an embedded behaviour and that the residents could do better in limiting heat gains
- That the design could have paid more attention to overheating risks
- Higher than expected electricity use contributing warming
- Reluctance to open windows for purge ventilation because of noise (aircraft), insects, etc.
- That blinds were not functioning or not being used effectively

Air stillness and freshness

Overall air quality was rated as good although individual indicators received a lesser rating. One household commented about draughts (based on leaky window seals), while others commented that the air was still. We think that the latter was meant as a positive being lack of draughts. However in the BUS methodology it is considered a negative.

Ratings for air freshness, a reflection of the ventilation effectiveness, were okay in winter, but more scattered in summer, with one resident saying 'stuffy' – perhaps a reflection of the level of overheating as opening windows ought to have easily eliminated stuffiness.

Noise

The highly-insulated triple-glazed nature of a Passivhaus inherently provides a high degree of sound-proofing against external noise. Beyond this, noise treatment between rooms, floors and through party walls is the same as for any other property. Having said this, the quiet nature of a Passivhaus perhaps accentuates other noises.

The 2022 responses repeat the finding that noise from neighbours in the terraces is annoying; comments being '*excessive screeching of dragged furniture (chairs) from 2 houses away! Due to hard flooring and Passivhaus design?*' and '*Between houses you can hear a lot - e.g. chairs scraping, dogs barking, people shouting, music etc.*' Also that '*aircraft*[20] *noise audible via bedroom window bad seal*'.

Appearance

There was consensus that the appearance of the development left a lot to be desired: '*After ten years this is totally compromised from lack of re-painting & difficulty of access to clean both door canopy & brise soleil (hazardous)*', and '*Because of a textured finish & never gets any sun, all fronts are covered in mould.*'

20 Stansted Airport isn't far away.

10. Heating and Hot Water Systems

The system is somewhat unusual, even for a low energy house:

- Water in a hot water 250/210 litre store is heated by combination of the solar thermal panel and the gas boiler.
- Hot water is used directly, or, via a plate heat exchanger, for space heating
- Heating is via a towel rail in the bathroom, and an in-duct heater in the supply air.
- A portable thermostat is used to control the heating

Overall

Generally the occupant surveys over the ten year period have indicated that the residents are able to achieve a comfortable temperature in winter, and the author is not aware of any complaints about hot water provision.

Unfortunately the heat flow meters installed in three of the properties with the aim of measuring how much heat came from the panels and how much from the boiler and where it was used, proved inadequate to the task thus we cannot answer these questions.

What we do know is that more gas is being used in the summer months than was expected. See section 3 Energy.

Solar thermal

A visual inspection of the system by manufacturer representatives during the Innovate UK study elicited the response that they were surprised they hadn't been installed in a more consistent manner, and that there were some installation faults which would limit the effectiveness of the install. More recently reports by the service engineers have advised that some remedial work is desirable.

Gas boiler

As can be seen earlier in the report the energy efficient design and construction means that gas consumption is a fraction of most UK homes (and bills are likewise low).

It has long struck the author that it must be rare that the annual service charge is probably more than the cost of the gas the boiler consumes.

There have been a handful of instances where low gas consumption by a household has been linked to a fault Hastoe has needed to remedy; and one recent instance where the household had come to the conclusion that they had no heating system. During the site visit it was realised that the batteries in their thermostat needed replacing.

Residents reported that the complexity of the heating system, and its use of non-standard parts, meant that work on them was beyond a typical service engineer and that a specialist had to be called. This is particularly an issue for shared-ownership properties who stated that they do not have access to the service engineers retained by Hastoe[21].

[21] Looking at the service engineers' website it seems that they do offer a service to householders. We have not been able to ascertain whether this is a recent innovation.

Conclusions

While the Wimbish system ‘ticked the boxes’ at the time of the build it was perhaps overly complex to install and maintain to enable optimum performance at minimal cost. The 10 year study has emphasised the need to consider maintenance when designing low energy buildings – it is all too easy to include technology which may not stand the test of time.

A new project would be unlikely to use a natural gas boiler for a number of reasons:

- The government drive to net zero will soon preclude their use
- Green hydrogen production and distribution for use in a hydrogen boiler is yet to be proven and there are doubts whether it can compete financially as a fuel
- Properties that require minimal heating are penalised by utility companies[22]. It is likely preferable to have a single fuel, that is electricity.

With increased awareness of and interest in whole life net zero[23] a wider range of considerations comes into play (albeit going beyond the Passivhaus agenda).

Alternative solutions for a new project might include:

- a communal system – though for low usage schemes losses in the underground elements can be prohibitive [an ambient loop system may solve this]
- an air-source heat pump (if a small-enough one can be found and bear in mind the embodied carbon of the refrigerant gas)
- direct electric – though this makes Passivhaus compliance more challenging. It is likely to reduce capital and maintenance costs but will increase operational costs[24].

Wimbish largely relies on heating through the air supply[25], which in turn depends on a carefully designed and fully functioning ventilation system. Perhaps a solution which relied more on radiators than on the supply air[26] might be preferable.

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22 The ‘per kWh’ tariff is higher and/or the standing charge becomes a significant element of the bill.

23 For example see the CIBSE-LETI Net-Zero FAQs

24 While the c£280 gas bill would be lost, at Apr 2022 prices, and assuming the same kWh are required (actually electricity should be more efficient) then the electricity bill might rise by around £700.

25 It is a secondary definition of a Passivhaus that the air supply is capable of heating the house.

26 Some supply air warming might be desirable to avoid cold draughts – say to 18°C.

11. Build approach

The Wimbish development was one of the earliest Passivhaus projects in the UK. In the intervening period significant experience has been gained, not least from performance evaluation such as this one, and a new project with similar objectives would differ in a number of regards.

Solar gain

In winter the solar gain in a Passivhaus is valuable in providing free heating, but in summer it may need to be managed to minimise overheating. At the same time the design must ensure adequate daylight and views for the residents.

The strategy for Wimbish involved larger windows to the south side with large overhang, external blinds and brise soleil. The design used the 2007 version of the PHPP software; more recent versions have emphasised overheating analysis more than was thought necessary in 2007.

In practice the residents have tended to employ the blinds more for privacy than for shading; and after 10 years they need some attention to ensure that they still operate as intended.

While the high levels of insulation in these properties assist in keeping them cooler in heat waves than other properties, they can still get hotter than desirable – technically overheating. It helps if the residents understand when to keep windows and doors closed, and when open to provide a through draught. Surveys earlier in the period found that those residents which understood how to manage the solar gain were more forgiving of high temperatures (although they might not actually be cooler).

If the design was being undertaken in 2022 this topic would be given more attention, and the design strategy would be different. Most likely the size of the south facing windows would be reduced.

Walls

The choice of thin joint blockwork with external insulation and render remains a viable approach for a Passivhaus. However it is rarely used in the UK.

The Innovate UK study found that contractor struggled with ensuring a good fit of insulation to blockwork and of one insulating block to its neighbours. However, the thermal mass of the blockwork is an advantage.

Heating system

See the discussion on the previous page

Ventilation

The importance of good ventilation in dwellings, supplying fresh air and removing odours and particles, has been highlighted by the pandemic. In a Passivhaus this should be in conjunction with heat recovery (MVHR) such that 85 to 90% of the heat in the outgoing air is retained in the house.

A high quality system is important to minimise risk of issues arising over time. Design should ensure that cleaning supply and extract terminals doesn't affect the air flows.

A significant issue is the need to exchange filters on a regular basis. Dirty filters can limit air flow, and load the fans, wearing them out more rapidly. Until MVHR is commonplace relying on residents to carry out this important task is probably overly-optimistic; on the other hand a servicing contract may be costly and reliant on access to the properties. Despite the hope early in the study that manufacturers might offer solutions to this issue it remains unresolved.

Other

A number of details such as how floor joists and roof trusses were constructed to ensure air-tightness and enable insulation continuity would be revisited.

12. Performance considerations in a Passivhaus

Passivhaus design is holistic[27] 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) [28].

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, along with an increase in appliance use. Not only will the latter increase electricity consumption, but, at least in winter, the heat emitted by 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 reduce 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 will be lost through the fabric, and left alone with the ventilation off, a house will only cool very slowly even in the coldest weather. However, a running ventilation system, even with well-performing heat recovery, will cool the property if the lost heat is not replaced[29]. 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[30]. Of course, if the household chooses to leave windows open, 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.

This study has coincided with some of the warmest years on record in the UK, 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).

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27 In respect of its focus, being comfort and energy efficiency in use. It does not seek to address the materials used in construction – whether or not they are sustainable, low carbon, or help provide good air quality is outwith the scope of Passivhaus design; albeit many Passivhaus practitioners would seek to address such issues alongside Passivhaus design.

28 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. Changes in PHPP v9 introduce a more realistic estimate of expected occupation levels – though these may remain unrealistic for UK social housing.

29 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.

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

13. Monitoring Kit

The monitoring kit was installed by the building contractors to meet the requirements of the Innovate UK study. The Wimbish study was being managed alongside one of the Thomas Paine building at UEA by a consultant working for UEA on the EU Build with CaRe project, since the latter employed Trend BMS kit the same was used for Wimbish to make data collection and analysis consistent.

The Wimbish properties are in three blocks. One property in each block was chosen to be 'fully' monitored and to host the Trend Controller; the other properties having a reduced number of sensors/meters; with all being wired back to the controller (where the data is temporarily stored) providing reliability. Download to an SQL database, using Trend 963, has been over a broadband connection to the 3 host properties and used Wi-Fi from router to controller.

The original proposal covered the following kit:

	Fully	Partially
Comfort – Temperature & Relative Humidity		
Lounge	✓	✓
Bedroom, Kitchen and Hall	✓	
Air quality – **CO_2** Lounge & Bedroom	✓	
External – Temp, RH & Solar	Once for the site	
Utilities – Gas, Electric & Water[31]	✓	✓
Electricity sub-metering at the consumer unit		
Kitchen and small power	✓	✓
MVHR, Boiler, Solar Thermal, Heating	individually	Collectively
MVHR air flow temps (3 locations)	✓	
Heat Flows (boiler, solar, DHW, heater, towel rail)	✓	

Although much of the kit has continued to function over the ten year period, there has been some loss of data and of accuracy:

- Heat flow meters – these were poorly installed and poorly specified – once the latter was realised there was little point in improving the install. Unfortunately no useful data was obtained, meaning that we have not been able to quantify energy used for space heating, or that used for hot water.
- Water and gas meter sensors – their below ground location meant that damp ingress caused most to fail over time.
- External sensors – these failed after a couple of years. Their inaccessible rooftop location meant that no diagnosis or resolution could be sought
- Gas and electricity meter sensors – replacement by pre-pay or smart meters led to loss of the connection

31 Manual meter readings have been taken at regular intervals by Hastoe staff. The two sets of readings have been used as a cross-check and to fill in gaps.

- Electric sub-metering – the boxing for these reduced resident space and was unattractive. After some years it was agreed, that if the resident wished, the kit, and boxing, would be removed. Some sub-meters were discovered to be on the wrong circuits anyway.
- Temperature and humidity sensors – their accuracy reduces over time (drift). Periodically those that could be accessed during a site visit were checked and re-calibrated. However, recent data cannot be considered accurate
- The system in the flats: despite adding a range extender, the Wi-Fi connection has been unreliable. This has meant that there are gaps in the downloaded data – sometimes only a few days, but sometimes weeks or months.
- The system in one block of houses: had worked well until the resident wished to switch to Sky broadband in October 2018. It wasn't possible to run two services and thus access to the data was lost.

Monitoring conclusions

In the main the monitoring has performed well, and a lot of the kit has exceeded lifetime expectations.

If a new project was being started marketplace options would need to be considered afresh, given knowledge of the above 'challenges'.

With hindsight some of the original specification and install could have been better; but, for example, higher quality sensors would have exceeded the available budget.

A wired solution has proven advantageous. It was unfortunate that a relatively late relocation of the controllers (to attic space) meant that link from router to controller was by Wi-Fi rather than a CAT5 cable. Ideally the broadband router would have been distinct from any resident system. However, access to it for any restarts might have been an issue. Note that at project inception, using GPRS was not an option given the poor local signal.

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