Technology Strategy Board
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Technology Strategy Board
Building Performance Evaluation
Project 450038

Wimbish Passivhaus Development: Performance Evaluation Executive Summary

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Synopsis

This is an executive summary of the Building Performance Evaluation study of the Hastoe Housing Association's Wimbish Passivhaus Development carried out from 1st April 2011 to 30th September 2013.

The study complies with Technology Strategy Board requirements for BPE of a ***Domestic Buildings: Phase 2: In-use performance and post occupancy evaluation study***

The project reported here is part of the Technology Strategy Board's Building Performance Evaluation programme and acknowledgement is made of the financial support provided by that programme. Specific results and their interpretation remain the responsibility of the project team.

1. Wimbish Passivhaus Building Performance Evaluation

This Building Performance Evaluation Study has verified that the Wimbish Passivhaus development has met 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

This study has proved that the Passivhaus approach delivers. Overall, the homes perform as designed and have provided 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 state that their heating bills are only £30 a quarter. This lack of a 'performance gap' is a reflection of the high quality process from design to occupation.

This study has been extensive, looking at the development from a number of perspectives. It is one of the most detailed studies of the performance of any kind of new build homes, and of the behaviour of their occupants, that exists. The way it was done, and the lessons learned about how to do it even better, set the template for future studies.

It is extremely important that UK house builders have paradigms for successful low energy homes, as effort accelerates to comply with the EU 'nearly zero-energy buildings' requirement in the Energy Performance of Buildings Directive. Studies show that we cannot rely on estimates such as SAP ratings or Energy Performance Certificates to predict in-occupation performance of a new home (or, indeed, of an existing home that has been made more energy efficient). Only by systematic in-use monitoring, both quantitative and qualitative, can we understand what works well and what does not, and how occupants can achieve the potential benefits of low energy living.

This evaluation demonstrates conclusively the benefits of Passivhaus design, and identifies those aspects of design, construction, occupation and maintenance that can be improved in future projects. The benefits are substantial in terms of occupant outgoings, health and well-being, and almost certainly in terms of housing association long-term rental income and asset valuations. Therefore, Passivhaus is sensible for new build to maximise benefits from constructing homes that are very energy efficient. As the skills and supply chain develop, any extra capital costs of building to the Passivhaus standard will become negligible compared to the longer-term benefits for occupants and housing associations.

Given that this was the first Passivhaus development by Hastoe, the first Passivhaus design by the architect, and the first Passivhaus construction project by the contractor, in essence making it an experimental project for all three, these findings are remarkable and demonstrate that Passivhaus provides a viable and successful route to low-energy living.

Background to the study

Research has shown that new buildings rarely perform as well as expected; there is generally a ‘performance gap’ between what the client and designer expect, what the contractor delivers, and what the occupants actually achieve in practice.

The Technology Strategy Board established a programme for domestic, and non-domestic, projects to bid for funding to support BPE studies to understand why the gap exists, and how it may be closed. A successful bid for funds to study the Wimbish Passivhaus dwellings ‘In Use and Post Occupancy’ was made by Hastoe with the support of the EU Build with CaRe project.

The study was fortunate also to have a PhD researcher from the School of Environmental Sciences at UEA to undertake additional and much more detailed occupant behaviour research alongside, and in conjunction with, the Technology Strategy Board required tasks.

Topics and contents

Figure 2: Site plan

The development comprises 14 units: a block of 6 51m^2 one-bedroom flats, and two rows of 4 houses, comprising 3 88m^2 three-bedroom and 5 76m^2 two-bedroom dwellings.

This document summarises the key points from the full, confidential report of 122 pages (plus 500 pages of appendix). This document comprises a double-page spread for each topic, with a brief review of findings and the lessons for future developments. Descriptions of the development, and of the BPE process, may be found at the end of this paper.

Acronyms

BPE	Building Performance Evaluation
DHW	Domestic Hot Water
MVHR	Mechanical Ventilation with Heat Recovery
PHPP	Passivhaus Planning Package; employed to design Passivhaus buildings
SAP	Standard Assessment Procedure UK Government methodology to assess the energy performance of dwellings

2. Heating Bills and Winter Comfort

Having low heating bills is only of value when these are accompanied by a comfortable environment.

A Passivhaus is expected to be comfortable throughout at all times, with no cold surfaces and with the ventilation system tending to even out temperature variations.

Heat losses are sufficiently low that they can be replaced by a small heat supply, via the ventilation air. The system can only respond slowly to changes in demand, and in cold weather heat supply as required 24 hours a day is desirable.

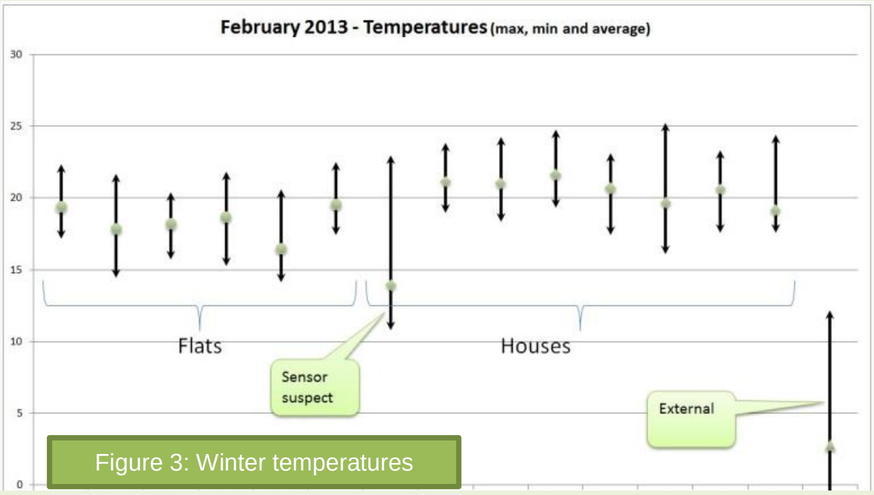

Figure 3: Winter temperatures

The Passivhaus standard sets the onerous target for space heating of 15 kWh/(m^2·a), along with figures for primary energy demand. Since the study was unable to monitor space heat directly, the target employed for performance monitoring was that for gas used by the boiler as calculated by the Passivhaus Planning Package (PHPP) 2007 for each property.

Figure 4: Room thermostat

The heating system design incorporated a portable room thermostat to allow residents a limited degree of control over the temperature.

The mechanical ventilation system (MVHR) removes warm moist air from the property and, in winter, brings in cold outside air. The warmth is transferred from outgoing to incoming air in the heat exchanger. Cold air holds far less moisture than warm air, and, in central Europe, the slow loss of moisture can sometimes over-dry properties. Although this undesirable outcome is less likely in the temperate UK climate, the internal humidity level should be monitored.

The mean temperatures in February 2013, the coldest month during the study (see Figure 3), were within a degree or two of the Passivhaus design level of 20 °C. Only two of the properties recorded a minimum temperature below 15 °C, and the tenant of one flat is known for liking fresh air – having his windows open and his MVHR off.

Inspection of the 5-minute monitoring logs showed that the residents experienced some diurnal temperature variation, presumably by turning down their thermostats overnight.

Overall, the tendency is for the residents to like higher temperatures, and to wear fewer layers of clothes. While this might be considered a negative ‘rebound’ effect, the data shows that the impact on energy use of such preference in a Passivhaus is small. Hence, Passivhaus design delivers a double win: a warm, healthy and comfortable environment with low heating bills.

What the residents say:

“never feeling cold”

“no longer use hot water bottles and extra blankets to keep warm in winter”

“(we) hardly ever use heating”

Pleased that the lack of radiators gives them freedom to position furniture, and that lack of draughts and cold spots permits beds to be placed right by the windows.

Loving their dry homes – no condensation.

Delighted that some are able to report annual gas bills as low as £120.

The Wimbish properties use gas only for heating and hot water, the boiler being supplemented by a solar thermal system.

Figure 5 shows the annual gas consumption in kWh for each property, compared with Ofgem's figures for typical consumption. The right hand scale shows what the cost would be if the residents had been on Ebico's Equigas flat rate tariff (most energy suppliers, by virtue of standing charges or a higher tariff for the first 'x' thousand kWh, penalise consumers who use small quantities of gas.).

The properties show a distribution of consumption that is typical for a set of dwellings. On average, savings from the Ofgem medium are around £500 a year (excluding VAT).

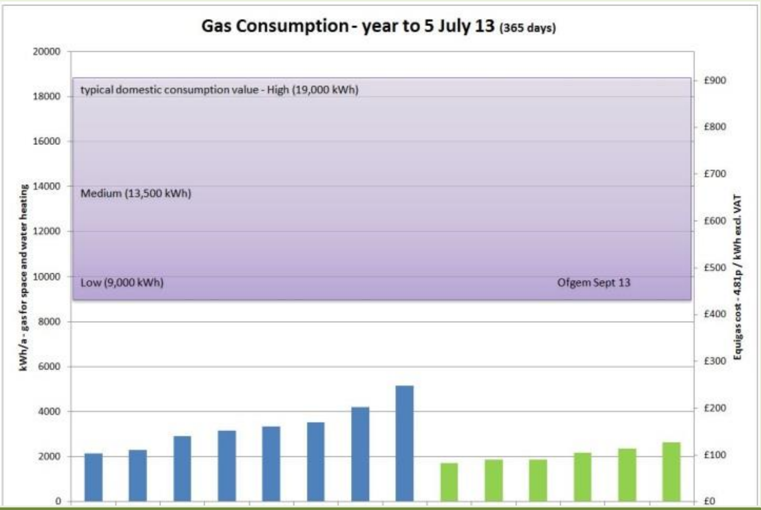

Figure 5: Annual gas consumption (houses blue, flats green)

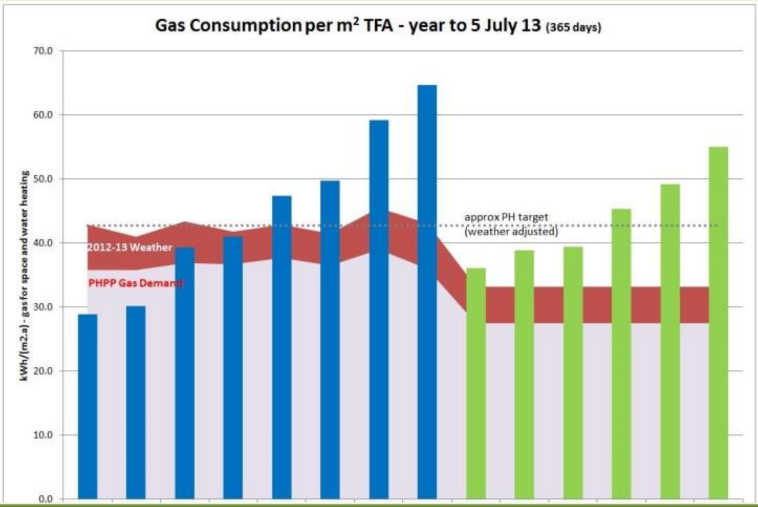

Figure 6: Annual gas consumption per m^2

Figure 6 compares the total gas consumption divided by the treated floor area with the expected gas demand. The dark red band is an allowance for the actual weather on site.

The annual gas consumption in the houses is close to (distributed about) the amended design expectations. The flats do not quite meet the expected (better-than-Passivhaus-requires) performance; but they do average the weather-adjusted Passivhaus target.

The highest consuming house uses double the quantity of gas of the lowest. However, even this property is achieving a major saving in comparison with 'normal' homes. In a Passivhaus, the energy and financial penalty for inefficient operation is small. These results show that no matter how residents use their homes, a Passivhaus home, very importantly, remains inexpensive to heat.

Lessons for winter comfort and low bills:

These results vindicate Passivhaus design and construction, which delivers much reduced heating bills, along with excellent comfort.

Actually, it is suspected that heat losses through the fabric are a little higher than they ought to be (*see pages on Construction and Commissioning*). The reason gas usage has not increased is probably that these losses are offset by gains from higher occupation and electricity use than assumed in Passivhaus design.

It is unusual that the annual cost of servicing the boilers is similar to the value of the gas consumed. Such light usage of a boiler does not help its performance efficiency, or its longevity.

3. Electricity and Appliances

Figure 7 shows that total electricity consumption in the houses ranges around Ofgem's medium figure of 3,200 kWh per year; whereas that in the flats is considerably less (comparable with Ofgem's low figure of 2,000). This is a consequence of reduced floor areas and lower occupancy.

The Passivhaus standard does not set a specific target for electricity use, though it must be accommodated within the primary energy target of 120 kWh/(m^2·a) for all energy used in the property.

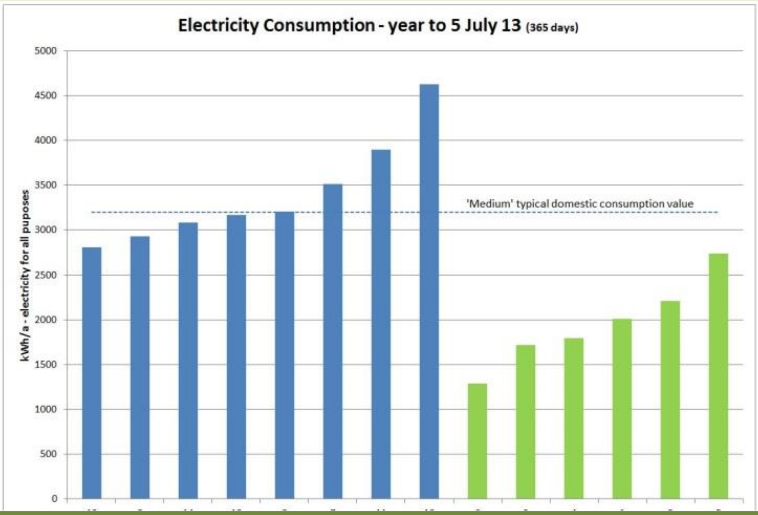

Figure 7: Annual electricity consumption (houses blue, flats green)

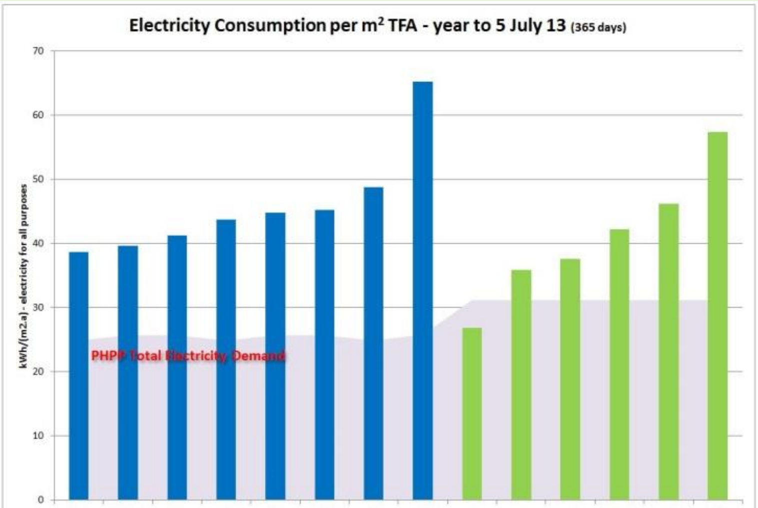

Figure 8: Annual electricity consumption per m^2

The PHPP 2007 calculations give us an allowable electricity use figure for each property if we are to stay within the primary energy target by deducting expected gas usage from the 120 and applying the appropriate primary energy factors. This calculated 'allowable' demand is shown as the shaded area in Figure 8.

With the exception of one flat, the electricity consumption per square metre in each of the homes significantly exceeds the PHPP expectation.

Consumption levels are similar to those in an 'ordinary' house (though allowance should be made for the 'extra' of running the MVHR fans).

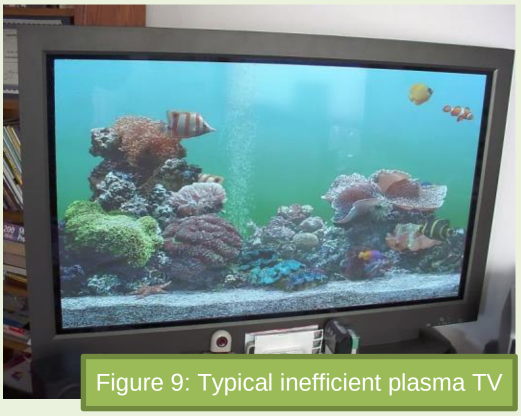

Figure 9: Typical inefficient plasma TV

Figure 10: Typical kitchen appliances

The following factors contribute to this divergence from the PHPP 2007 calculation:

- Property size: Some electricity use in any property, for example refrigeration, is 'per property', and the usage/m^2 will be higher for a smaller property. The space standards for new homes in the UK, as exemplified by the Wimbish properties, are significantly less generous than the average German new build (where the Passivhaus approach has been developed)

- Occupant density: The Passivhaus norm is one person per 35m^2, with a minimum of 20m^2. The Wimbish 3-bed properties are nominally for 5 people, but the PHPP calculation was based on just 2.3 people. The 'per person' electricity use, for example dishwashing, laundry or consumer electronics, will not have had the appropriate multiplier

- Appliance efficiency: PHPP assumes that appliances will be efficient. In practice, Hastoe was not able to provide appliances for their tenants. The appliance audit found that many of the appliances residents brought with them were inefficient. Even where new appliances were purchased, the selection was based more on capital cost than on energy-efficient operation (although the latter would be likely to save money over time).

- Appliance usage: There is an implicit assumption that occupants of a Passivhaus will be inclined to be energy-conscious, and thus be 'careful' in their use of appliances. The Wimbish residents, however, are simply local people who needed a home, only one of whom claims to be environmentally-minded

Figure 11: Low energy ceiling light

PHPP calculates the expected electricity demand based on the above assumptions, which means that at Wimbish it was likely to yield an underestimate. However, by default, PHPP does not use these 'likely-to-be-too-low' electricity figures when calculating the internal heat gains (instead, it applies a generic 2.1W/m^2).

The consequence of this 'normal' electricity use is firstly 'normal' bills, but secondly an additional heat gain as most of the electricity used will end up heating the property.

In winter, any extra heat will reduce the gas demand, but in summer, it will be less beneficial and may need resident action to purge it from the properties.

Lessons regarding electricity and appliances:

Having successfully addressed wasteful heat loss from housing, developers of Passivhaus homes could now turn their attention to how best to minimise electricity use:

- Efficient appliances – if possible, provide, or help households acquire, the most efficient appliances
- Efficient use – educate and encourage households to follow behavioural practices that minimise electricity use.

Designers should determine the sensitivity of the performance of a building to variations in electricity use (low usage as well as high) as early as possible in the design process. High sensitivity would indicate a need to change the design, or to take greater efforts to ensure that residents are supplied with, or have the knowledge to acquire, efficient appliances and to use them sensibly.

4. Client Brief and Design

Low energy building construction, especially of a Passivhaus, requires a change in ethos from that prevalent in mass house-building. The current ethos is to build as quickly as possible, and as cheaply as possible. This relies on flexibility on site to make ad hoc changes, and tends to lead to an adversarial culture. Too often, the result is poor quality buildings that fail to perform even to the relatively undemanding building regulations.

To address this problem, and to deliver energy-efficient buildings, an ethos of quality, with attention to detail, pride in workmanship, and working in partnership, needs to become widespread. In other modern manufacturing sectors such quality procedures are standard; no-one would buy a car or computer made in a sub-standard way. The Passivhaus approach can be a much-needed stimulus to transform construction industry quality.

Client brief

It should be clear to everyone involved in a project that the objective is to deliver a certified Passivhaus; and that quality and partnership are to be prioritised.

Senior management support is vital, and all parties need to know what their responsibilities are.

It may be appropriate to specify in the employer's requirements that a quality assurance process be followed by each party. Repayment of the retention monies should reflect whether the dwellings are meeting performance expectations.

A building performance evaluation should be expected. At a minimum, this should include energy consumed, comfort levels attained and occupant satisfaction. A Soft Landings approach is recommended.

The project budget may need to be increased to allow for learning Passivhaus skills, and to account for extra materials and fees. The final cost at Wimbish was assessed as being 12% greater than building to Code for Sustainable Homes Level 4.

In time, any extra cost is expected to reduce, as parties become familiar with what is required and find ways of streamlining their processes, and as the supply chain develops to meet the needs.

Extra capital cost can be justified by:

- reduced energy bills for the tenants, thus reducing the risk of rent arrears. Lower heating costs are expected to achieve payback on the increased Wimbish capital cost in around 20 years
- reduced snagging and maintenance costs accruing from the higher quality build, components, and finishes

and, in future, increasingly by realisation of:

- raised asset values of low energy properties
- the comfort, health and well-being benefits.

Organisations commissioning a new build project would be wise to specify Passivhaus now, to ensure that their asset does not have its value marked-down in future.

Design-and-build is frequently employed for UK construction to transfer risk to the contractor. However, for Passivhaus development, there is a need to minimise risk by fixing the design, including quite fine details, at an early stage. The contractual relationship requires careful consideration in future projects (not least to avoid inhibiting innovation in the build), perhaps with the client retaining design-control.

Supervision warrants a three tiered approach:

- By client Clerk of Works – visiting most weeks
- By the designer(s) – with frequent visits to check on progress and to resolve any issues quickly. It might be preferable that the architect be retained by the client
- By the contractor – employing a 'champion' to undertake full time supervision.

Those involved must have the necessary skills and experience in Passivhaus and construction.

Design

The design team must have the necessary Passivhaus expertise.

As with any design, it pays to keep it simple, using straightforward, repeated design elements.

The design cannot easily be changed during construction as the impact of any change needs to be considered in detail. Changes during construction must therefore be kept to an absolute minimum. The design, including the M&E works, must be completed to fine detail before works commence.

The designers - architect, and structural and mechanical engineers - must work in partnership to ensure that the building works as a whole. Having a fixed design means that the contractor will have much reduced flexibility during the construction. The designers must consider 'buildability' during the design phase, and it would be advantageous to involve the contractor.

The performance of a Passivhaus can be quite sensitive to some of the inputs to the planning package. The designer should assess this sensitivity, and if necessary adjust the design. For example, higher levels of occupation would imply greater electricity use and more heat generation. Together, these factors could increase the risk of overheating to an unacceptable level.

The design must address how the dwellings will be used by their occupants. What level of controls are appropriate for them to have; to what extent will they be responsible for adjustments with changing levels and pattern of occupation; what will they need to do to manage solar gain in hot weather? The sensitivity assessment should include the consequences of the designer failing to ensure that the occupants get the best from the dwelling.

The design should cover issues of servicing and maintenance. For example: *Who will be responsible for servicing the MVHR and its filters? Is access easy? What other routine activities are needed?*

Figure 12: Insects blocking the MVHR filter

Figure 13: Flats with Brise Soleil (solar shading)

Lessons for client and designers:

The client sets the scene for the project. Clarity over the expectations and the need for quality throughout is vital.

The client should ensure appropriate levels of supervision, retaining the architect or appointing a suitably qualified Clerk of Works.

A traditional design-and-build contractual approach may not be the most appropriate way to facilitate this level of supervision.

Settle all elements of the design early and involve all parties

Focus on what works for the occupants (and then for support and maintenance), making it easy for occupants to be comfortable and to obtain the expected energy performance benefits

Assess the sensitivity of the design to variations in materials, occupancy levels and behaviour patterns such as electricity use

The ventilation system is a vital component. All stages, from design to handover, must be to the best possible standard. It can be difficult to remedy faults in hidden components after occupation.

The design ethos should be documented and be retained for maintenance use.

5. Construction and Commissioning

Partnership

For a successful development, all parties should work closely together with a 'partnership mentality' throughout.

Defining roles and responsibilities at the outset may help ensure no misunderstanding later in the process. All partner operatives should be encouraged to identify defects as they arise so they can be rectified quickly. For example, when building to the Passivhaus standard, one cannot just 'patch up' or 'plaster over' defects later.

Quality

Adoption of a quality ethos requires buy-in at all levels of an organisation, not least from senior management.

Additional checks for compliance will be required before works can be covered-up, and tests, for example of air-tightness of building and ventilation ductwork, will be needed quite frequently. The construction programme must allow adequate time for these. As the works progress, management must ensure that this time is retained.

So-called 'value engineering' during the construction needs to be avoided. The impact of any unavoidable change (for example a product no longer being available) must be assessed as quickly as possible to ensure that the Passivhaus design and building performance are not compromised.

Site management

As well as allowing time for quality, management must also ensure that there are adequate resources. This means not only personnel, but also the appropriate tools and test equipment.

The site must operate a culture such that if anyone sees something being done incorrectly or inappropriately, then he or she should point it out so that it can be corrected, and so that everyone can learn how to do the task better next time. Everyone should be encouraged to suggest improvements.

The change in ethos must extend to sub-contractors and their staff. When selecting sub-contractors, their appreciation of the need for quality should be a major factor, and selection should not be based solely on their ability to work fast at low cost. Those who employ their own labour may be favoured, as this will help ensure that a consistent approach can be followed.

Cultural norms, where the tradesmen know what is normally expected of them, can prove difficult to remould. For example, it is normal to fair-face block-work internally ready for plastering, but, at Wimbish, it was more important to lay the blocks with a smooth external face so that the insulation could be fitted against them snugly.

Advice and guidance on best practice must be provided to all who work on site. This can be reinforced by toolbox talks, to impart skills and improve quality.

M&E Systems

Workmanship must be to the highest quality, in setup and commissioning as well as installation. Setup must be to the design documentation, and commissioning to the appropriate standards.

In the Wimbish build process, the parties generally recognised the need to prioritise partnership, quality, and attention to detail. What was not so easy was to achieve consensus on what this meant and how far it needed to be taken.

Figure 14: grommets and seals on penetrations

Testing

The performance evaluation study reassessed the commissioning and other tests carried out during the construction, as well as conducting additional tests on air-tightness, on the thermal integrity, and on the u-values achieved in practice.

Unfortunately, a whole-house heat loss (co-heating) test could not be conducted, as there was no vacant property during a period of cold weather.

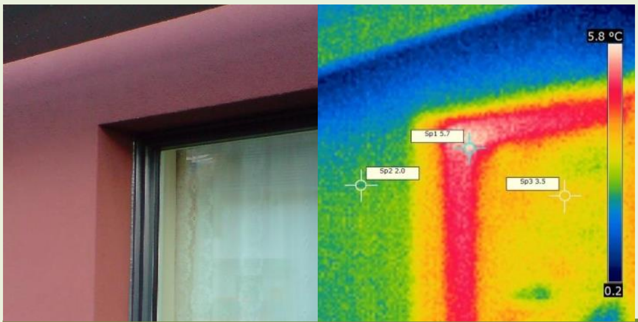

Figure 15: Window and its thermal image

The thermal imaging surveys found no significant defects, only a few small possible thermal anomalies, for example at door and window junctions with the walls.

Three in-situ u-value tests on the largely uniform external walls returned results around 0.15 W/(m^2·K); poorer than the 0.09 design value, but still far better than building regulations require.

Figure 16: In-situ u-value test kit

This shortfall is probably a result of a combination of factors, which might include deficient materials, thermal bypass (air circulation within voids in the wall), poor construction, and windows or thermal bridges being near the test site.

Greater care in construction detail and practice to avoid the risk of a thermal bypass is recommended.

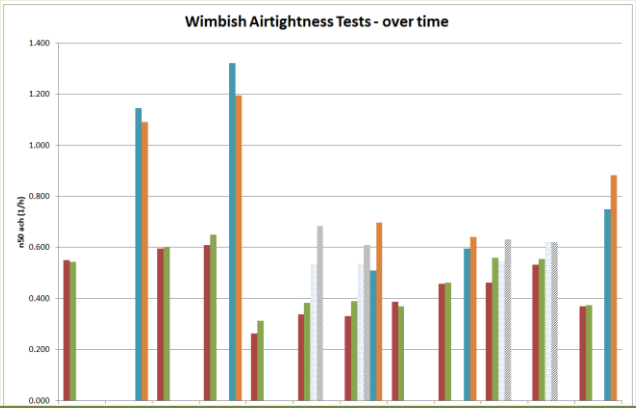

Figure 17: Airtightness test results

Air permeability tests were conducted for the contractor by BSRIA at the end of construction as required for Passivhaus certification. Some properties passed the 0.6 ach requirement easily, whereas others only just satisfied the criterion. Further tests, 18 and 21 months later, found some deterioration in performance (Figure 17). This was attributed to window settlement and the impact of this on seals, and perhaps failure of last minute actions with a mastic gun that may have been taken to achieve the initial pass.

These test results indicate that the fabric at Wimbish was not quite delivered to the expected standard, and that there has been a little deterioration. Assuming these losses to be cumulative then an extra 2.5 kWh/(m^2·a) of gas would be required; adding about £10 a year to the cost of heating the largest 3-bed properties.

Lessons for the contractor:

Employ workers who understand the need for quality process and who take pride in their workmanship.

Appoint one or more quality champions and empower them to ensure that quality workmanship is delivered.

Resist 'value engineering' during the works. For any unavoidable substitution of material or equipment, ensure that the consequences are thoroughly assessed.

Undertake early testing so that defects can be addressed.

Ensure that commissioning achieves the design intent.

6. Resident education and feedback

Considering residents

A Passivhaus development should deliver homes that are a delight to live in, which are comfortable and healthy, easy to manage, and inexpensive to heat.

Living in a Passivhaus should be no more burdensome than living in any other property, and residents should be able to achieve acceptable comfort and energy performance without changing their behaviours. However, to achieve the best performance, some understanding of how to interact with their home will undeniably be beneficial.

This means that future residents must be considered by the designers from the outset: *how will they live in the houses day-to-day? What will make life easier for them? How can what they need to do in 'running the house' be minimised, for example by making it self-controlling and forgiving?*

Having designed the properties to avoid any later assertion that 'the residents do not know how to behave properly', focus must then turn to how best to convey essential understanding to the residents.

'Handover'

A plan is required to convey the necessary knowledge to the residents. This can start when they first know they will get one of the homes, continue around the time when they move in, and be reinforced after a period of occupation.

Face-to-face instruction can be most effective, but needs to ensure comprehension, and to avoid any negative messages.

A variety of handover media can be used to ensure residents take on board the lessons, and this is likely to include presentations, discussions, handbooks, reminder sheets, manuals etc. (but take care that the residents are not overloaded).

Ensure that support services understand the buildings and can support the occupants. This can be challenging, because of the level of knowledge required and the need to support new tenants at changeovers, and because the support service often has high staff turnover. Ideally, support staff would have an opportunity to visit site during the build and, once it became occupied, would have a full set of the handover media, and would be provided with appropriate training.

The PhD research

The post-occupancy experiences of the households living at the Passivhaus development were investigated to understand how different and unfamiliar domestic technologies would influence everyday household practices (e.g. cooking, cleaning, showering, hosting guests).

This research found that technological change not only influenced practices directly, but also affected the elements of practice; these being institutionalised and expert knowledge, know-how and experience, as well as engagements and social expectations. New technologies changed the connections between practices and between elements. New technologies required new understanding and skills for almost every practice that utilised those technologies; in particular regarding how to meet the household's thermal comfort expectations in their new homes. This required a shift in practices for many households since almost every domestic practice now had a knock-on effect on internal temperatures.

Passivhaus design creates a stronger relationship between performance, domestic technologies and everyday life; the simple act of occupation (body warmth), as well as domestic practices (appliance usage), having implications for thermal comfort in the home. The ties between practices were strengthened as households sought to meet their thermal comfort expectations.

The relationship between different types of knowledge was also a recurring theme. Specifically, trade-offs existed between knowledge that was tacitly acquired through experience (know-how and embodied habits) and knowledge that was gleaned from an expert explicitly presenting it (institutionalised knowledge and explicit rules). To be able to perform practices in new (and crucially, unfamiliar) technological surroundings, households began to rely on their experience. However, historic performances (and thus the tacit knowledge they created) were in a different context from their new, energy-efficient Passivhaus home. Consequently, households were sometimes misinterpreting and (perhaps in the designer's eyes) misusing the new technologies, with the design intentions of the technologies very often

not mirrored by actual usage. The emphasis placed on experience reiterates the importance of considering how a practice's history impacts its current and future interpretation.

These findings undermine research and policy-making assumptions that deem that technological provision will linearly change everyday life and implicitly reduce domestic energy consumption.

This research supports the need for more careful consideration of how technologies are interpreted and used in the everyday lives of those encountering them for the first time. This is especially important if the energy reduction potential of these technologies is to be realised, as intended by client and designer

Surveys

Two standard resident surveys were conducted to obtain feedback from the residents on their perceptions of the performance of their homes. This valuable information complemented the PhD research and other engagement with households that included resident evenings for two-way feedback and discussion.

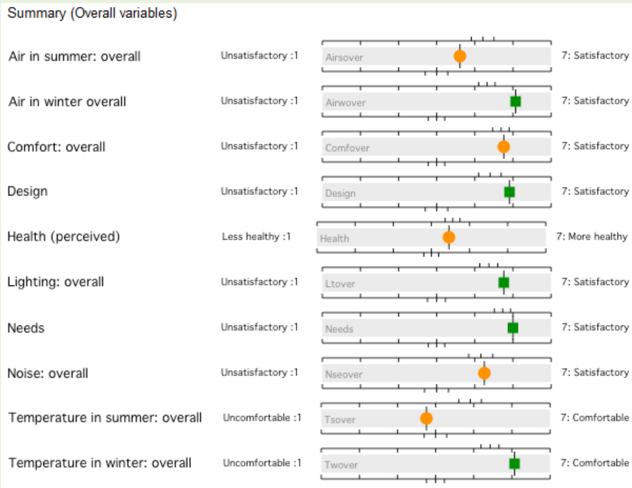

Figure 18: 2013 Resident Survey Summary

Though most indicators remained at the good/satisfactory end of the scales, some of the 2013 values had slipped from the excellent 2011 values; in particular, those for air and temperature in summer, and for perceived health. The decline in summer scores is possibly a consequence of conducting the 2013 survey during a heat wave. The early good health score result was probably gained when it was really too early for respondents to judge. A more general slight reduction in marks, which overall

Figure 19: Windows tilt (shown) and turn

remain good, may be a consequence of raised expectations generated by the study.

Lessons for resident education:

- Design to minimise the learning necessary to realise the benefits of the new technologies
- Carefully orchestrate resident education and support to convey essential lessons:
  - Engage with households in advance so that they are aware of what to expect
  - Only provide essential guidance on move-in day
  - Provide detail in handover sessions for each household a couple of weeks later
  - Encourage residents to 'try it for themselves' during the sessions
  - Reinforce learning, especially as seasons change
  - Provide context-sensitive (what-to-do-if) advice
  - Ensure support services understand how to get the best from the Passivhaus dwellings
  - Repeat the education for new residents
  - Continue the engagement as long as practicable
- Conduct resident surveys to enable adverse indicators to be addressed, to learn lessons for future developments, and to compare the development to its peers.

7. Air quality and ventilation

As buildings are constructed to be increasingly air-tight in order to conserve heat, it becomes important to have a reliable means of removing pollutants effectively and of providing a supply of fresh air. Adding heat recovery to the mechanical ventilation system ensures that this can be done with minimal heat loss. At Wimbish, the system also delivers thermal comfort by warming the supply air when needed.

To achieve these aims it is essential that the system be properly designed, installed, commissioned, operated and maintained.

The process followed at Wimbish could be described as 'barely adequate' practice. In operation, the electrical energy consumption of the system is suffering: the fans are working harder than desirable. From the resident perspective, however, the systems are working well, keeping the air fresh and the environment comfortable, to their great delight.

Design to commissioning

Pressure drop and return path design calculations should be undertaken. Vent locations should be optimised to ensure air circulation.

Air flow rates were set for Building Regulations Part F and Passivhaus compliance. Some rates were considered somewhat high, raising the risk of 'drying out', and incurring extra electricity consumption.

Paul Focus 200 units were employed throughout for consistency. They are at the bottom of their operating range in the flats, and near the top in the 3-bed houses.

Best practice advice should be followed for ductwork (to minimise leakage and make installation easy), for its insulation, and for acoustic attenuation.

Installation in the houses was complicated by the late change to timber joists, meaning that the ducts needed to be threaded. This resulted in extra use of loss-inducing flexible ducts, and made the sealing of joints with mastic and tape more difficult.

Figure 20: Joists and supply duct

The system was balanced and the room air flows adjusted to the designed levels by the MVHR supplier. This was undertaken after handover to the residents, and was repeated on several occasions before acceptable results were obtained. In a couple of properties there was a significant disparity between the amount of air exhausted, and the amount extracted from the rooms; this implies a high level of leakage from the ducts, and some of the fans had to be set at a higher rate than desirable.

In Use

In practice, households failed to adjust the fan speeds to the extent expected. Most simply leave the system set to the default speed. This is partly because some were daunted by the control panel, and partly because they saw little need to make an adjustment. Only one household decided to switch off the ventilation, preferring to have fresh air from open windows.

Figure 21: MVHR touchscreen control panel

This lack of adjustment does not seem to have a significant impact on air quality, nor on the residents' perception of it. Simpler controls, perhaps with just a boost, may have sufficed.

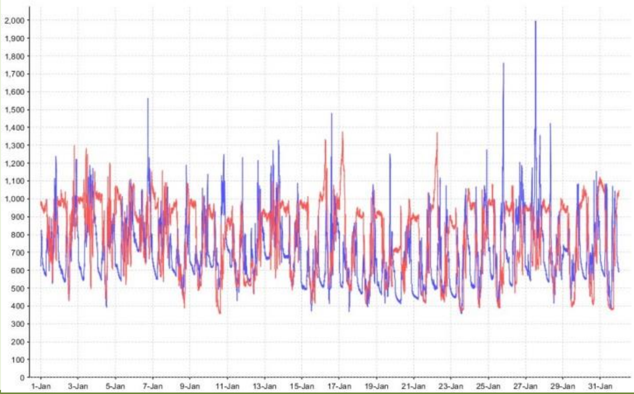

Figure 22: CO_2 ppm levels (bedroom red, living room blue)

The Carbon Dioxide level in a room (see Figure 22) can be used as a proxy for the air quality. It is desirable that the level remains below 1,000 ppm

most of the time when a room is occupied (though not too far below as this may indicate excessive ventilation).

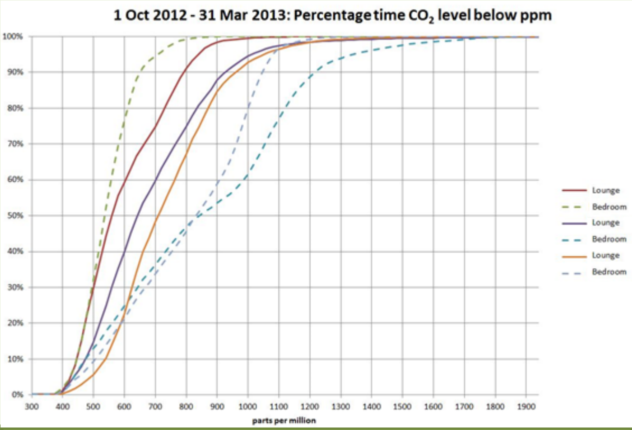

Figure 23: CO_2 levels cumulative distribution

Data from the CO_2 sensors in the three fully monitored dwellings (Figure 23), drawn as a cumulative distribution, illustrates that this requirement is being met, with the exception of one bedroom where a leaky duct is suspected and another where the level of occupation is high.

The air quality and thermal comfort are good, as is the heat recovery, being in the range 85-90% most of the time. The downside is that where the fans are working a little harder than they should, they use more electricity. Fan consumption should range from 25 watts in the flats to 40 watts in the 3-bed houses; in practice, the latter have peaked when the filters need changing at over 100 watts. The annual cost of running the fans ranges from £31 to £89.

Notwithstanding this, a simple calculation shows that the value of the heat recovered significantly exceeds the cost of running the fans. One must bear in mind that the quantity of space heat required has been hugely reduced by the Passivhaus design, for which ventilation is essential. Having saved several hundred pounds a year on heating, no-one should quibble over spending a small portion of this on providing fresh, healthy air.

Regular maintenance is required for the filters and vents, and periodic maintenance for the unit itself. Servicing is covered by a service contract for the tenanted dwellings, but is the household's responsibility in the shared ownership dwellings (they have the option of paying to be added to the service contract). Service intervals depend upon how quickly the filters become blocked.

Figure 24 (showing daily electricity use) illustrates that once a filter starts to block the fans work harder to maintain the air flow, using more electricity, until the filters are replaced. It appears that the initial 8 month interval was too long; 6 months may have been better.

Figure 24: Daily MVHR electricity consumption

The cost of replacing the filters, at nearly £50 a set, is an impediment to frequent replacement by shared owners.

If the filters are not changed, the fan will reach maximum power and then air flows will gradually be imbalanced and compromised, along with their ability to deliver heat. The electricity consumption will rise, and the fans will become noisy (with increased wear-and-tear), the air quality will reduce, and it may be difficult to deliver sufficient heat to keep the house warm.

Lessons on air quality & ventilation:

- The ventilation system should be delivered to the highest affordable quality, as it is essential to the performance of the properties, as well as contributing health and wellbeing benefits.
- The frequency of filter change, and triggers for doing so, should consider the risk of reduced air quality and reduced heat recovery performance
- It is vital that the filters do an efficient job with minimal load on the system. They must be inexpensive, easy to replace, and only require changing infrequently. The householder should be made aware that a change is needed. Product design innovation is required.
- A cost-benefit analysis of the ventilation system includes running the fans, replacing filters, and the value of recovered heat. Analysis must be in the context of the saving in heating of the building it has enabled.

8. Heating systems in use

Description

The solar thermal system heats water in a storage cylinder, with the gas boiler making up any shortfall. Hot water is drawn directly from the store for bathing and other uses. Space heating, via an element in the supply air, also takes heat from the cylinder when required, in this case via a heat exchanger.

Figure 25: ‘plant room’ in a flat

The monthly seasonal space heating demand is expected to be greatest in December and January at around 300 kWh, with zero demand in summer months; in contrast, domestic hot water (DHW) demand is calculated in PHPP to be 164 kWh per month throughout the year. The annual demands for heating and for DHW are similar quantities. The PHPP 2007 calculations show that the annual losses from storage and distribution are also at a similar level (this being a reflection of relatively low demand rather than spectacularly high losses). The solar thermal is expected to contribute a fourth similar quantity.

In common with the overall strategy for consistency, it was decided that all dwellings would have the same boiler and solar thermal system. A larger than necessary 15 kW Baxi boiler was chosen, smaller ones being more expensive. A Honeywell 9400 programmer with wireless portable digital room thermostat for householder control was selected. The Megaflo thermal stores are 250litre in the houses and 210litre in the flats; as supplied, they include an immersion heater element. Since these were not specifically identified in the design (for use in the event of boiler failure), they were not connected.

Configuration

The system should be designed as an integrated whole to ensure that the solar thermal provides the maximum contribution while the risk of legionella is minimised, and to ensure adequate hot water for bathing and for space heating. The design objectives, and how they are to be met, must be clearly recorded and be retained for maintenance. The manufacturer advises that the solar controller should be ‘in charge’, calling on heat from the boiler as and when required.

Commissioning should ensure that the system has been set up correctly. Since this will be undertaken for the level of occupation the buildings are designed for (which is not necessarily the figure used in the PHPP calculation) guidance should be available for adjustment in the event of significant over or under occupation.

Programmer

The design intention was to have 3 modes for hot water supply from the boiler to the store:

Winter – on
Mid-seasons – timed
Summer – off

(in summer relying on the solar thermal).

Figure 26: Boiler programmer

This was not conveyed to the residents at handover, and in practice, the study has found that the programmers have been left as commissioned on ‘timed’.

Having space heating on a timer in the winter is contrary to the ethos of a Passivhaus, where the expected low demand is to be met by a very small heater, which in the coldest weather may need to provide a boost to the incoming air temperature all day long to maintain comfort.

There is a concern at Wimbish that drawing heat from the cylinder continuously for heating, while having the boiler DHW programme (the control for supplying heat to the cylinder) on timed, could sometimes deplete the thermal store, leaving only cold water for bathing. Alternatively, putting the DHW programme on continuous as well, would mean a reduction in the small contribution the solar thermal might still make in winter months.

A further concern is that the residents' education in use of the system may be insufficient to ensure that they change the programmer settings seasonally, should this be necessary.

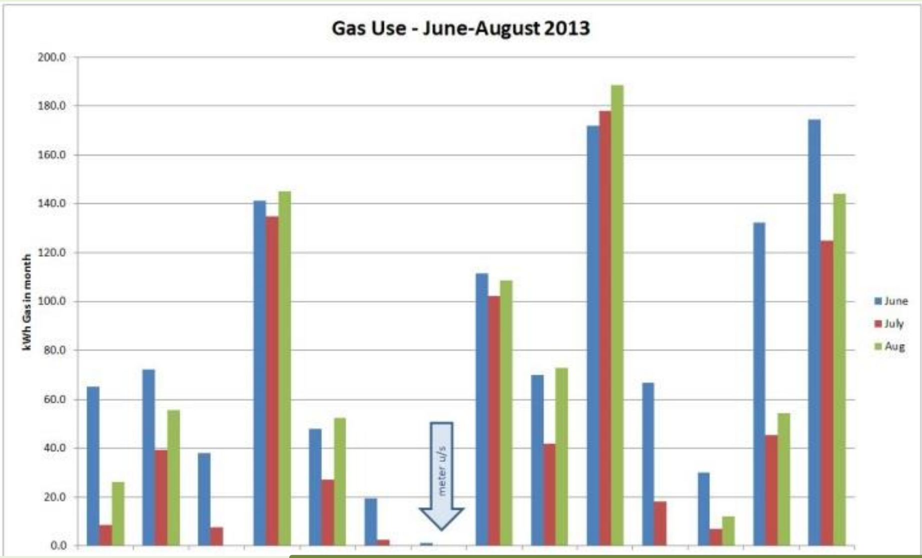

Figure 27: Summer gas use

Solar thermal contribution

Over a year, the solar thermal is expected (PHPP calculation) to meet about 50% of the demand for hot water. In the summer months, it should provide close to 100%, with gas usage negligible.

Summer gas usage however, (see Figure 27) has been surprisingly varied; reasons for this are likely to include the divergence from expected occupation levels, bathing habits, the system programmer settings, and, possibly, malfunction of the solar system in some properties.

The solar system control panel should make it far more obvious to the residents whether the system was working, and ideally, the heat contribution it is making.

Heat Losses

Losses from hot water supply to the store, from the store, and from distribution systems, should be minimised in design and by careful installation of insulation during the build.

If losses are high, then the boiler is likely to be called on to work harder, increasing gas bills (the solar system may also contribute more). However, the extra heat is not actually lost – most warms the building, offsetting space heating in winter, but likely to need to be purged in summer.

Designers should carefully consider whether point-of-use hot water supply systems, that all but eliminate such losses and the ensuing problems, might be preferable. The extent to which the boiler is being used raises questions about the capital and maintenance costs of such an approach.

Lessons on heating systems:

The design of the heating system must be carefully thought through:

- To ensure adequate heat for hot water and space heating (allowing for variation from the design in the occupation level)
- To meet health and safety requirements
- To maximise the 'free' solar contribution
- To enable maintenance services to reconfigure the system appropriately following any maintenance
- To permit simple adjustment for the seasons, and to suit occupation levels and bathing habits
- To enable residents to know that it is working
- To avoid heat losses that exacerbate summer excess heat problems
- Considering capital and maintenance costs (financial and carbon emissions), and the costs of 'unintended consequences', alongside operational energy costs.

9. Summer comfort

Housing in the UK is generally considered to have a heating season – for example October to April, and a summer season when one hopes no heating will be needed, and when, occasionally, homes will get hot. More thermally efficient homes, of which the Passivhaus approach is leading edge, reduce the length and severity of the heating season. There is a risk that they (indeed any new home) can exacerbate overheating during hot weather. Although they will keep heat out, should it get in, then it can be retained. Passivhaus design (assuming the construction is compliant) is an enabler to allow the residents to keep comfortable with least effort and cost. However, it is then down to the residents to live in the home in a manner that works to optimise heat gains in winter and, when necessary, minimise them in summer and thus manage comfort.

Note that this is not, in any way, intended to imply ‘bad behaviour’ on the part of the residents should they fail to learn how to conform to the design expectations. Rather it is the responsibility of the designer to ensure that the building facilitates appropriate behaviour from the residents, by making such behaviour easy to learn and to follow, becoming the new norm.

Temperature in a ‘heat wave’

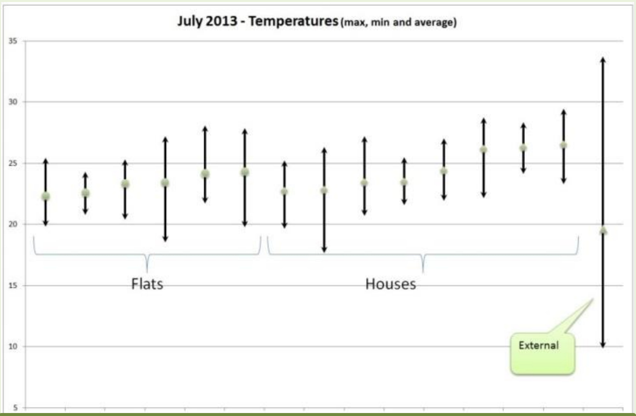

Figure 28: Summer temperatures

Internal temperatures at Wimbish in the summer months have generally been above the 20 °C Passivhaus expectation, quite often being close to the Passivhaus 25 °C threshold for overheating. The residents tell us that they like it! However, when, as at Wimbish, internal summer temperatures are normally high, they can easily rise even higher during a hot spell as in July 2013. Nevertheless, the monitoring shows that temperatures have never exceeded 30 °C, in contrast to other new non-Passivhaus homes that can suffer from overheating.

In the resident survey, some households found raised temperatures perfectly acceptable in hot weather, whereas a small, but vocal, minority complained that they were too hot. There was little correlation between the score awarded and the temperature level monitored. There was, however, a much stronger match with whether or not the household felt in control. It seems that if you think you know what to do to control the temperature then you are more accepting of excesses.

The design expectation is that, when external temperatures are high, the fabric will keep most of the heat out and that residents will manage the solar gain using blinds, will avoid heat-generating activities (such as using high-power appliances), and will open windows to purge any excess heat when it is cooler outside (and keep internal doors open). In practice, few households apply this guidance appropriately, though even knowing what you should do, seems to help!

What the residents say:

“Have been cool in summer. Really good”

“The only way to keep [cool] is to have windows open so a draft comes through”

“This summer we have kept cool, even the kitchen, I think that we are more aware of how things work now.”

“Open windows in evenings and during night and turn off ventilation to prevent hot air being drawn in”

But also:

“No cooling - so hot all day and night.”

“Cannot do anything to cool down the flat.”

“Still feel we don't know how to work the ventilation system, heating etc. & when to use blinds / open windows etc. as never been told by someone who knows how it all works”

Blinds are installed on first floor south-facing windows. They should mainly be closed in the summer (though can be open at night to aid a through draught), and be open in winter. Residents tend to use them primarily for privacy, as a substitute for curtains.

Figure 29: External window blinds

No single reason explains why some properties are warmer than others – many factors are likely to have a bearing:

- Fabric keeps the heat in
- Thermal mass can ameliorate temperature peaks
- Excess heat gains:
  - Appliances – higher usage leading to more heat
  - Plumbing losses – from storage and from distribution
  - Occupation density – both numbers, and period of occupation. Not only are people 'heaters', but they are users of appliances and hot water – increasing other gains
  - Building layout – can aid or hinder effective natural ventilation
- Residents unable/unwilling to behave as expected:
  - Not home at the time action is needed
  - Concerns such as security or insects prevent the opening of windows for night-time cooling
  - Lack of understanding – open windows but close internal doors
  - Lack of understanding that they need to do things more like they would on a Mediterranean holiday
- MVHR lack of summer bypass does not help.

The relationships between these factors are complex. Correlations have been sought, but it has proven difficult to reach conclusions on causality. For example:

- Some of the warmer properties have high electricity consumption, as would be expected; but some have more modest usage, and some with high electricity use are relatively cool
- The flats are generally cooler; perhaps this is because they are benefitting from the additional thermal mass (in floor slab), but then they also have lower levels of occupation, which equally could be the cause.

A study at a finer level of detail would be required to fully understand which factors are most important; our study can only conclude that all contribute and thus warrant attention.

Although summer overheating is an issue in a great many new homes, the Wimbish Passivhaus homes have shown that they avoid the worst temperature excesses in summer as well as in winter. Indeed, the careful design and attention to detail, along with the high level of insulation, mean that temperature rises are less than in many existing homes.

Lessons to maximise summer comfort:

Design/Development

- Minimise need for resident education
- Consider sensitivity – to occupancy, electricity use etc.; applying more realistic internal heat gain figures
- Layout to encourage night-time cooling
- Benefits of thermal mass
- Anticipate and forestall resident concerns, for example, provide fly-screens

Education, handover and support

- Appliance choice and use
- Seasonal advice and guidance
- Repeat education for new residents.

10. Description of the Passivhaus Development

Figure 30: Elevations of the flats

The Hastoe Housing Association development is at Tye Green, Wimbish, near Saffron Walden.

It is a social housing development, approved as a ‘rural exception scheme’ to meet housing need. There are 14 dwellings, which provide a mixture of rented and shared-ownership accommodation: 6 x 1 Bed flats; 5 x 2 Bed/4 Person houses; 3 x 3 Bed/5 Person houses. The gross internal floor area of these dwellings is 51, 76 and 88 m^2 respectively.

The development was handed over to residents at the end of June 2011.

The buildings were required to achieve Passivhaus certification. Having a desire to reduce the impacts of fuel poverty for their tenants, Hastoe were persuaded of the merits of the Passivhaus approach, and saw certification as the means to be assured that designers and contractors would comply. The design strategy thus requires high levels of insulation, a highly air-tight build, and minimal thermal bridging.

Each individual household was provided with their own services. Hot water, for space heating and bathing, is taken from a thermal store, which is fed by a solar thermal panel and a small boiler.

MVHR is employed to remove pollutants and provide fresh air, and to deliver any additional space heating required. The units are within the thermal envelope

The stringent Passivhaus verification requirements had to be met; in particular that the specific space heating demand will be less than or equal to 15 kWh/(m2•a), air leakage will be no more than 0.6 air changes per hour, and the frequency of overheating will be less than 10% over 25 °C

The buildings were also expected to meet Code for Sustainable Homes level 4 requirements; this resulted in additional performance targets, for example for water consumption.

The properties were built using 190mm thin joint blockwork on a reinforced concrete slab over 400mm of insulation. The walls are clad externally with 285mm of EPS insulation, with a 16mm render. Roofs are traditional pitched roof trusses with 500mm mineral wool insulation laid flat at ceiling joist level. Traditional methods of construction were chosen to minimise the learning curve for the contractor and to keep maintenance simple. It was an aspiration to employ local tradesmen.

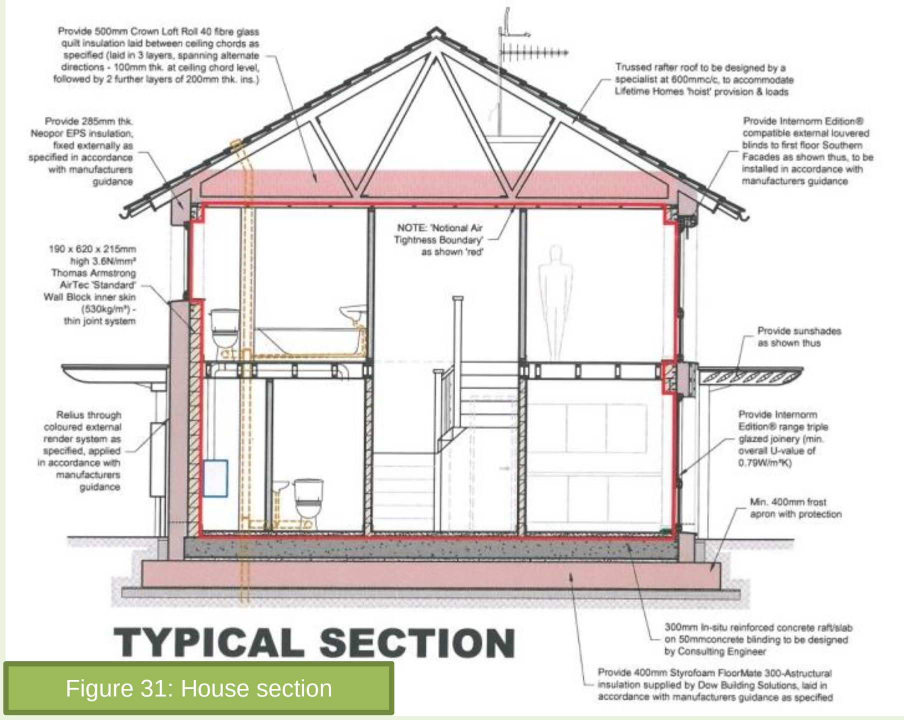

Figure 31: House section

Penetrations were minimised by the use of free standing external porch frames to receive services, letter boxes and meter cabinets, with service penetrations generally underground and sealed with specialist grommets.

The windows are triple-glazed wood/aluminium with insulating thermal foam. Solar gain was managed by large eave overhangs, brise-soleil at ground floor and external venetian blinds with a manual crank handle at first floor level to south-facing windows.

Precast concrete slabs were specified for the first floor. These were employed in the flats, but were replaced by timber joists in the houses.

Air tightness is generally provided by a wet plaster system and specialist tapes at junctions. Windows and doors are triple glazed and installed within an insulated reveal to minimise thermal bridging, and made air tight with appropriate specialist tapes.

Figure 32: Neopor insulation

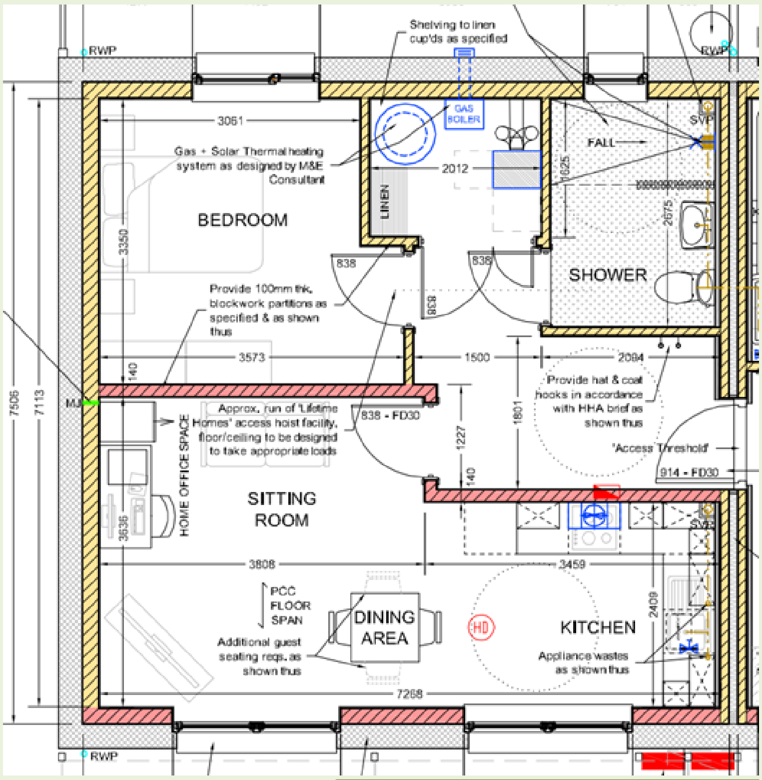

Figure 33: Floor plan of a flat

11. Building Performance Evaluation

Academic research has shown that even low-energy buildings, carefully built to perform well, rarely perform to expectations, either in use, or in the fabric alone. Only by systematic evaluation of the performance of buildings can we determine a set of measures to apply during design, construction and use such that we can be confident that the desired benefits will be realised.

In the event that aspects of performance are found less than satisfactory, then building performance evaluation (BPE) can aid in the diagnosis of the reason or reasons for this, and, assuming that remedies can be applied, can evaluate the effectiveness of the remedies.

Technology Strategy Board studies

This study conforms to the requirements set out by the Technology Strategy Board for an In-Use and Post Occupancy Evaluation study.

The study commenced on award of funding in April 2011. The residents mainly moved in at the end of June 2011. The monitoring formally concluded at the end of September 2013 (ensuring two full years of data), however it is intended that most kit will remain in place to enable further studies to be carried out; data continues to be collected.

The primary tasks have been:

- Design and construction audit – from observation of the build, interviews with and walkthroughs with the development team
- Systems review – interviews with the contractor and sub-contractor, observations on site, critical review of documentation, retesting
- Collection and analysis of in-use performance monitoring data
- Handover – observation of the process; starting before completion, on the day, and subsequent sessions for occupants and Hastoe
- Fabric performance review – thermal imaging, air-pressure tests, and in-situ u-value tests to determine whether the fabric was performing as expected
- Occupant satisfaction – the views of the occupants, collected in several ways:
    - PhD research involving several interviews with each household
    - A pair of standardised Building Use Studies (BUS) surveys
    - Interaction when visiting to carry out the other tasks
    - A pair of Resident Evenings to provide two-way feedback.

Monitoring data

Three representative properties, one flat, one 2-bed house and one 3-bed house, were selected to be fully monitored. In these, temperature and humidity are logged in living room, hall, kitchen and a bedroom, and CO_2 levels are recorded in the living room and a bedroom. Electricity used for the MVHR is logged, as are the temperatures of the air flows. Heat meters were installed to record where the heat was sourced and used; unfortunately, the data from these meters was low quality.

All 14 of the properties had consumption measured at the utility meters (gas, electricity and water), along with sub-metering of electricity in the kitchen, small power and plant room circuits. In all properties, the temperature and humidity of the living room were logged.

Externally, the temperature, humidity and solar radiation have been logged.

Concerns about reliability of wireless systems, and previous experience with building management systems at the University of East Anglia, led to the selection of a Trend BMS and associated kit. Each sensor/meter is wired back to a central controller, with one controller for each of the three blocks of dwellings at Wimbish. With GPRS reception on site being poor, the controllers were accessed remotely over a broadband connection. The controllers log data from the sensors/meters at a configurable interval; initially at the default 15 minutes, subsequently adjusted to 5 minutes where it made sense to do so. Trend software on a remote PC polled the controllers each day to update a SQL Server database logging the data values.

This building performance evaluation (BPE) study and report would not have been possible without the support of many individuals and organisations, and their considerable assistance is acknowledged.

First and foremost Hastoe Housing Association: not only did they have the innovative foresight to undertake the rural Passivhaus development, but also they were also keen to learn whether it actually worked for the residents and for themselves.

The Wimbish development team too made a significant contribution in explaining the background to numerous decisions made during the development.

Secondly, the University of East Anglia (UEA): The School of Environmental Sciences' partnership in the EU Build with CaRe project stimulated interest in the evaluation of building performance and supported the bid process seeking funds for the Wimbish study from the Technology Strategy Board and the production of interim reports. Separately, the School of Environmental Sciences also led the study of practices and technological change, using Wimbish as a case study, so making a major contribution to the overall BPE study, balancing the technological view with that of social sciences.

Thanks also to the Technology Strategy Board for the funds they provided to enable the study to proceed, and for the advice and guidance received throughout from the monitoring officers and evaluator.

Lastly, but by no means least, thanks are due to the residents. Their forbearance, allowing us into their homes on many occasions, completing our questionnaires and answering our prying questions, was indispensable. The study team recognise that we have been extremely fortunate in being able to work with such an open and helpful group.

The Technology Strategy Board is a business-led executive non-departmental public body, established by the Government. Its role is to promote and support research into, and development and exploitation of, technology and innovation for the benefit of UK business, in order to increase economic growth and improve the quality of life. It is sponsored by the Department for Business, Innovation and Skills (BIS).
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