WimbishPassivhaus

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Technology Strategy Board
Building Performance Evaluation
Project 450038

Wimbish Passivhaus: Building Performance Evaluation Second Interim Report – March 2013

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

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Wimbish Passivhaus: Building Performance Evaluation Second Interim Report – March 2013

Author: M Ingham, Adapt Associate, UEA

Date: April 2013

Synopsis

This is the second interim report on the Technology Strategy Board study that is evaluating the performance of the Wimbish Passivhaus development.

This report summarises the findings from occupation at the end of June 2011 through to March 2013.

The Build with CaRe project supported the production of the first release of this interim report.

The Study itself is funded by the Technology Strategy Board under its Building Performance Evaluation programme.

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Contents

1. Overview

The Wimbish project is a development by Hastoe Housing Association of 14 social and shared ownership certified Passivhaus dwellings in north-west Essex.

The study is to evaluate the performance of these dwellings over a couple of years to determine whether the development is meeting expectations, to learn lessons, and to disseminate these. The study is supported by funding from the Technology Strategy Board Building Performance Evaluation programme and follows their processes and procedures.

This interim report is based on observation of the development from several months before completion, and about 20 months of study from occupation onwards. This study includes results from sensors throughout the dwellings, interviews with the development team and the occupants, and surveys of the building and of occupant behaviours. The Technology Strategy Board-required tasks are supplemented by PhD research into the occupant behaviours.

Production of the first interim report was supported by the University of East Anglia, through its partnership in the EU Interreg IVB North Sea Region funded Build with CaRe project. Build with CaRe earlier supported the development of Hastoe's bid to the Technology Strategy Board for BPE funding. The first report was timed such that it could include preliminary findings from the first winter occupation, and be delivered before the end of the Build with CaRe project.

This report is the second interim report; it will evolve into the final report, which will be delivered to the Technology Strategy Board at the end of the project. It has been structured to follow the template for the final report; this means that some sections are sparse or empty in this release.

the Technology Strategy Board stipulate a number of individual tasks to be performed as components of a domestic study, each of which delivers a report. Many of these tasks are in hand, but not complete; where possible the provisional findings of the task have been listed.

Our intention is to provide maximum benefit by fully disclosing our findings. However, we need to be certain of our facts; thus, where a finding is not as expected, we plan to undertake further investigation to confirm the finding before releasing it.

1.1. Expectations

Fundamentally this is that the dwellings and their systems, taken as a whole, perform as expected of a Passivhaus; meeting the demanding standards specified by the Passivhaus Institute for the fabric and for the systems.

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This implies:

- that the space heat demand will not exceed 15 kWh for each square metre each year;
- that hot water heating requirements will be met by combination of boiler and solar thermal system; and
- that the overall primary energy requirements of the dwellings, including household electricity and the auxiliary electricity required to run the ventilation and other systems, average not more than 120 kWh/(m^2.a).

These require the fabric of the buildings to be very good, extremely well insulated and air-tight, with minimal thermal bridges. Passivhaus planning, using PHPP 2007, makes a number of assumptions about thermal comfort (20C), use of energy efficient appliances, and appropriate occupant behaviour. If these assumptions are not met, then the performance expectations may be exceeded.

Ultimately, it means that the residents are happy, with comfortable and healthy homes that are easy and cheap to run. This, in turn, will mean that Hastoe are happy in keeping their tenants' utility bills low, keeping them out of fuel poverty, and enabling them to afford their rents.

1.2. Performance so far

1.2.1 Fabric

Air-permeability tests were undertaken, and passed, as part of the Passivhaus Certification process. A sample set of dwellings has recently been retested.

A thermographic imaging survey was undertaken with generally very good results. Only minor issues were detected, for example, small leaks on window seals, leading to a recommendation that their alignment be checked and adjusted. A second survey has recently been conducted.

1.2.2 Handover

Living in a Passivhaus is different. There is no central heating, but instead there is a ventilation system, which also keeps you warm; the residents also need to learn how to manage solar gain, to benefit from it when it is needed, and to avoid it when it is not.

Providing appropriate guidance is essential if the residents are to be able to maintain their comfort, and to get the most, at least cost, from the systems in the houses.

Guidance is also vital for Hastoe support and maintenance staff.

Although Hastoe expended significant effort on this from well prior to occupation, through handover, and on to support during occupation, there remains room for improvement. The timing could be improved, as could the degree to which residents are encouraged to be 'hands-on' during instruction and the availability of on-going support.

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1.2.3 Occupant Perceptions

We know from what the residents have told us that they are happy:

> *"You just don't have the bills you would have in a normal house"*[1]
>
> *"We would not want to live in a non-Passivhaus again"*

Their responses to the Technology Strategy Board 'BUS' survey confirms this, with the Wimbish development scoring highest[2] of all the domestic surveys conducted on most metrics, including the overall summary index.

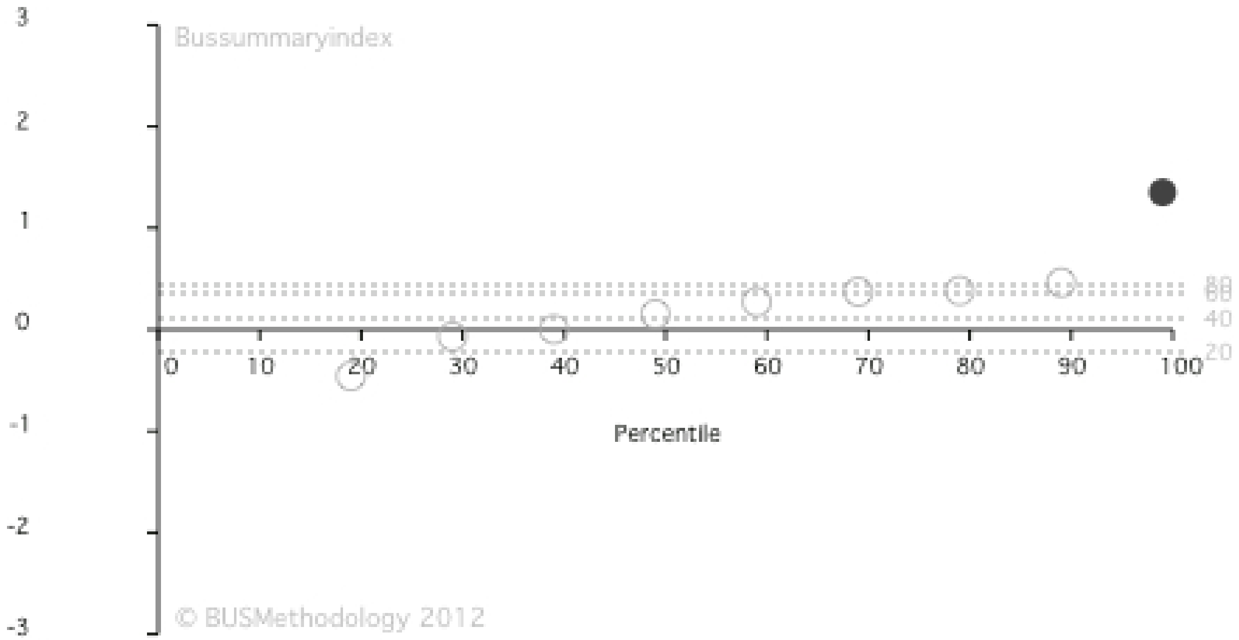

Figure 1: BUS Survey - Summary Index

1.2.4 Findings from monitoring

Energy Cost

The residents are delighted with their low gas bills, and assessment of annual consumption aligns closely with expectations. This shows that Passivhaus delivers.

Unfortunately, electricity consumption is running ahead of expectations, and the figures are more like those of an ordinary house, than those expected of a Passivhaus. The higher-than-hoped-for electricity consumption is the subject of additional study. This is the result of resident behaviour in choice of appliances, and the frequency of their use, rather than a function of Passivhaus design.

1 From ITV Anglia broadcast 2nd March 2012 (see also footnote 29).

2 Admittedly, against a small set of surveys conducted.

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Temperature

The records from the temperature sensors, along with the other quantitative comfort measures, confirm the BUS survey results. The dwellings are never cold; indeed the houses remained comfortably warm throughout both winters. This may be personal preference, or it may be attributed to their appliances.

This raises concern that there might be overheating problems in hot weather, should the residents fail to behave in an appropriate manner in such circumstances to avoid unwanted heat gain, and to maximise heat loss. Summer 2012 weather failed to provide an adequate test of the dwellings.

Humidity

The humidity levels started a little high because the dwellings were still drying following the plastering during construction. Through the period, the humidity levels fell, such that they were marginally low in the houses at the end of each winter.

Dryness of the air is a known potential weakness of a Passivhaus (though deemed less likely in UK climate than in Germany). To date it has not been a problem at Wimbish.

Air quality

The levels of carbon dioxide, measured as a proxy for air quality, have only very rarely exceeded acceptable levels, an excellent result.

Heat recovery

The heat recovery of the mechanical ventilation systems has met the Passivhaus standard and has been recorded to be recovering almost 87% of the outgoing heat.

1.2.5 Other issues

Appliances

Selecting energy-efficient appliances, and using them appropriately, is doubly important in a Passivhaus. Firstly because an inefficient appliance will cost more to run; and secondly because the house will have been designed assuming efficient appliances efficiently used, and inefficiency will bring unwelcome heat gains. In winter, these gains will offset gas usage, which is cheaper and releases less carbon; in summer, the heat increases the risk of over-heating.

It is interesting that a recent analysis[3] has shown that lifetime costs for using the most energy efficient appliances on the market may be no more than if buying the current standard products. It might be interesting to consider ways in which housing associations can help tenants acquire the most energy efficient appliances without a capital cost financial penalty.

[3] *Energy Savings in Practice: Potential and Delivery of EU Ecodesign Measures*, coolproducts for a cool planet, December 2010, http://www.coolproducts.eu/resources/documents/EnergySaving-in-Practice-summary.pdf.

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Energy Tariffs

Currently, energy suppliers design tariffs that are unfriendly to low-usage consumers. The tariffs either have a standing charge, or a tiered approach with a higher price for the first few thousand kWh each year. The cost per unit consumed is much higher for an energy-efficient house, effectively encouraging profligacy.

We hope that utility or service companies will soon come forward with tariffs that reward low usage, benefitting society as well as occupants. We are aware of one or two suppliers such as Ebico who do now do this; however, inducements offered by the 'big six' for direct debit and online dealing can outweigh the lower tariff.

1.3. Conclusions

The building performance evaluation so far suggests that the Wimbish Passivhaus development is very good. The residents are always comfortable, and heating bills are only a fraction of those of a normal house.

The residents are delighted with their low gas bills. But normal, rather than Passivhaus, electricity consumption will warm the properties, and thus reduce the need for gas for heating.

Some of the minor shortfalls in design, construction, handover, operation, and even resident behaviour identified may be remedied by physical or behavioural measures, and these are noted in the text; in other cases, they are lessons for future developments by the Wimbish team, or by the wider house-building industry.

Issues arising for further study are also noted and will be reported on in the final report.

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2. Wimbish Development

2.1. Background

Hastoe Housing Association[4] is a social landlord, with a growing stock of in excess of 4,000 rented, shared ownership and leasehold homes across the south, east and west of England. Hastoe focuses on rural schemes, of which Wimbish is one (as a 'rural exception' scheme only people with a local connection are eligible to live there). Hastoe east region has a history of building to sustainable standards, for example having over 200 properties at Code for Sustainable Homes (CSH)[5] level 4. Hastoe East also has a significant build programme, for example, 370 new homes were built in 2010/11.

Hastoe are concerned both to ensure that their tenants do not fall into fuel poverty[6] as energy prices rise, and also that tenants remain able to afford their rents. These considerations led Hastoe to explore ways of ensuring minimal fuel bills while maintaining comfort levels. Passivhaus construction is the paramount way of achieving this and, in 2010, Hastoe determined to build new homes to passivhaus quality to examine how this standard could be achieved in the UK and how much extra cost might be involved.

With support from the local authority for the project, Uttlesford District Council, the architects Parsons+Whittley[7] were employed to work with Hastoe to progress Wimbish Passivhaus development[8].

2.2. Why study Wimbish

Hastoe are keen to ensure that their commitment to Passivhaus delivers the expected benefits. There is widespread recognition that far too few new buildings perform anywhere near as well as expected in their design specifications[9]. The Technology Strategy Board Building Performance Evaluation programme[10] was

4 See http://www.hastoe.com/content/95/about-us.aspx for more information.

5 http://www.communities.gov.uk/planningandbuilding/sustainability/codesustainablehomes/

6 *Getting the measure of fuel poverty*, Final Report of the Fuel Poverty Review, John Hills, Centre for Analysis of Social Exclusion, CASE Report 72, March 2012, http://www.decc.gov.uk/en/content/cms/funding/fuel_poverty/hills_review/hills_review.aspx.

7 http://www.parsonswhittley.co.uk/

8 http://www.wimbishpassivhaus.com/housing.html

9 *Low and zero carbon homes: understanding the performance challenge* (NF41), NHBC Foundation and Zero Carbon Hub, February 2012, http://www.nhbcfoundation.org/Researchpublications/NF41/tabid/500/Default.aspx.

10 http://www.innovateuk.org/content/competition/building-performance-evaluation-.ashx

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instigated to address this gap. The study of Wimbish is being supported by the Technology Strategy Board[11].

The attention to quality required throughout the design and construction of a Passivhaus, and that is essential if certification is to be achieved, significantly reduces the risk of performance failings.

Passivhaus construction is well established in Germany, Austria and Scandinavian countries, but only in the last few years has it attracted growing interest in the UK[12]. The majority of UK schemes are currently one-off buildings, often developed by an enthusiast. The Wimbish Passivhaus development provides an opportunity to study a group of buildings developed in a manner that could be the basis for mass-market house-building. Hastoe's cost engineers have calculated that the Passivhaus units at Wimbish cost around 12% more than an equivalent unit to CSH level 4, and they confidently expect this margin to be reduced with subsequent schemes (the second scheme at Ditchingham is now certified and occupied, and several other are under development) as skill sets and the supply chain mature.

A further benefit of studying Wimbish is that the occupants were not initially Passivhaus-enthusiasts, eco-minded or green; they were simply local people who needed a home for themselves and their families. Thus, they constitute a realistic representation of the public-at-large for study.

UEA are partners in the Build with CaRe (BwC) project[13] that is seeking to promote low carbon, low energy construction and refurbishment becoming mainstream. UEA have monitored high quality new build homes in Norfolk as part of the BwC project[14], and have been keen to support local initiatives to evaluate the performance of new build and refurbishment projects in the east of England.

The Wimbish study is project managed by Hastoe, with consultancy by Martin Ingham[15]. It is a Technology Strategy Board phase 2 study, that is an In-Use

11 The **Technology Strategy Board** is a business-led government body that works to create economic growth by ensuring that the UK is a global leader in innovation. Sponsored by the Department for Business, Innovation and Skills (BIS), the Technology Strategy Board brings together business, research and the public sector, supporting and accelerating the development of innovative products and services to meet market needs, tackle major societal challenges and help build the future economy. For more information, please visit: www.innovateuk.org.

The grant has been provided by the Technology Strategy Board through its 4-year Building Performance Evaluation programme, which is funding the cost of building performance evaluation studies on a wide range of both domestic and non-domestic buildings. Grant recipients benefit directly through the involvement of expert building performance evaluators, who will help them to determine how their buildings perform and why. Longer term, generic learning from across the studies will help the sector as a whole deliver more efficient, better performing buildings.

12 See http://www.passivhaustrust.org.uk/projects/ for information about UK projects and a link to a map of projects.

13 See www.buildwithcare.eu for details of the project and its deliverables.

14 See BwC report on Diss Low Carbon Houses, April 2012 (www.buildwithcare.eu)

15 Martin is a UEA Associate who works on the BwC project. For Wimbish he is contracted directly to Hastoe, who claim fees back from the Technology Strategy Board. The Build with CaRe project assisted the

Performance and Post-Occupancy Evaluation study, although we have undertaken to include most of the Phase 1 tasks. The tasks being undertaken are[16]:

- Physical Tests
    - Air-tightness and tracer gas
    - Thermographic imaging
    - In-situ u-value measurement
- Process Evaluation
    - Design and construction review
    - Implementation and commissioning review
    - Observation of the handover
- Monitoring[17] – quantitative
    - Energy use
    - Comfort (thermal and environmental)
    - Technology
- Occupancy – qualitative
    - Survey (BUS)
    - Interview – to explore perceptions and issues in greater depth.

The Wimbish study goes beyond the Technology Strategy Board requirements by studying occupant behaviour, and how this influences the performance achieved. This additional PhD research is being undertaken by Chris Foulds of UEA's School of Environmental Sciences.

2.3. Content of this report

This report covers use of the development to March 2013. The residents moved in at the end of June 2011, although they were the subject of study for some time prior to that. Quantitative monitoring started in August 2011.

All 14 homes on the development are the subject of detailed study. Three of the homes have been chosen to be 'fully monitored', with extra sensors and more detailed monitoring of the ventilation and heating systems.

development of the proposal to the Technology Strategy Board and is enabled by Hastoe Housing to receive and disseminate data collected during the initial period to provide information on a UK passivhaus project to complement that obtained from passivhaus homes in Germany and Sweden.

16 For background to the tasks see the BwC publication '*Building Performance Evaluation – Why and How'* published on www.buildwithcare.eu March/April 2012.

17 For description of the monitoring see Appendix A.

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The data collected has been reviewed on a regular basis, and there have been frequent interactions with the residents, including surveys, interviews and feedback meetings.

This first interim report was produced for the EU Build with CaRe project, who helped initiate the study. It reviewed the findings to date, and summarised perceptions and findings from the occupant surveys.

This is the second interim report, providing an update on performance from March 2012 to March 2013.

This report has been written for a general audience; future releases are likely to be more technical. The report follows the basic structure expected by the Technology Strategy Board for the final report, into which it will evolve. Placeholders are provided for sections where insufficient analysis has yet been undertaken to permit reporting.

2.4. Design description

2.4.1 Architectural Design

The design of the scheme was largely driven by a consideration of the context of the site and an appreciation of the typical vernacular style of the site and locality. The settlement largely comprises plain fronted houses under simple natural slate roofs, and this context led Hastoe to consider a rendered finish under plain simple roofs. The economic solution of externally applied insulation was therefore possible within the local vernacular. Strong render colours are also a feature of this part of Essex and these were used to place the properties.

Colours were chosen with a similar tonal balance so as allow the properties to settle into the landscape without competing with each other. Internal layouts were then adopted to provide the primary living rooms on the south side and limit north facing openings to less important spaces such as bathrooms and entrance halls.

As well as Passivhaus certification, the plans comply with the UK design standards for dwellings funded by the Homes & Communities Agency, and the following standards:

- Secure By Design
- Lifetime Homes
- Housing Quality Indicators
- Code for Sustainable Homes Level 4
- Hastoe Housing's Design Brief

2.4.2 Construction

These properties are built using 190mm thick thin joint aircrete blockwork constructed off a reinforced concrete slab that sits upon 400mm of XPS insulation. The walls are clad externally with 285mm EPS insulation, which receives a 16mm polymer, modified render. Roofs are traditional pitched roof trusses with 500mm

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mineral wool insulation laid flat at ceiling joist level, utilising a dropped ceiling chord to achieve a thermal bridge free eaves detail.

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.

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.

2.4.3 Site Plan

An East-West orientation was employed to profit from passive solar gain and the houses arranged so that the private gardens benefitted from this private 'solar' space.

Figure 2: Site plan illustrating orientation credit: Parsons + Whittley Architects

The development comprises 14 units: a block of 6 one-bedroom flats, and two rows of 4 two/three bedroom houses.

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Property Type	Number of units	Planned occupancy	Gross Internal Floor Area	Treated Floor Area (from PHPP)
One bedroom flat	6	2	51 m^2	47.7 m^2
Two bedroom house	2	3	76 m^2	71.0 m^2
Two bedroom house	3	4	76 m^2	71.0 m^2
Three bedroom house	3	5	88 m^2	80.4 m^2

2.4.4 Cross Section

This drawing illustrates the general arrangement of all the major components including illustration of the thermal junctions. The red line indicates the air leakage barrier position.

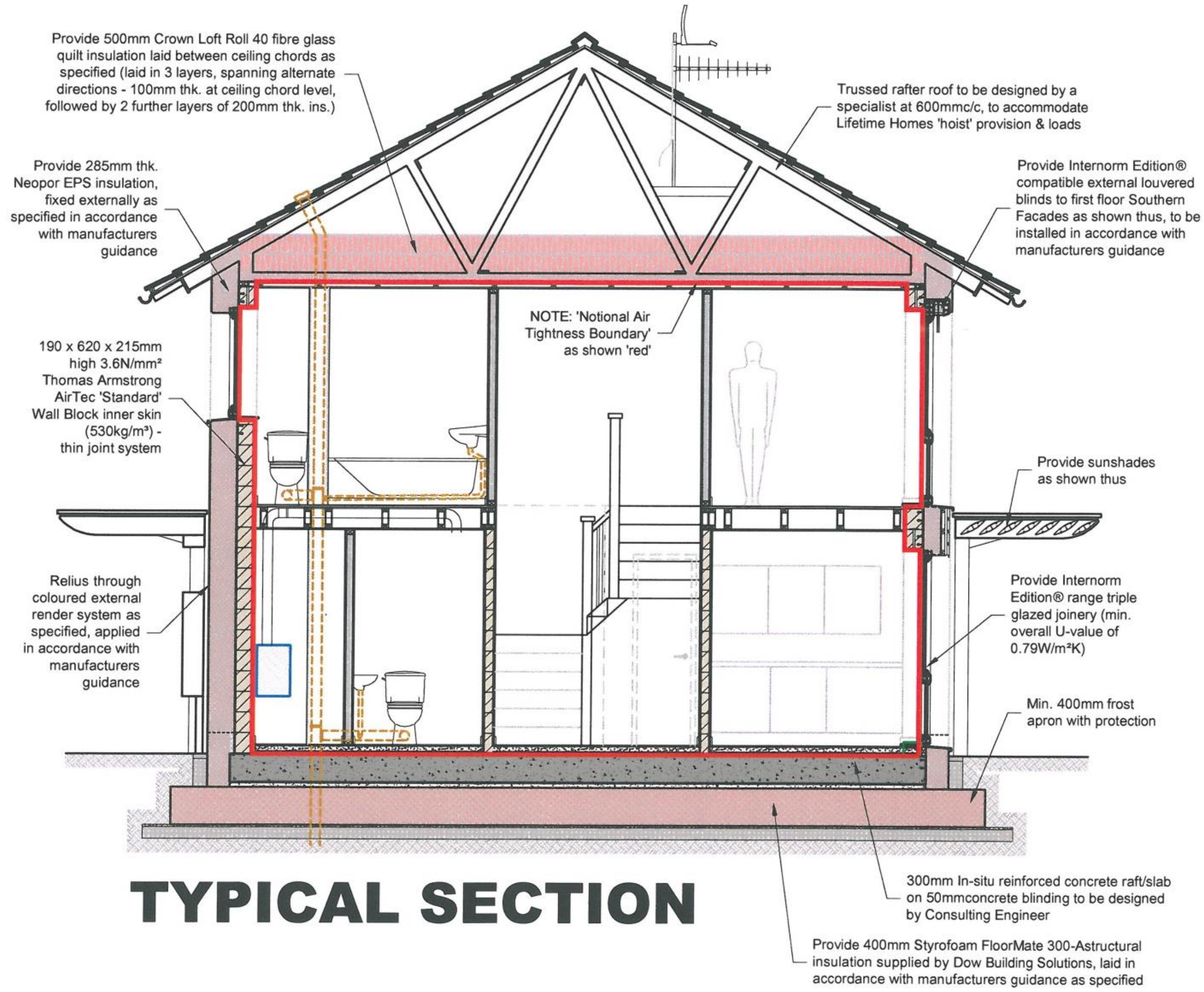

Figure 3: Typical cross-section (looking East) **credit: Parsons + Whittley Architects**

2.4.5 Building Services Planning:

Hastoe required that each house have individual systems under the control of the individual tenant and this prohibited consideration of communal systems. Solar thermal panels were provided for each unit, with a small gas boiler[18] to provide any additional heat needed. The solar thermal panels and gas boilers both provide heat to a 210 litre thermal store, which is used to provide domestic hot water and occasional top-up heating to the incoming air supply.

MVHR utilises a Paul Focus 200 unit, mounted on an external wall with sound attenuated ducting to distribute fresh air into the living and sleeping spaces, with extract ducts from kitchens and bathrooms.

The insulated ventilation ductwork was contained within space joists at first floor level. The ducts rise through risers to first floor ceiling level to avoid the need for a high level service zone.

The MVHR units are within the thermal envelope and mounted on a north-facing external wall. The intake and exhaust ducts were taken out through the external wall. An electric frost-protection pre-heater was installed, with a wet system coil heater applied to the supply air duct for heating when required. In the houses, the units are positioned in a dedicated cupboard near the front door, with the thermal store in an 'airing' cupboard on the first floor. In the flats the MVHR, boiler and thermal store are co-located in a 'plant' room.

2.4.6 Insulation

High levels of thermal insulation were required because the small UK house size standards make the Passivhaus requirement of 15 kWh/(m^{2}a) difficult to achieve.

The following u-values were needed[19]:

external wall	0.107 W/(m^{2}K)
floor	0.091 W/(m^{2}K)
roof	0.078 W/(m^{2}K)
windows	0.79 W/(m^{2}K)

In practice the external walls were designed to 0.0879 W/(m^{2}K).

2.4.7 Air-tightness

The properties were designed to achieve the Passivhaus air-tightness requirements of 0.6 air changes per hour. The air-tightness barrier is shown in red on figure 1.

Window and door frames were carefully taped to the block wall, the latter forming a fairly air-tight barrier even before application of the plaster.

18 15 kW; not as small as it could have been as a smaller boiler would have cost more.

19 Taken from the Architect's Passivhaus Object Documentation.

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2.4.8 Solar gain

Solar gain was managed by large eaves overhangs, brise-soleil at ground floor and external blinds at first floor level. The brise-soleil is designed to passively shade the large south facing windows during summer but allow warm sunshine through in the cooler seasons when the sun is lower.

The windows are from the Internorm Edition range, being triple-glazed wood/aluminium with insulating thermal foam. The coated glass is laminated or toughened as required, there are thermix spacers, and they are argon filled. The u-value of the window is 0.86 W/(m^2K)[20].

Upstairs south-facing windows are fitted with an external venetian blind with a manual crank handle.

2.5. Expectations

Performance expectations are conditioned by developing and certifying the dwellings as Passivhaus.

2.5.1 Energy consumption

A key verification for a Passivhaus is that it is designed using the Passivhaus Planning Package (PHPP) to achieve a Specific Space Heating Demand of no more than 15 kWh/(m^2.a).

The fabric was designed to ensure that all units meet this requirement. Since the fabric is uniform, the mid-terrace units have a lower demand of around 10 kWh/(m^2.a).

Actually, the total heat losses calculated are significantly higher than these figures, but they are offset by useful solar and internal heat gains – the latter from the occupants and their appliances.

PHPP also calculates the demand for domestic hot water. There is no verification target for this, except that it must be met within the overall metric for Specific Primary Energy Demand. A typical figure from the Wimbish PHPP calculations for Total Specific Heat Demand of DHW is 26 kWh/(m^2.a) – note that distribution and storage losses account for around 40% of this. Solar thermal is expected to meet around 45% of the DHW demand, hence the boiler will be expected to supply 14.3 kWh/(m^2.a), and, adding the Specific Space Heating Demand, is, in total, expected to supply 29.3 kWh/(m^2.a). Allowing for the efficiency of the boiler about 37 kWh/(m^2.a) of gas is predicted to be used in a typical year.

The second key Passivhaus verification metric is that the Specific Primary Energy Demand be less than 120 kWh/(m^2.a). This figure includes DHW, Heating, Cooling, Auxiliary and Household electricity. That is, it is electricity consumption times a primary energy factor of 2.6, plus gas times 1.1.

20 Supplier data. Individual windows vary from 0.81 to 1.02.

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The figures calculated for Wimbish range from 104 to 111 kWh/(m^2.a). These values are based on assumptions[21] regarding levels of occupancy and that all appliances are A-rated or better.

From these figures the expected electricity consumption is about 33.5 kWh/(m^2.a).

2.5.2 Fabric performance

The overall heat transfer coefficients (u-values) are specified in section 2.4.6.

Air permeability should be no more than the Passivhaus limit of 0.6 air changes per hour at 50 Pascal. (Note that for these small dwellings, the conversion to m^3/m^2.hr is approximately 1:1).

It is also expected that internal surfaces will remain at 17C or higher in a Passivhaus.

2.5.3 Thermal comfort

The Passivhaus Planning Package (PHPP) design temperature is 20C, however it is at the occupier discretion to raise this. If this is done then Energy Consumption targets may not be met.

The thermal comfort can also be affected by deviation from assumed levels of occupancy or energy efficiency of appliances.

In domestic Passivhaus, overheating is defined as exceeding 25C more than 10% of an average year, which is more than 876 hours. The high thermal mass of the Wimbish construction is expected to moderate temperature fluctuations.

Thermal modelling in IES software[22] was carried out, and showed that no room would exceed the 25C threshold more than 5% of the time. The warmest rooms were found to be the sitting rooms in the houses. Only 3 rooms were predicted to exceed 26C more than 1% of the time. The modelling was based on a number of assumptions that could be challenged, for example, that natural ventilation would be employed by opening windows whenever the room temperature exceeded 24C between 0800 and 2000. In practice many residents are out during the day, and are unlikely to leave windows open for security reasons; conversely they may be willing to leave windows open at night[23].

Relative Humidity is expected to lie within the band 40% to 60% most of the time.

2.5.4 Quality of life

There are no specific metrics for a Passivhaus to judge quality of life or overall satisfaction. It is generally expected, however, that a Passivhaus will score highly on factors such as air quality, usable space, lighting and health.

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21 Neither of these are true in practice, as the residents have brought old appliances, and there is considerable variation in levels of occupancy from the norm.

22 See http://www.iesve.com/

23 There have been reports of “too many insects” to do this.

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2.6. The development partners

The development partners are listed below; they are all assisting in the conduct of the BPE Study:

Hastoe Group: a leading housing association with a stock of 4,000 homes and builds approximately 500 new homes each year. Hastoe is linked to Sustainable Homes Limited and has a long record of accomplishment building innovative and low energy homes. http://www.hastoe.com/

Hastoe's Sustainability Manager is project managing the performance evaluation, and worked with Hastoe Housing Management on the selection, engagement, and education of tenants.

Inbuilt: were responsible for advising on the energy and sustainability credentials for the scheme including advising and certifying on all aspects related to PassivHaus (including certification), Code for Sustainable Homes and SAP calculations. http://www.res-inbuilt.com/

Parsons and Whittley: are the architects for Wimbish; they specialise in sustainable housing and have a great deal of knowledge in construction methods and detailing. http://www.parsonswhittley.co.uk/

Robinson Engineers: provided M&E consultancy, and have a rare but detailed knowledge of M&E systems in low energy housing. http://robinsonengineers.co.uk/

Bramall: built the new homes on the Wimbish development to a set of exemplary industry standards as specified by client Hastoe. http://www.bramall.com/[24]

Dedication to community regeneration has seen Bramall become one of the country's most forward-thinking construction companies. Bramall Construction has a dedicated team who lead the way with the latest industry knowledge. Bramall employed a full-time PassivHaus Design Coordinator for Wimbish with the roles of installation quality assurance and air-tightness champion.

[24] Bramall have subsequently merged with Keepmoat – see www.keepmoat.com

3. Fabric Performance

A number of tests have been performed on the building to determine whether, 'as-built', it performs to the design specification in terms of the fabric and envelope of the building.

The most definitive test that can be undertaken is the Whole House Heat Loss Test, also known as a co-heating test[25]. This, however, can only be undertaken in the winter months, as a large differential temperature is essential, and the property must be vacant, with everything switched off, for the duration of the test, which ideally is several weeks. Wimbish was completed in June and immediately occupied, thus we were not able to undertake this test.

The three other tests are:

- Air permeability – the 'blower door' test to ascertain the leakiness of the building
- Thermographic imaging – using a thermal image camera – to obtain a visual indication of where heat is leaking from the building, either generally through the fabric, or through a thermal bridge
- In-situ u-value test – a means to measure the insulation value of a specific element of the fabric.

These tests were first carried out at completion of the development, or within the first few months of occupation. They were then repeated early 2013.

3.1. Air permeability

Tests were conducted during, and at the end of construction, to ensure that the units complied with Passivhaus requirements having infiltration no more than 0.6 ach (air changes per hour). Air Tightness standards were generally achieved at the first attempt, although particular attention to this element was necessary as the target was felt to be challenging. Whilst wet plaster and appropriate tapes were able to deal with 95% of the issues, the use of timber floor joists caused significant difficulties in forming continuity between ground and first floor. The Contractor purchased his own blower door and undertook frequent interim tests to improve techniques and understanding of air tightness issues.

The tests in June 2011 were carried out by BSRIA for Bramall Construction. BSRIA certify that "*the test procedure was carried out in accordance with the requirements of ATTMA TS1 Issue 2, CIBSE TM23:2000 and BS EN 13829 : 2001, and is UKAS accredited*".

25 See http://www.leedsmet.ac.uk/as/cebe/projects.htm - Co-heating Test Protocol.

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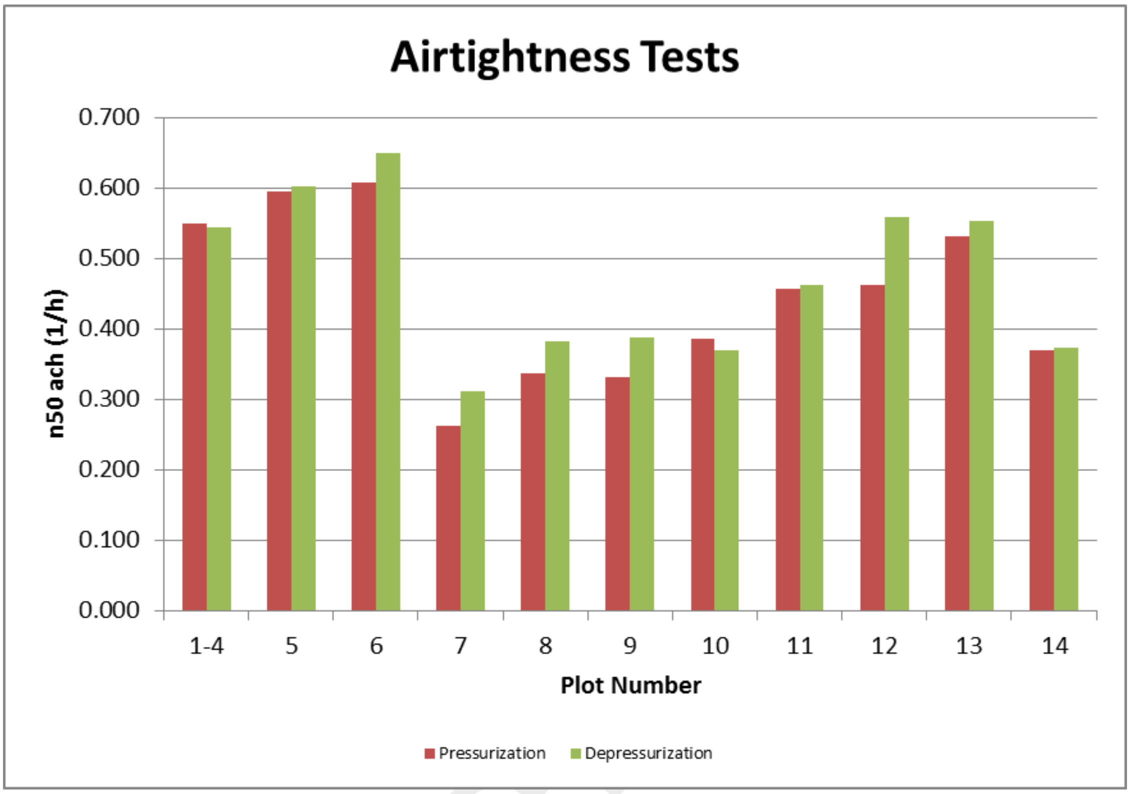

Figure 4: End of Construction Airtightness Tests

All the units passed the test, most of the houses by a considerable margin, although flat plots 5 and 6 only just.

BSRIA also quoted some of the results as q50 (air permeability index). For example, the test on plots 1-4 equates to 0.60 $m^3/m^2.hr$, and plot 14 to 0.34 $m^3/m^2.hr$[26].

Further tests have recently been conducted to assess whether the units remain air-tight. Some tests were conducted by the contractor subsequent to replacing some of the windows with opening lights[27], and other tests by BSRIA, directed by the study team.

Five of six tests of the houses remain within the Passivhaus standard, the other property being 0.8 ach. The results of the two flats tested were less satisfactory. Originally, the flats were tested as a group, thereby eliminating leakage between them. It is thought that much of the increase is down to such leakage as we were now only able to obtain access to test individual flats. Detail of these tests will be published in the final report.

[26] For Swedish readers divide by 3.6 to get $l/s.m^2$

[27] Incorrectly initially fitted as fixed lights in the living rooms of the 2-bedroom units.

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3.2. Thermographic Imaging

The objective was to carry out a site-wide quick inspection of the exterior of the dwellings, followed by a more detailed internal and external survey of two of the fully monitored properties (one house and one flat).

A survey was conducted on 21st December 2011 by David Frost Associates using a FLIR camera. David is a construction professional of many years' experience, having previously been Head of the School, Construction and the Built Environment, at West Suffolk College[28]. As such, he has the extensive knowledge of construction detailing necessary for interpretation of the images.

The early morning conditions were generally very good, being cold, still and dry. The outside air temperature was constant at 5°C. However, a bright winter sunrise precluded detailed survey of the south and east elevations.

The images, both infra-red and digital, were loaded into the FLIR software. Comments on the readings and anomalies were recorded in the software, from which a set of Adobe PDF reports, to BS EN 13187, were generated.

The thermal envelope of the buildings was found to be excellent. The buildings are thin-joint block-work with external insulation and render. The surface of this was found to be at uniform temperature on each plane. No evidence of gaps in the insulation was found.

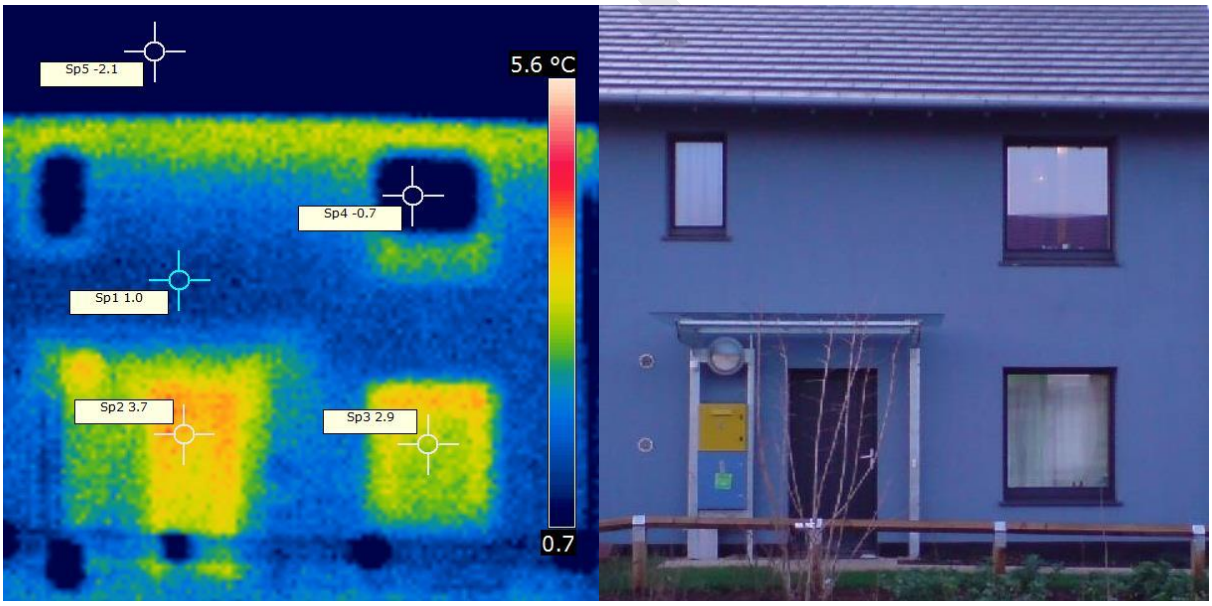

Figure 5: Illustrative mage of a House - thermal and digital **credit: David Frost Associates**

However, small issues of window and door seals were identified and need attention to adjustment and alignment.

[28] West Suffolk College are a BwC partner, and David led their work on the project in the area of skills and training.

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Triple glazed window frames in general show high performance but sills show signs of possible cold bridging, or leakage through the seals.

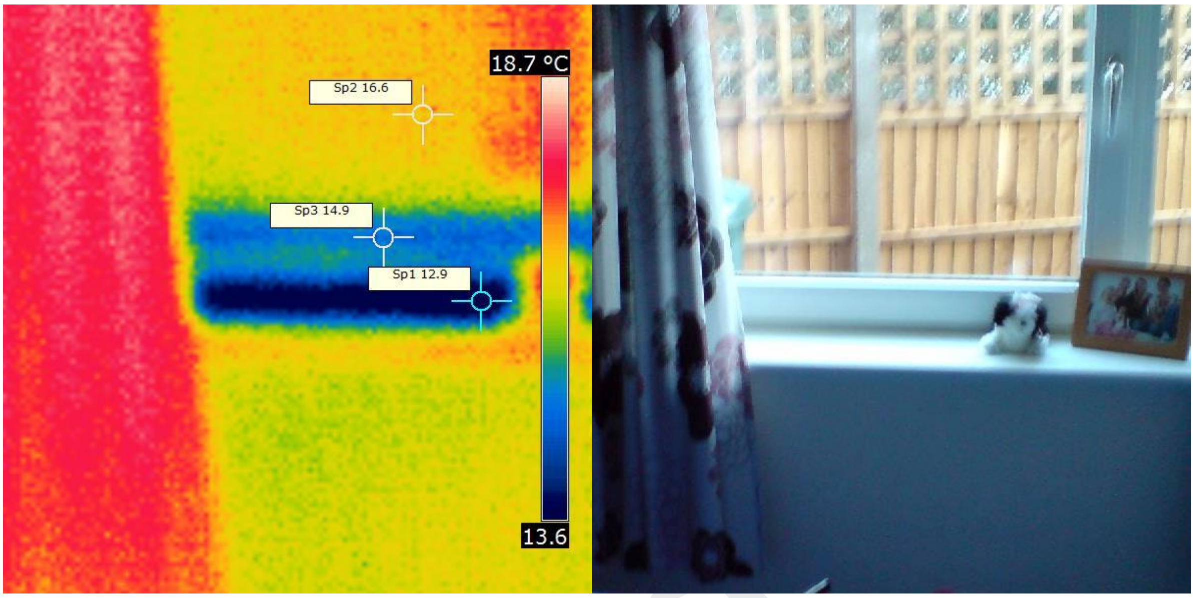

Figure 6: 'Cool' bedroom window sill credit: David Frost Associates

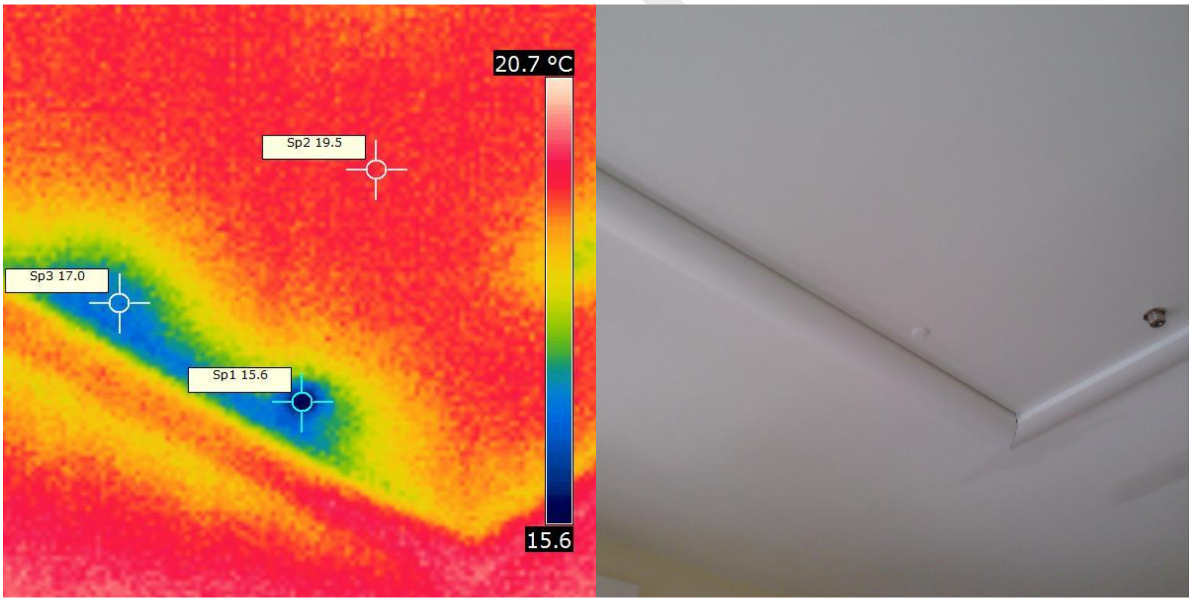

Figure 7: Loft hatch - minor bridging at hinge fixings credit: David Frost Associates

It appears that attention to detail regarding entry of service points to the structure is good.

Some ‘cooler’ spots were noted; however, most of these were at higher temperatures than would be found on external wall surfaces of anything but a

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Passivhaus, and in only a handful of locations was the value less than the recommended minimum value for a Passivhaus of 17°C.

A second survey was carried out by BSRIA in March 2013. This was to verify the earlier survey, and to investigate if there were any obvious reasons why one house was using more gas than other properties. It also checked the sites of the in-situ u-value tests.

Again nothing of any significance was detected, with no major hot (or cold) spots detected.

3.3. In-situ u-value test

A pair of tests was carried out by BSRIA from 8th to 17th January 2012 using Hukseflux HFP01 heat flux sensors and an Eltek data logger.

The sensors were located on the MVHR cupboard wall on the north side of a house. The test was conducted in accordance with the ‘average method’ detailed in ISO 9869:1994. The dwelling was occupied throughout the test (with small ‘blips’ in the data visible when the occupants retrieved coats from the cupboard).

Figure 8: Heat flux sensors 'placed' against the wall

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Finding a good location for testing is quite difficult. It needs to be on a north-facing wall to minimise any external influence. It needs to be fairly near a window or other opening to enable the external temperature sensor to be connected, and it needs to be on a uniform area of wall to avoid any thermal losses to known bridges or areas of ‘weakness’ such as window surrounds. Most important of all it needs to be located where it is not an impediment to the residents, nor is likely to be disturbed by them. Ideal locations were not available at Wimbish, and those available were, of necessity, a bit closer to windows than we would have liked.

The first test returned a result of 0.16 W/(m^2K), disappointingly well above the design expectation (see section 2.4.6).

To determine whether this was an isolated result, the test was repeated in two further locations Feb-March 2013, such that we had a reading from each block. The results were 0.13 and 0.15 W/(m^2K) – good results (much better than UK 2010 Building Regulations), but not as good as hoped for.

Possible reasons for this gap between expected and measured performance are being reviewed. It is thought probable that the unavoidable proximity of windows was a contributing factor.

3.4. Lessons and Recommendations

All three sets of tests provide valuable information about the building.

Despite contractor air-pressure tests during the construction, and great attention to air-tightness detail, some units passed by a considerable margin, and others took a great deal of effort to achieve a pass. This implies that the quality processes necessary to achieve a pass were not consistently applied, and perhaps not fully understood by all tradespeople. More recent, poorer results, may just be a reflection on differences in procedure when carrying out the tests, or might be a reflection that some of the sealing processes were short-term expedients.

The triple-glazed windows generally utilized in Passivhaus construction are inherently very heavy, and place a major load on hinges. Over a few months, there is a tendency to ‘settle’. The thermal imaging suggested minor leakage, and adjustment of the windows and doors is recommended – this should probably be normal practice a few months after installing triple-glazed windows.

Identifying a location for the in-situ u-value test proved difficult. It needs to be on a north-facing surface, and be where it is not at risk of being knocked over. The Wimbish Passivhaus homes were carefully designed to maximise use of natural light from the larger southern aspect windows. Consequently, the north wall is populated with bathrooms, services cupboards, toilets, stairs, and kitchen units – none of which are conducive to conducting the test. This is not to suggest that the layout should have been designed to accommodate the test; indeed pre-allocating a location might pre-dispose a contractor to taking particular care and attention at that point.

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4. Design and Delivery

A summary of the Design and Construction Audit will be included in the final report.

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5. Handover

A summary of the Review of Handover report will be included in the final report.

This interim report includes some brief notes, and identifies lessons, to enable these to be applied for the follow on developments.

5.1. Notes

'Handover' (seen here not just as 'move-in' day, but from approximately a month before move-in to at least 6 months after, i.e. the transitional period) provides considerable understanding necessary to explain quantitative and qualitative findings through the study; consequently both Martin Ingham and Chris Foulds (the UEA researcher) were deeply involved in observing handover sessions and other interactions where new residents were informed about their new homes..

Living in a Passivhaus requires new skills. The residents need to learn:

- how to control solar gain, getting the maximum in winter, and the minimum in summer;
- how to use the ventilation system to provide fresh air, or to remove moisture from the bathroom or smells from the kitchen
- what to do if they are a little cold (they should never find it more than a little cold)
- what to do if they are a little warm, for example when should they open the windows?

The transition to a property with no visual heating system, but with the addition of a ventilation system, might be considered similar in nature to the change from open fires to central heating. The main obstacle is quite simply that the technologies used in new Passivhaus dwellings are not comparable to the residents' previous homes. Therefore, their previous experience does not, by itself, sufficiently equip them with the knowledge required to achieve the expected project benefits. The handover period is when these 'different' technologies are encountered for the first time, and is thus especially insightful.

For social landlords, the issues are not only for the residents, but also are for the support staff, who will need to be able to answer resident queries, and for the maintenance staff. The latter need to understand:

- how to get the best out of the heating supply system, that is to maximise supply for the solar thermal, and minimise that from the boiler.
- How to maintain an MVHR installation, especially the filter changes
- Any other maintenance requirements specific to the Wimbish properties, including the need to preserve air-tightness.

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The Technology Strategy Board requirement is simply to observe handover to the residents. We recognised, however, that the simple event of handing over the building was part of an extended process (a transition of responsibility regarding ownership/occupation) and that we should observe as many aspects of this as possible, including the training/handover for support staff and maintenance.

At Wimbish, the process of resident engagement was an extended one:

- Several evening sessions were held in the adjacent village hall for the prospective tenants, and for interested local people, to explain what the development was seeking to achieve, and to enable them to ask questions.
- Once the residents had been nominated to live there, it was explained to them that they would be living in houses with very low bills, but to be certain they benefited from this they would have to learn some new skills.
- Close to completion, the residents were given a guided tour, which also gave them the opportunity to measure for carpets etc. This visit was combined with another information session, which included outlining the Technology Strategy Board-funded and UEA PhD plans and the provision of a handbook (containing lists of do's and don'ts).
- On move-in day, as well as signing tenancy agreements, they were given a more detailed tour of the properties and the systems therein by a Bramall representative.
- This session was repeated a few weeks later for those residents finding the transition difficult
- It was also given to the Hastoe support and maintenance staff.
- Hastoe frequently visited the residents during early occupancy. This was more formally at the 2-week de-snagging and 6-weeks resident visits, as well as more informally on an ad-hoc basis,

5.2. Lessons and recommendations

Summary points:

- Timing – on the day they were moving in the residents were understandably more concerned about carpet fitters and the location of their furniture and appliances than they were about how to control the MVHR. It would probably have been better just to explain the key points then, with the main education a couple of weeks later. Starting the whole process earlier, prior to move-in day, will also help to lay the foundations for better understanding.
- Maintenance – maintenance staff really should have been involved first. They did not want residents changing MVHR filters for fear it might invalidate the warranty. If this had been known earlier then there would have been no need to attempt to teach the residents how to change all the filters. Six months after move-in most residents are still confused about this, thinking they will soon need to change their filters.

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- ‘Hands on’ – it is widely acknowledged that learning by doing is most effective. The handover might have taken longer, but it would have been better to get the residents to show that they had understood by operating the controls, for example to wind the blinds down and up again.
- Support – adjustment to new technologies is not instantaneous, it is a journey. Hastoe need to be with them during that learning process. On this, all residents were complimentary regarding Hastoe’s support: “always wanting to help if they can and make a success of it”.
- Controls – their usability is highly subjective, with the effectiveness of control strategies varying across age, gender, and whether the residents are techno-phobic. For example, one young resident thought the MVHR control very easy as it was like her iPhone, but others have struggled with the choice of functions. Great care must be taken in selection of appropriate controls in the design phase. This topic is the subject of detailed study.
- Negative messages – it probably was not productive to tell the residents ‘that research had shown it might take them two years to learn how to live in a Passivhaus’. While this may be true, we should not be telling them it is difficult, rather that it is like learning to ride a bike, tricky at first but they will soon get the hang of it.
- Seasonality – different behaviours are likely to be needed in winter from summer. Residents are likely only to take in lessons pertinent to them in the short term. This might mean that further advice may be needed when the seasons change.
- Household focus – energy use is a consequence of households made up of individuals interacting with each other, and who may have differing preferences, for example regarding comfort and temperature. Therefore, wherever possible, handover guidance should be given to all occupants, not just one representative who, in addition, may struggle to accurately relay the guidance.
- Information provision – education is actually one of the smaller pieces of the puzzle. Individuals are not rational decision makers who always take action based on information that tells them they will benefit (e.g. ‘do action x to save money’). Few residents at Wimbish ever consulted the manuals/handbooks given to them (some lost them), with almost all residents saying that they were overloaded with information on move-in day.
- Non-Passivhaus guidance – because of wanting to ensure residents understood the Passivhaus technologies as much as possible, the more standard aspects were to a certain degree neglected. The tour of technologies needs to be incorporated into a more holistic move-in day tour.

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Note that the continuing interview sessions and other interactions[29] with the residents are providing a measure of education, as well as picking up issues to be dealt with by Hastoe or Bramall. Such an extended engagement process is probably exceptional, being only for this development, Hastoe's first Passivhaus project, and is highly unlikely to be widely adopted. However, some form of continuing engagement may be beneficial until Passivhaus practices become normal.

29 These are the monthly visitor experience sessions, filming by BBC East and ITV Anglia (see http://www.buildwithcare.eu/component/content/article/234-qyou-just-dont-have-the-bills-you-would-have-in-a-normal-house), and visits to check the monitoring equipment.

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6. Occupant Perceptions and Behaviours

In-depth study of the occupants is the subject of post-graduate research; this will be reported in the final report.

This section will also describe the verbal responses we have had from the occupants, and compare them with the findings from the monitoring, which are reported in section 8.

Despite the occasional, and seemingly inevitable, glitches in the build or the systems, the occupants report overwhelmingly a very high level of satisfaction with their new homes:

> *"You just don't have the bills you would have in a normal house"*
>
> *"We put aside £50 a month to cover heating bills, and when they only came to £30 for the first six months our children had a better than expected Christmas"*
>
> *"The houses are so light and spacious[30]"*
>
> *"I'm happy putting my children's bunk beds by the window as there's no draughts, and the glass is not cold"*
>
> *"I'm less stressed. Having a lovely house we are proud of, and look forward to coming home to, is benefitting all of us."*

6.1. BUS (Building Use Studies) Survey

This survey was undertaken during Early Occupation, in September/October 2011, as part of the Building Performance Evaluation study part-funded by the Technology Strategy Board. The survey employs a standardised questionnaire developed by Building Use Studies Ltd. The responses to surveys are analysed by Arup on behalf of the Technology Strategy Board. They provide analysis against 50 metrics (for example, '*control over heating*', '*temperature in summer: hot/cold*') and a number of summary indices.

The standardised approach enables a project to compare its results against those of buildings previously surveyed. For domestic projects, this is currently a rather small data set; being the best of 9 surveys does not have quite the same cachet as being the best of 99 would be. However, Wimbish is still the best.

Fourteen survey responses were received covering twelve of the properties.

30 This despite the houses being built to miserly size standards.

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The summary index[31] shows that, as we are indeed aware from our contact with them, the occupants are delighted with their homes:

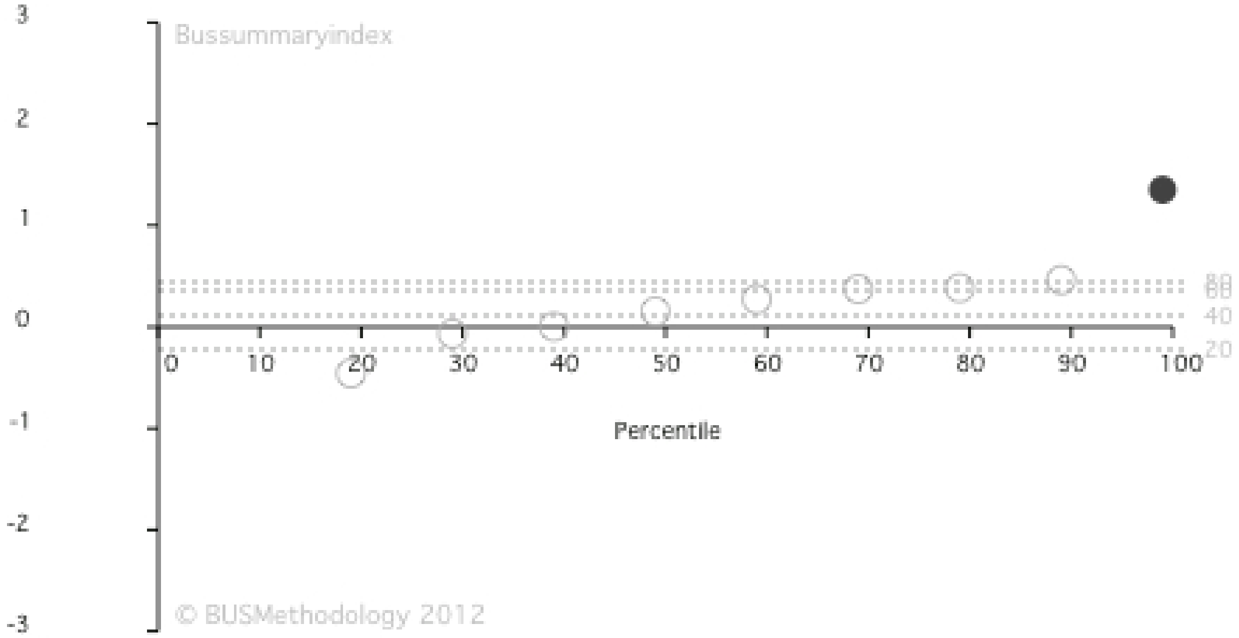

Figure 9: BUS Survey - Summary Index

A handful of the metrics show less than satisfactory results. Some of these are not warranted, for example those relating to '*air in winter*', because the properties had not been occupied in winter at the time of the survey.

Others, however, may be indicators of issues to be addressed; for example, the air in summer is perceived as being a little too still. This is an odd response, as we feared the MVHR might make the properties draughty, and because the residents had been encouraged to open windows. Such issues are being discussed with the residents in the current round of interviews to establish whether this is generally considered a problem (it might actually be something they like, that is absence of draughts!).

31 The Wimbish result is the filled circle; the vertical axis shows increasingly positive responses towards the top and increasingly negative ones towards the bottom.

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7. Installation and Commissioning

A summary of the Review of System Design and Implementation will be included in the final report.

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8. Findings from Monitoring

These results are based on data from monitoring from August 2011 to March 2013.

This section reports the quantitative data.

For confidentiality, in this interim report, we do not identify the individual properties.

See Appendix A for details of the monitoring methods.

8.1. Comfort

For the occupants, the primary comfort measures are being neither too hot, nor too cold, neither too dry, nor too damp, and having fresh air (see section 8.3 for findings on air quality).

Secondary comfort measures would relate to draughts, odours, light (natural and artificial), and noise. These measures are not being monitored directly, rather they are being reported as occupant perceptions in section 6.

8.1.1 Temperature

What constitutes a comfortable temperature varies significantly by individual. The Passivhaus Planning Package (PHPP) pre-supposes 20C is comfortable; UK Government exhorts us to turn the thermostat down to reduce energy consumption and save on bills.

The Wimbish thermostats were restricted to only a couple of degrees range above 20C so that the residents felt they had control, but could not actually live in a hot-house.

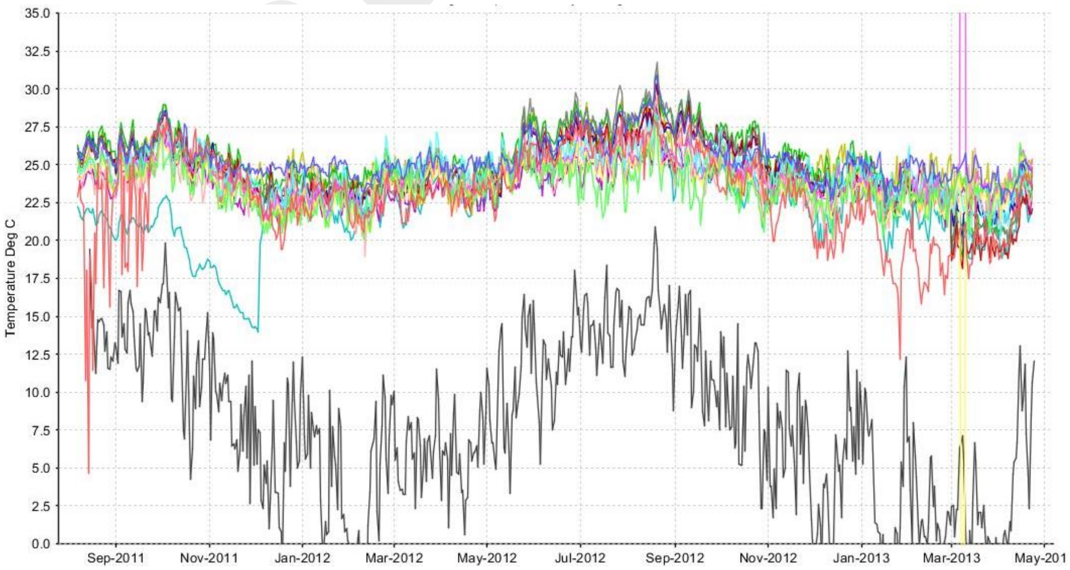

Figure 10: Temperature in the houses, and outside (daily averages) – subject to recalibration

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Notes on the temperatures in the houses:

- One sensor (the red line) malfunctioned for the first couple of months (and probably again in Jan-Feb 2013
- Each house has a lounge sensor; the two fully monitored ones also have sensors in the hall, kitchen, and bathroom.
- One end-terrace house (the pale blue line) was not occupied until early December. The MVHR was left on at a low level to provide ventilation, but there was no heat supply other than solar gain. The property only lost heat very gradually, and remained at least 7C above the outside temperature.
- The internal temperatures could be considered to be 'on the high side' much of the time (especially as the period is mainly during the winter). This may be attributed to personal preference[32]. (For further discussion, see 8.1.3 Overheating below).
- On 28 February 2013, the calibration of sensors in houses and flats we could access was checked. These were found to be reading high, and were adjusted. Retrospective correction is pending, subject to access to the remaining half of the properties to check their sensor calibration. The temperatures are not as high as they seem on these graphs.

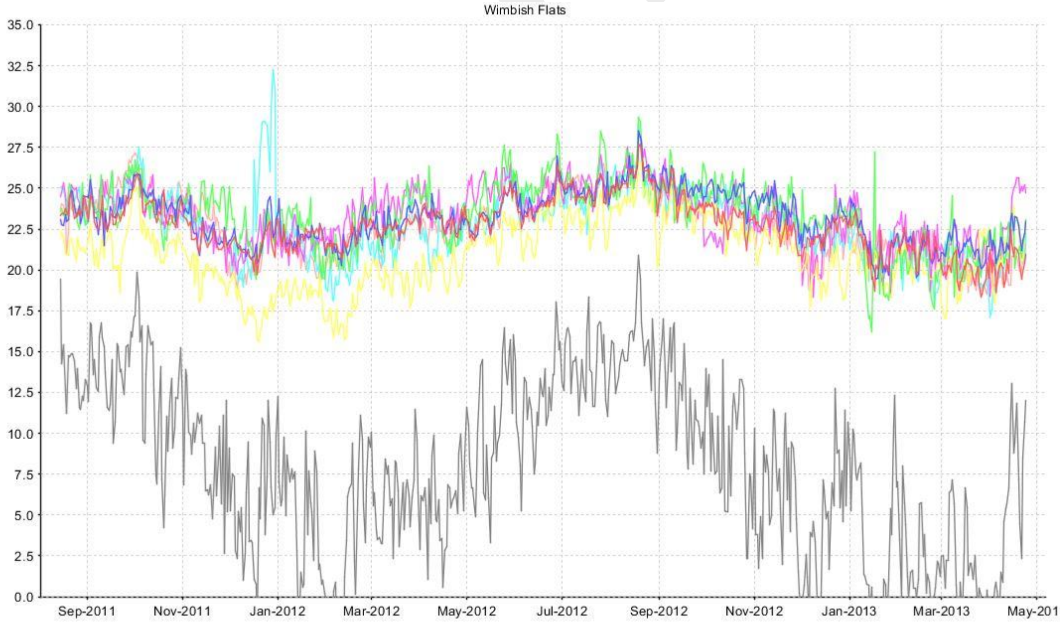

Figure 11: Temperature in the flats and outside (daily averages) – subject to recalibration

32 The consistency of recording is such that it is unlikely that all sensors are reading high.

Notes on the temperatures in the flats:

- One flat had a burst kitchen pipe in December 2011[33] and use of a de-humidifier for a fortnight raised the temperature.
- The occupant of one flat prefers opening windows to using the MVHR (the yellow line)
- Temperatures generally are a little lower than the houses. All would be considered comfortable.

8.1.2 Humidity

Relative humidity levels should ideally be in the band between 40% and 60%. Above this level, there is increased risk of mould, and below it, the occupants can feel that the air is a bit dry.

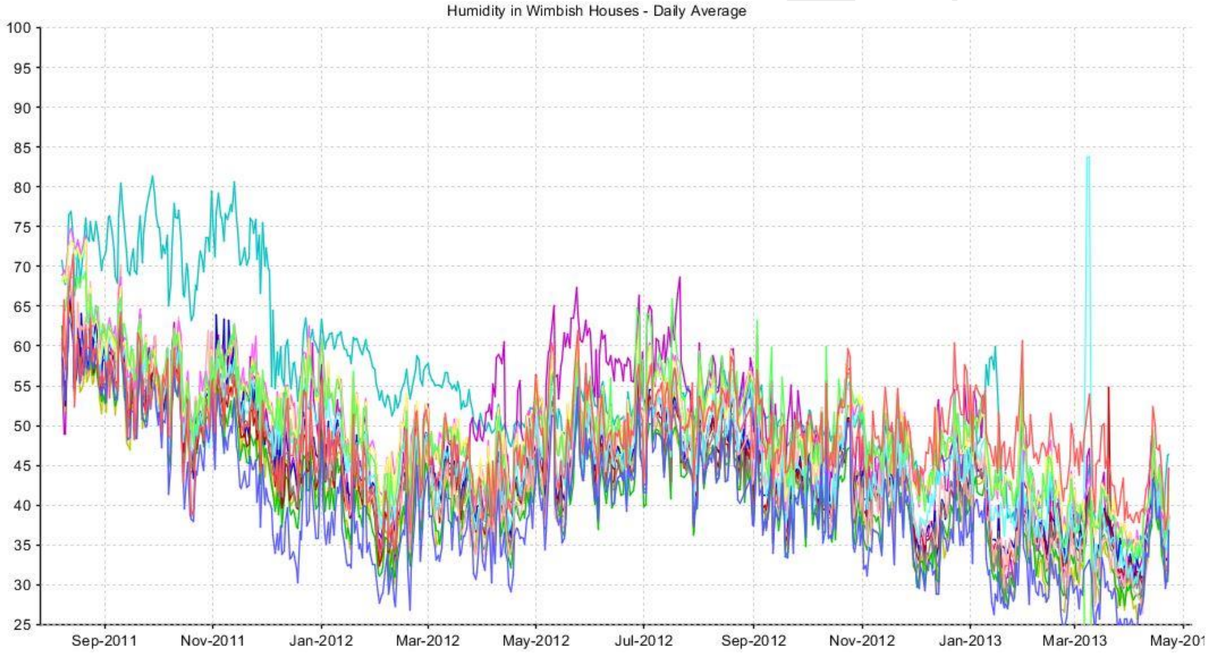

Figure 12: Relative humidity levels in the houses (daily average)

Notes on the humidity in the houses:

- Initially the levels were high. This is believed to be a result of the water in the build (wet plaster mainly) and that the occupants were not yet conversant with managing ventilation – that is sometimes the MVHR was off and the windows were closed – they had not all understood that the MVHR should be on, and should only be off if the windows were wide open

33 A construction fault

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- One house remained high until December 2011 (dark cyan line); this is because it was unoccupied and not heated. If its lower temperature is taken into account then the moisture content of the air is found to be similar to that of the other houses. Its curve lags behind the others.
- Each house has a lounge sensor; the two fully monitored ones also have sensors in the hall, kitchen, and bathroom.
- In February 2012 and Jan-Mar 2013, average levels for several of the houses fell a little below the acceptable range. This is attributable to low external temperatures, which means that incoming air can hold little moisture. This is a known risk for air-tight dwellings with MVHR such as a Passivhaus
- Calibration checks have shown no adjustment necessary

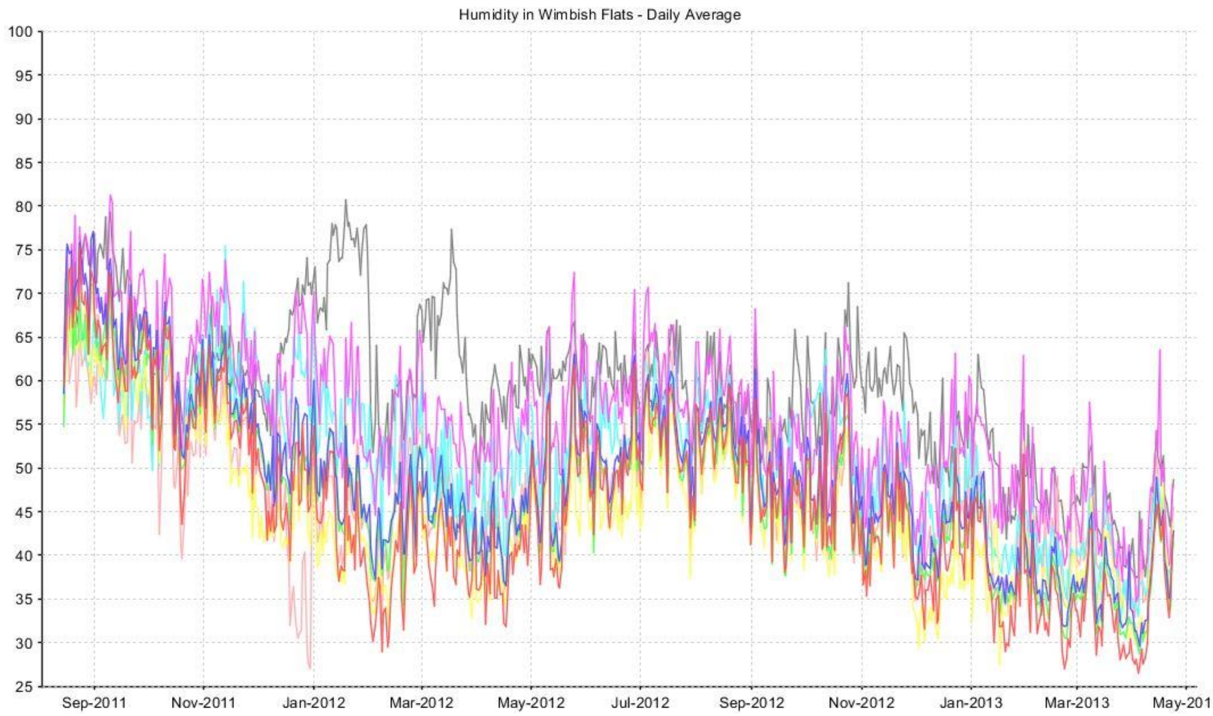

Figure 13: Relative humidity levels in the flats (daily average)

Notes on the humidity in the flats:

- Like the houses, humidity levels started a little high and have fallen, but not quite as far.
- One flat suffered MVHR problems Jan-Mar 2012 with consequent higher humidity levels (grey line). Subsequent to this the resident ran the MVHR at lower than advised level (Oct-Nov 2012) – again with higher humidity.
- The low levels in December 2011 are in the flat where the de-humidifier was used. (see notes on Figure 11).

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- As with the houses, winter 12/13 is dryer than the previous winter, suggesting a drying out of the properties.

8.1.3 Overheating

This section has not been updated from the first interim report (hence in italics).

> Thermal data from summer 2012 indicated that, despite it not being a particularly warm summer, the properties were quite hot. This did not agree with qualitative feedback that the residents did not feel their homes were overheating, or rather no more than they would expect in hot weather. Before analysing this further, we felt we should check the calibration of the sensors in case they had drifted. While undertaking a number of tests on site on 28th February 2013, we were able to check sensors in about half the houses, and found that most of the temperature sensors were reading one or two degrees high. Further analysis, including adjustment of historic data, is pending – dependent on accessing the remaining properties to check their sensors.

Passivhäuser are designed to balance heat losses (through the fabric and from ventilation) and the gains (from the sun, occupants and appliances) in order to minimise the heat that must be supplied to the dwelling to keep warm.

In practice, however, if gains exceed losses then the temperature will rise. If an imbalance continues over several days or weeks then the rise could be considerable.

The Passivhaus, and Wimbish, answer is firstly to keep heat out – the thermal insulation is equally good at stopping heat from outside from getting in during the summer, as it is for keeping heat in during the winter[34]. Secondly, the design aims to minimise solar gain in summer through use of shading (brise soleil, overhang and blinds), and, thirdly, to use thermal mass to smooth fluctuations.

The Passivhaus Institute expects occupants to have energy efficient appliances. At Wimbish, tenants are responsible for providing their own appliances. They have been guided in making a wise choice, but in most instances, they are believed to have brought their existing appliances with them, and many of these are likely to be old and inefficient (as is borne out by high electricity usage, see section 8.2.2)[35]. Consequently, heat gains from the appliances are likely to be higher than the figures used in design.

It is interesting that a recent analysis[36] has shown that lifetime costs for using the most energy efficient appliances on the market – as recommended in a passivhaus

34 Unfortunately, it can be just as good at keeping excessive heat in during the summer!

35 An appliance audit is being undertaken.

36 *Energy Savings in Practice: Potential and Delivery of EU Ecodesign Measures*, coolproducts for a cool planet, December 2010, http://www.coolproducts.eu/resources/documents/EnergySaving-in-Practice-summary.pdf.

– may be no more than if buying the current standard products - which are, however, likely to be cheaper to purchase. Given the savings on heating costs achieved in a passivhaus, and demonstrated in this report, appliance use is now the biggest energy cost to a household living in a passivhaus. Forward-thinking housing associations such as Hastoe have invested in energy efficient construction, as at Wimbish, in order to help tenants to continue to have the ability to pay their rent. At the same time, the reduction in energy use creates a wider benefit to society via the reduction in greenhouse gas emissions that result. Using the most energy efficient appliances will have very similar benefits both to tenants (financially) and to society (via reduction in greenhouse gas emissions). It might be interesting to consider ways in which housing associations can help tenants acquire the most energy efficient appliances without a capital cost financial penalty just as associations such as Hastoe are helping tenants to live in the most energy efficient homes. Such action is not currently easily possible but, as well as creating the benefits to tenants and to society outlined, it would also help stimulate the wider introduction of the most energy efficient appliances and thus drive down the costs for all.

If temperatures do rise above desired levels in a Passivhaus the expectation is that the occupants will open windows to provide through ventilation. When external temperatures are even higher than inside this is undesirable – the approach then is to ‘batten down the hatches’ to minimise any gains until such time as the external temperatures have fallen. This is effectively a ‘night-time cooling’ strategy, which is most effective if the thermal mass can be cooled.

The generally high temperatures, especially in the houses, give slight cause for concern that overheating may prove to be an issue in summer, or perhaps even in the spring. So far, however, there has been little need for occupants to learn how to deal with excess heat. The outside temperature in summer 2011 was unseasonably low; from when monitoring started in August through to mid-September it only exceeded 25C once.

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At the end of September, however, there was a short warm spell:

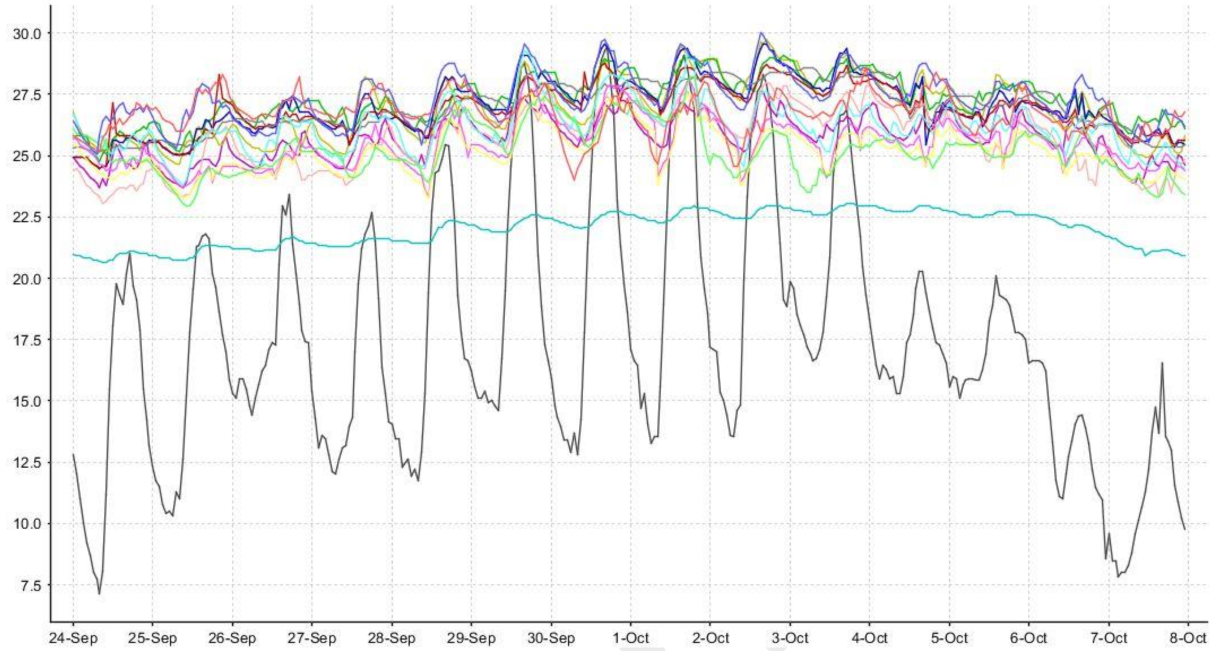

Figure 14: Temperature in the houses end September 'warm spell'

Notes:

- *The black line is the external temperature – it exceeded 25C 6 days in a row. The temperature fell quite quickly after 17:00 – this being after the vernal equinox.*
- *The cyan line is the unoccupied house. It did not warm as much as the other houses.*
- *The houses did not lose as much heat during the (long) night as they gained during the day – so there was a day-by-day rise.*
- *Internal temperatures started to rise before there could have been any gain from high external temperature – indicating solar gain was the main cause. At this time of the year, the sun's rays probably go under the Brise-Soleil.*
- *On closer inspection of the data, there is some evidence (faster than normal temperature loss) that one or two residents opened doors and windows around 09:00 for an hour or two to cool the house. Doing this would be subject to being at home, and having due regard for security concerns.*

This data would appear to confirm that the occupants' behaviour might well be key to ensuring they stay cool in hot weather. A close eye on performance in warm and hot periods will be maintained, and appropriate guidance will be given if necessary.

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8.2. Energy Use and Cost

Issues with the utility meter logging (see section 8.5.2) make us reliant on periodic manual meter reading. Consumption data from 20 months' occupation enable us to assess annual consumption with confidence.

8.2.1 Gas Consumption

Figure 15 shows total annual gas consumption and Figure 16 the consumption per m^2 of floor area.

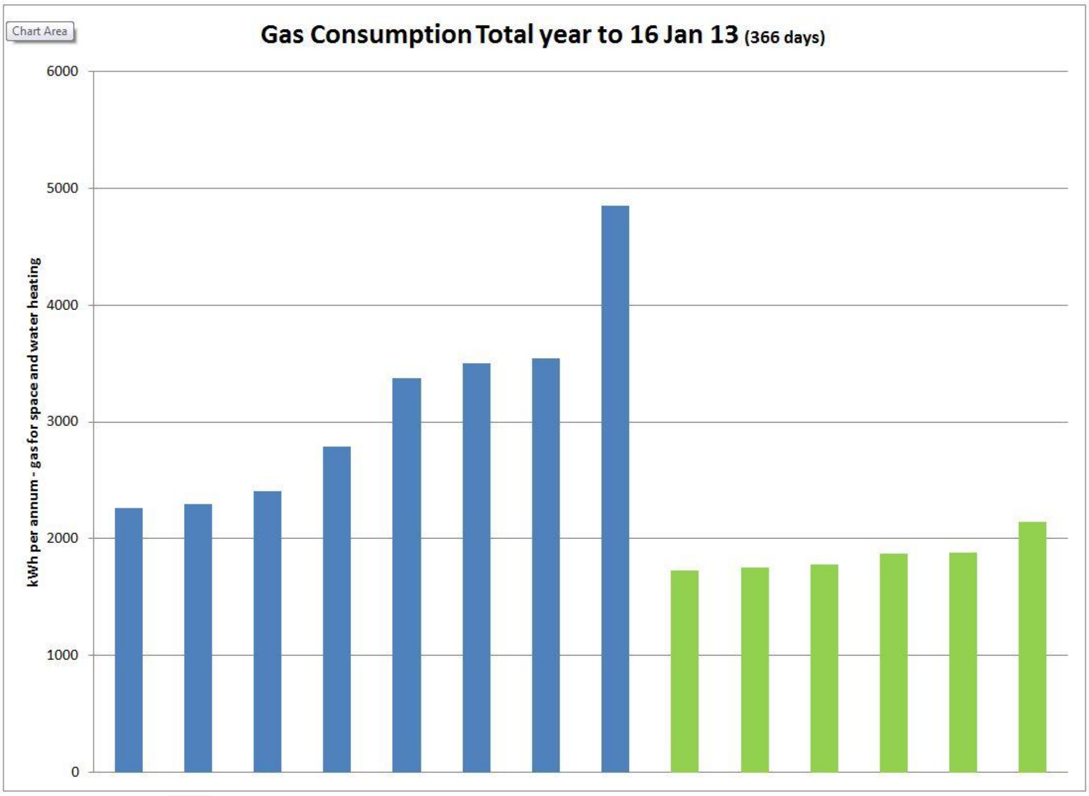

Figure 15: Annual gas consumption in kWh to 16 Jan 2013

Notes:

- Houses to the left, flats to the right
- Even the highest consuming house consumes only a shade more than ¼ of the national average household gas consumption.

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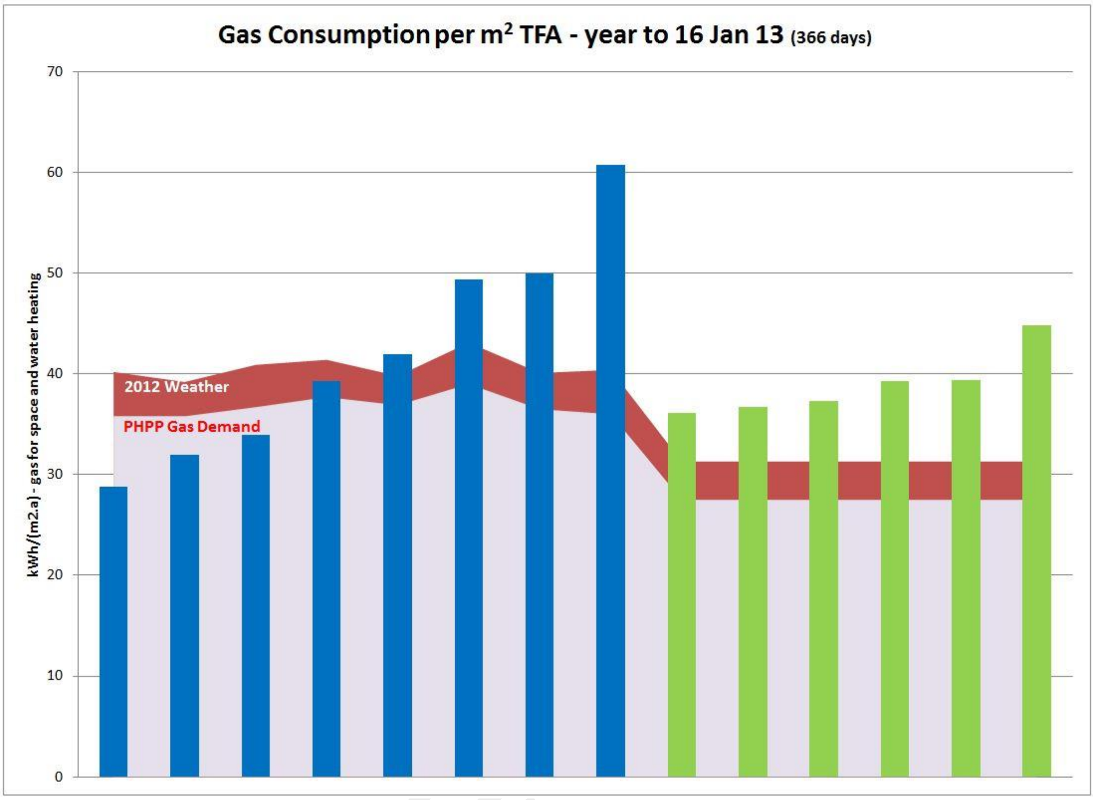

Figure 16: Annual gas consumption in kWh per m^2 to 16 Jan 2013

In Figure 16, the total consumption has been divided by the treated floor area taken from the PHPP calculations. This is then compared with the expected gas demand (also from PHPP – see also section 2.5.1).

The performance of the Wimbish properties is dependent upon sunshine, both for solar gain, and for heat from the solar panels[37]. 2012 was an unusually dull year, with only about 85% of average radiation from April through July. Amending climate data in PHPP to reflect the on-site weather recordings increased expected gas demand as shown. The annual gas consumption for the houses is close to the amended design expectations, whereas it exceeds expectation by a small margin for the flats. Note that this exercise has not accounted for actual levels of occupancy.

Currently energy supplier tariffs are unfriendly towards low consumers in that they either have a standing charge, or a tiered approach with a higher price for the first x,000 kWh each year. The Wimbish properties will be very unlikely to get out of the first tier. Low-energy homes as at Wimbish, either new or refurbished, will become much more common-place, hopefully quite quickly. We hope that utility or service companies will come forward with tariffs that reward low usage – which benefits society as well as occupants – without delay.

[37] The impact of cold weather is much less significant.

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For example of current[38] tariffs, npower's 'Go Save'[39], which has no standing charge, has a first tier threshold at 4,572 kWh p.a. Consumers pay 8.276p inclusive of VAT per kWh up to this point and 3.079p thereafter[40]. Oddly, this becomes a good deal for low consumers[41] since npower offer a direct debit discount of £52.50 per year for gas.

Applying the above tariff would give an average annual gas bill for the houses of approximately £220, and the flats £110.

8.2.2 Electricity Consumption

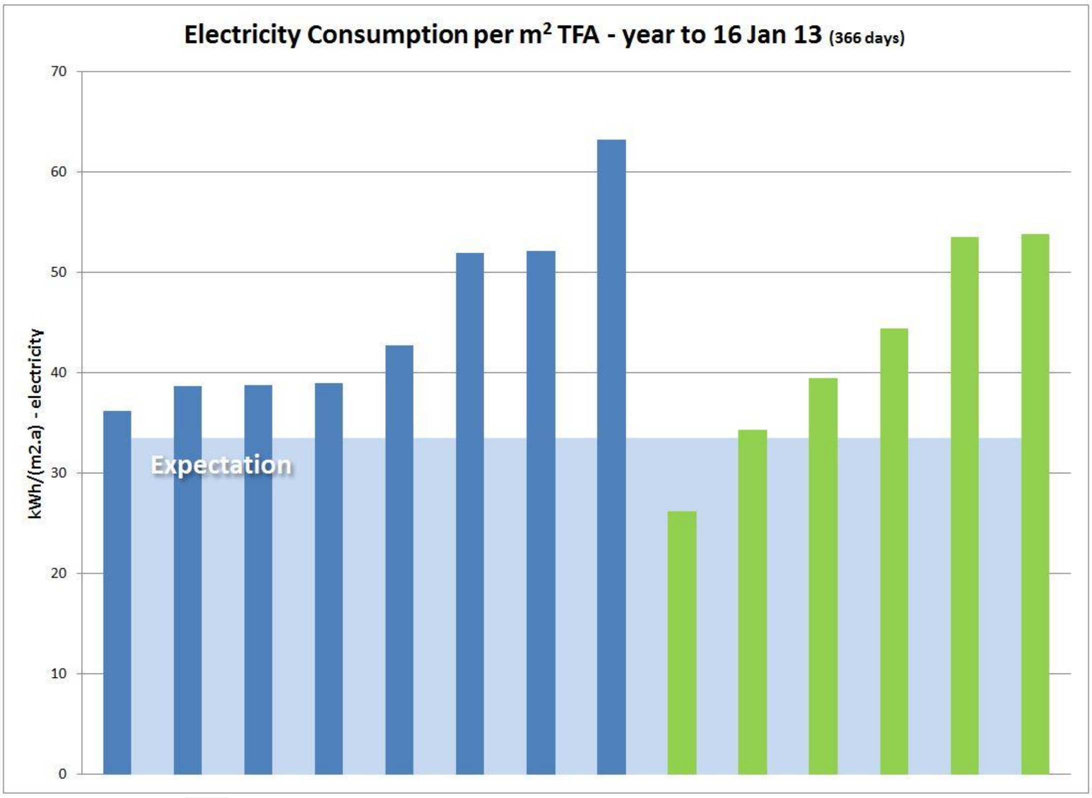

Figure 17: Annual electricity consumption in kWh per m2 to 16 Jan 2013

With the exception of one flat the consumption exceeds the expectation of around 33.5 kWh/(m^2.a) set out in section 2.5.1. Consumption levels are similar to those in an 'ordinary' house (though allowance should be made for running the MVHR fans).

38 Reviewed March 2012

39 I selected a random price comparison site and entered the predicted gas consumption of a typical Wimbish dwelling – this tariff was the cheapest, on that day, because of its discount.

40 For comparison, npower's 'Energy Discount Dec 2013 Gas' tariff charges only 3.017p per kWh, but has a £233.02 annual standing charge.

41 Note that this is not intended to be a recommendation. Consumers should regularly use a price comparison website to choose a supplier with the best deal that suits their needs.

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The 'excess' consumption is largely down to the very low expectations for a Passivhaus. It is assumed that the residents will give high priority to energy efficiency, and will only use efficient appliances, and lighting, sparingly. Wimbish residents were not selected as being eco-minded, and because Hastoe were unable to provide white goods, they mostly brought old inefficient ones with them. See also section 8.2.3.

8.2.3 Sub-metering

A summary of where the electricity has been used will be covered in the final report.

We are metering consumption in the kitchen (excluding the cooker) and the (downstairs) small power circuits for all 14 dwellings. For the 3 fully monitored units we have individual meters for the MVHR fans, for boiler pump, and for the solar thermal pump; for the remaining 11 properties, we log the 'plant' circuit. Disappointingly, we have discovered that the MVHR has not been connected to the plant circuit, meaning we lack the clear detail of its use in the eleven properties.

8.2.4 Correlations

Further study is being undertaken to compare consumption with what is understood regarding occupation levels and behaviours. It is considered likely that high electricity consumption leads to incidental gains that offset the need for gas for heating.

Aspects of this are:

- Household size and patterns of occupation
- Household attitude to energy consumption
- Comfort levels set (thermostat)
- MVHR controls – understanding and use
- Blinds and windows – use of to manage solar gain and purge any excess heat
- Appliance choice and levels of usage
- Bathing and laundry patterns

These result in seasonally varying patterns of energy and water use.

Some correlations are straightforward to verify, for example kitchen appliances and consumption on the kitchen circuit sub-meter; others have instances that confirm a hypothesis, but other instances which do not. For example, one house might seem to confirm that high usage of old appliances leads to lower gas usage, but one neighbour might have similarly old appliances without the lower usage, and another low gas usage but with new efficient appliances. This implies that the relationships are complex.

8.3. Ventilation and Air Quality

The ventilation system has two roles in a Passivhaus. Firstly to ensure an adequate supply of fresh air, both for the occupants and for the building; and secondly to manage the comfort level by providing additional heat or cooling as required.

In this interim report release, we evaluate the air quality, and discuss, briefly, the performance of the MVHR units.

Note that detailed quantitative data on ventilation and heat recovery is being recorded in the three fully monitored units only.

The ventilation systems were commissioned for the dwellings; that is based on room sizes and nominal levels of occupation. It would be better if they could be set up to suit actual levels and patterns of occupation, however it would be too costly to have a dwelling re-commissioned each time these changed, for example because of new tenants, new partner, or child leaving home. Commissioning for the dwelling can mean that it is a little over or under ventilated, implying either excess running cost, or slightly impaired air quality.

8.3.1 Air Quality

Carbon dioxide levels in a room are used as an easily measurable proxy for air quality. A figure of 1,000 ppm (based on the long standing Pettenkofer value[42]) is often quoted as an acceptable upper bound; a range of 800-1,000 ppm is considered adequate air quality[43].

Historically, homes have been leaky, which ensures, through draughts, that the air is refreshed; of course we lose a significant quantity of heat at the same time. As we build our homes more air-tight, there is an increased risk that this ‘natural’ ventilation, for example through trickle vents, will be inadequate, resulting in poor air quality (measured by CO_2, though other gases and moisture content can also be a factor). We need to ensure adequate ventilation throughout the property – one way of achieving this is mechanically with fans. To avoid heat loss while so doing we should add a heat recovery unit, thus employing mechanical ventilation with heat recovery (MVHR). It is of concern that ill-advised retrofit, which may not give adequate attention to ventilation (it tends to add cost without direct benefit so does not help cost-justification), can lead to poor air quality and ill-health. By going to Passivhaus levels of air-tightness performance one should ensure that air quality is good, with minimal MVHR running cost[44].

To achieve this, the MVHR must be designed to provide the quantity of air appropriate to living room sizes and to occupation levels (see paragraph above), and similarly to extract the required quantity from bathrooms and kitchens. The supply and extract must be balanced, and the design must ensure flows around the living rooms and via an uninterruptible route to the extracts. The system must be

42 This 19th century value is widely debated, for example, see http://www.ncbi.nlm.nih.gov/pubmed/9453792.

43 CIBSE Guide B, *Heating, ventilating, air conditioning and refrigeration*

44 An MVHR may not be cost-effective in a property that is insufficiently air-tight.

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regularly maintained, especially cleaning/replacement of filters, both to ensure that the air supply, and hence quality, is not compromised, and that the fans run efficiently.

In the summer months, Passivhaus residents are free to open windows to achieve air quality. In winter, this is frowned upon, as it would waste heat; hence it is more important to assess the effectiveness of the ventilation system in delivering air quality in the winter.

Overall, as evidenced by the BUS survey (see section 6.1) and by the extensive interviews, the residents are very happy with the good air quality, and the benefits they are obtaining from this.

Few households, however, have actually grasped how to get the best out of their ventilation system by adjusting the controls. Initial reaction when introduced to the touch screen control panel ranged from horror through to 'easy, just like my iPhone'.

In practice, those who have simply ignored the controls and left them on the normal level 2 setting have achieved good indoor air quality – although they have perhaps had slightly higher bills than they ought, and not using the boost may mean cooking smells and humidity from bathing lingers longer than it otherwise would.

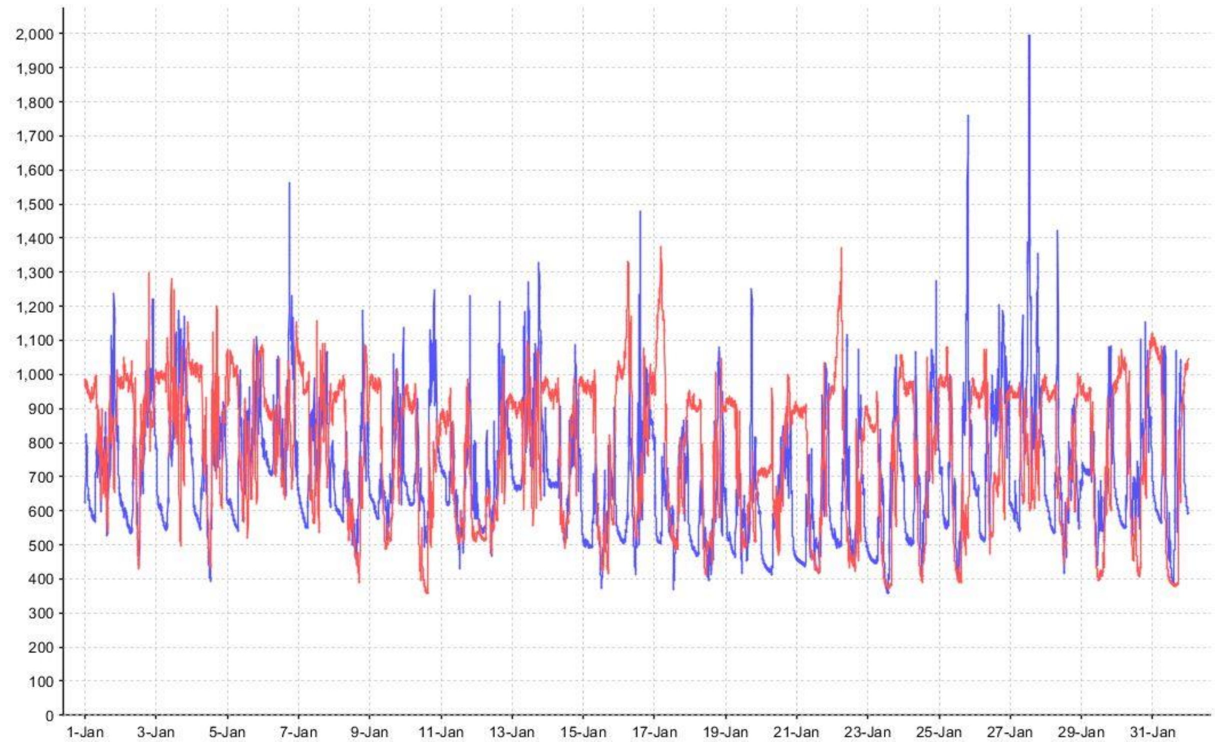

Figure 18: Lounge (blue) and bedroom (red) January 2013 CO_2 levels in a house

Figure 18 shows CO_2 levels in one house. The levels are generally acceptable, with the 'spikes' of short duration.

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The other house has similar CO_2 levels, but the levels in the flat are somewhat lower (nb the vertical scale is different):

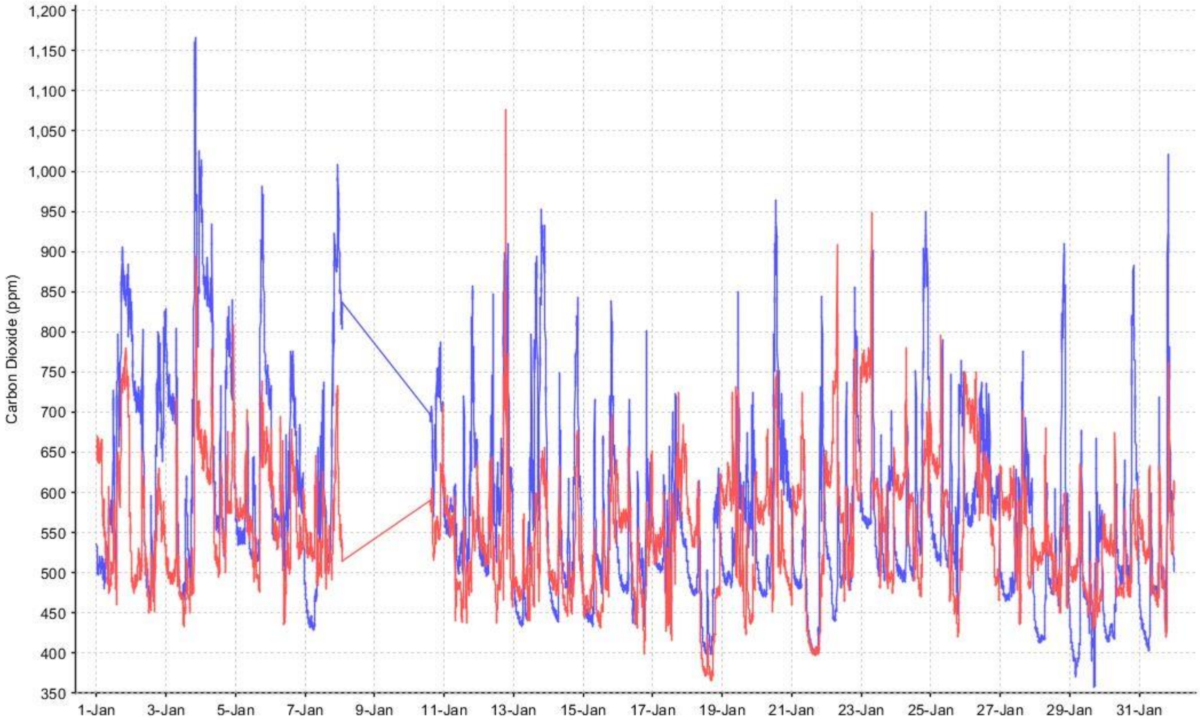

Figure 19: Lounge (blue) and bedroom (red) January 2013 CO_2 levels in a flat

The low values imply a degree of over-ventilation.

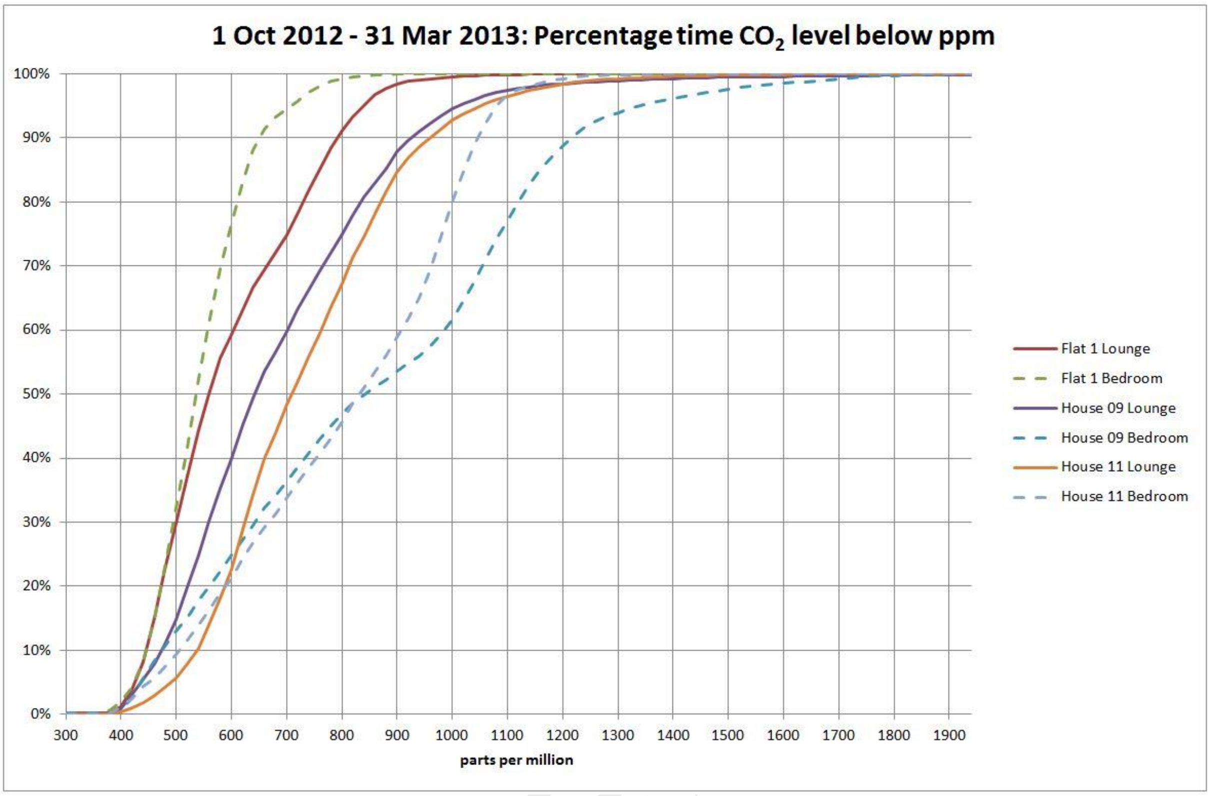

Figure 20: Percentage of time CO_2 levels below ppm Winter 2012/13

Figure 20 shows the percentage of time that the CO_2 level is below various concentrations. For example in the lounge (orange line) the level is below 1000 ppm about 92% of the time. This figure shows that the bedrooms (dashed lines) perform worse than the lounges, perhaps there should have been a relatively higher air supply to these rooms.

Ideally, we would only assess levels of CO_2 while the rooms are occupied. Not having occupancy sensors we can inspect the CO_2 logs (see Figure 21 and Figure 22). It is fairly easy to detect when someone enters the room as the ppm rises rapidly, but because it only decays slowly it would be less easy to detect, using a formula in Excel, when the room became vacant again.

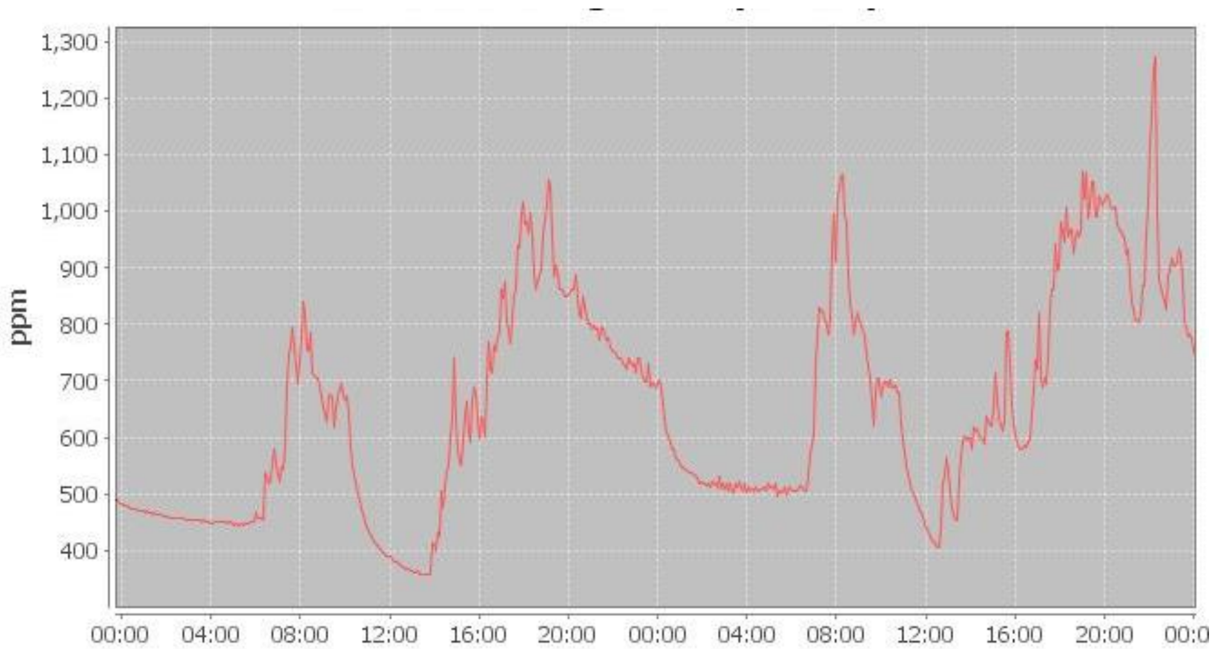

Figure 21: CO_2 in house lounge over 48 hours

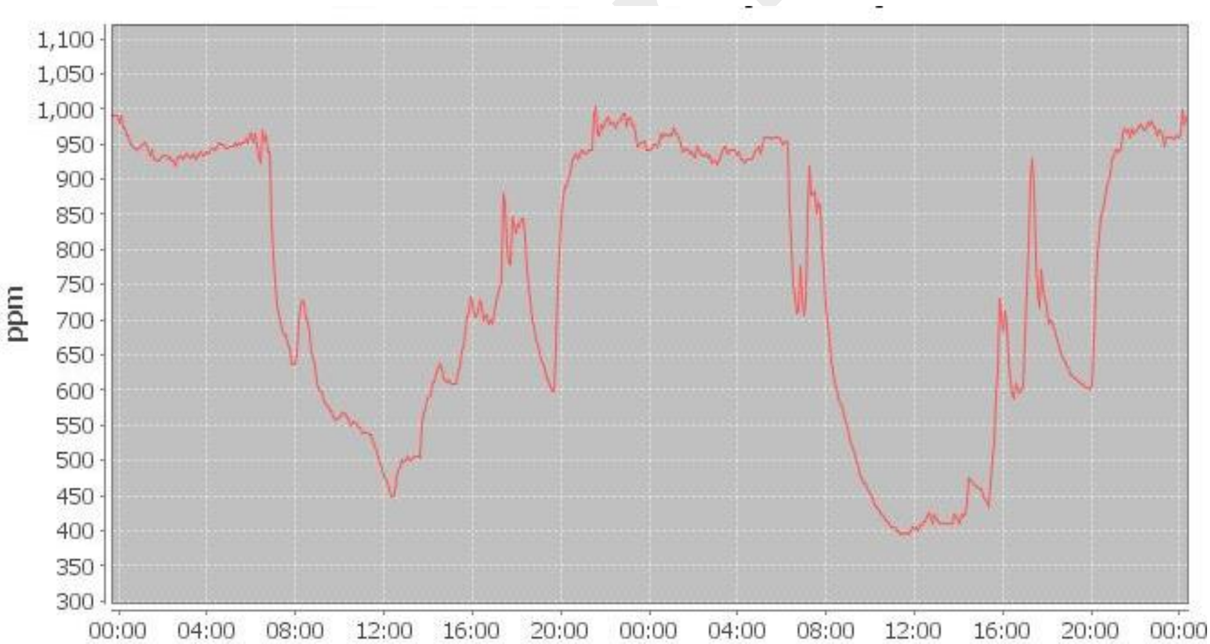

Figure 22: CO_2 in house bedroom over 48 hours

Note that this is a bedroom occupied by children.

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8.3.2 Heat Recovery

In the MVHR systems, we have three temperature sensors:

1. In the return air duct – effectively the temperature of the air extracted from bathroom and kitchen
2. In the incoming air duct, just after the Frost Coil (electric pre-heater)
3. In the supply air duct, after the Reheat Coil (hot water post-heater)

If (2) is above the outside air temperature then we can see that the frost coil is operational, and if (3) is elevated this shows that the reheater is working. We also log MVHR electricity consumption. Figure 23 also shows when the frost protection is operating (the lower blue line is the outside temperature).

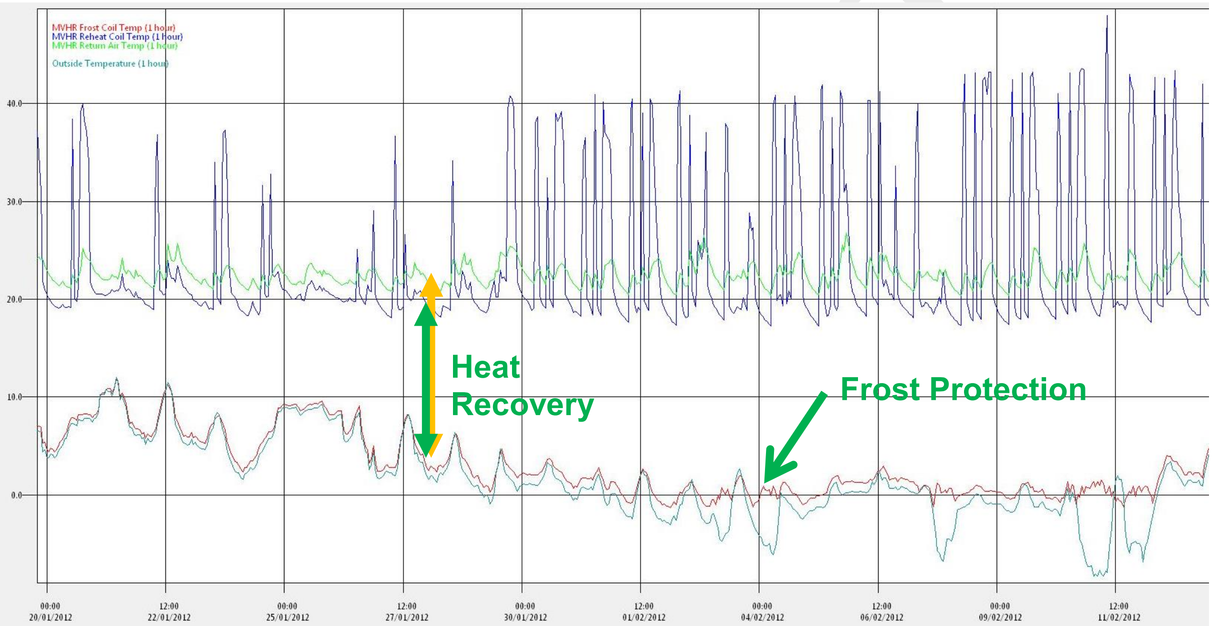

Figure 23: Temperature sensors in an MVHR system during cold weather

This data enables us to make a simple assessment[45] of the heat recovery performance, so long as neither the frost protection nor the reheater is in use. For example from mid-December 2011 to mid-January 2012, an MVHR in a house averaged 86.6% heat recovery.

[45] Based on the increased heat of the incoming air (green arrow), divided by the lost heat of the outgoing air (amber arrow). This presumes that air flows are equal, and ignores the moisture content of the air, and the energy input by the fans.

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A rough calculation on the value of this was carried for feedback to the residents at an open evening in November 2012. Providing an appropriate level of ventilation, without heat recovery, with indoor temperature 10C higher than outside would cost about 80 pence per day to replace the lost heat. With recovery, we only lose about 10p of heat a day, saving 70p. The cost of running the fans is about 14p a day; thus overall ventilating with MVHR costs 24p a day, against 80p without.

8.3.3 Filters

Air quality is maintained, and the MVHR fans are protected, by having filters on the incoming and outgoing airways. Over time these will become blocked, and eventually will need to be replaced. The frequency at which this is needed is dependent upon local conditions. While Wimbish does not suffer from vehicle pollutants in the same manner as city-centre installations, it is prone to dust from agricultural sources, for example at harvest time, and probably to a higher level of insects.

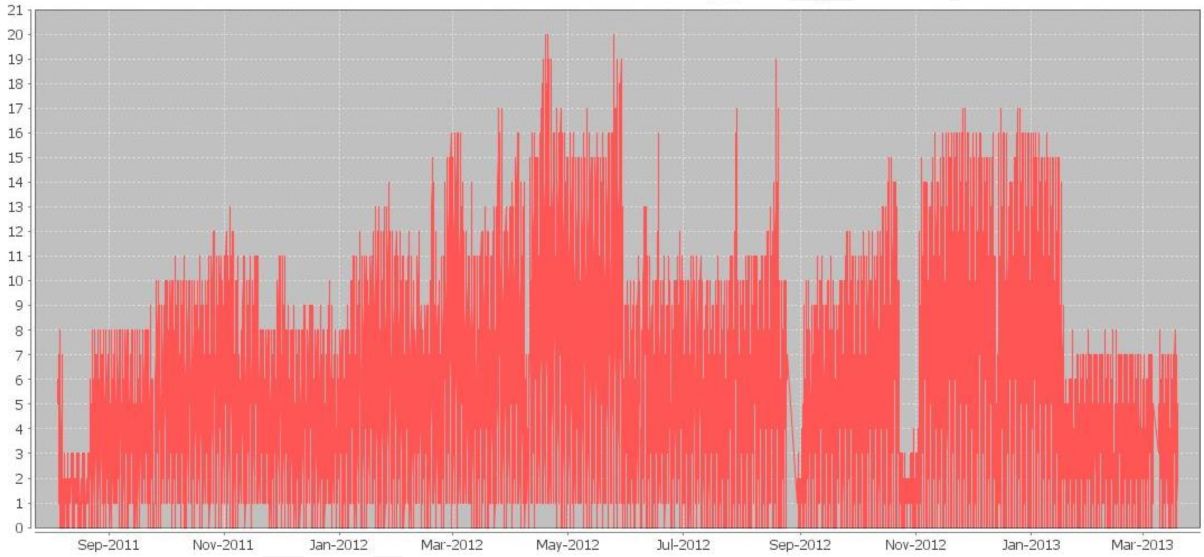

Figure 24: MVHR daily electricity consumption in a house

Monitoring of MVHR fans electricity consumption (see Figure 24 for an example daily log – note that the vertical scale is 'pulses', 20 pulses = 2.0 kWh – roughly 80 watts) provides an indicator of when the filters need to be changed. This was done in May 2012, and January 2013; it probably should have been done a bit sooner, probably every six months.

At Wimbish, the MVHR units are located in small 'plant' rooms, making access to the filters to change them relatively straightforward. For the tenanted properties, Hastoe provide the service, for the shared owners it is their responsibility.

As the filters become more clogged-up the fans work harder in an attempt to maintain the required levels of air flow. They will become increasingly noisy, and ultimately there is a risk of damaging the motors. If not changed, eventually, the fans

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will reach their limits and be unable to maintain the air flow. This is likely to mean that:

- air quality will deteriorate
- the system will be out of balance, reducing the heat recovery effectiveness – more heat is likely to be lost
- low air flows will mean that in Winter the post heater cannot provide as much heat to the dwelling as is needed – this is likely to mean that the house gets cold (especially if the heater is on a timer).

The cost of filters is an impediment to shared owners, as in inertia and simply 'not getting round to it'. Evidence from Wimbish shows how important it is to carry out timely replacement.

8.4. Heat generation and use

A summary of the relative heat contribution from the solar thermal system and from the boiler by month, and where the heat gets used, will be included in the final report.

8.5. Monitoring: Installation and Commissioning

8.5.1 Timing

As with all systems in a Passivhaus, finalising the design early, and minimising any changes during installation, should be practised to avoid any risk of damage to the envelope.

At Wimbish, we recognised that we would need to undertake works before we knew whether the Technology Strategy Board would award the funds necessary for the study to proceed. This was because monitoring was not initially planned, and only became an option following Build with CaRe engagement. Hastoe chose to take the chance and install the necessary wiring at their cost in advance. In an ideal situation, the whole system would have been designed in detail, especially where it interfaced to other M&E systems for electricity sub-metering and the heat flow meters. These meters need to be installed by the M&E sub-contractor into their circuits/plumbing to avoid invalidating their warranty.

In practice, this detailed design could not be undertaken until the Technology Strategy Board contract had been awarded and funds were available for it. This coincided with the contractor installing the M&E kit and inevitably caused complications and delays. For example, it proved difficult to accommodate the box required to house the electricity sub-meters.

8.5.2 Utilities

The Contractor was asked to provide utility meters capable of providing pulsed outputs that could be logged. We should have provided secondary meters to avoid any need to interact with the utility companies.

It has proven time-consuming to obtain the necessary permissions to connect, an issue complicated by the wrong type of electricity meter being installed, occupiers changing suppliers, and the need for permission to replace them.

Half the electricity primary meters have been replaced, unfortunately with meters that log at a low resolution; providing satisfactory secondary meters remains outstanding.

Identifying the reason(s) why minimal useful data is being obtained from the gas meters has proven extremely difficult. This has been compounded by low gas usage, especially in summer months, hence uncertainty whether no data means a fault in the data capture, or simply that gas is not being used. Likely causes of the data shortfall have been exhaustively investigated, but without the detection of a fault. On 28 Feb 2013, it was discovered that a standard 'fly lead' connecting sensor to its cable had been inconsistently connected. Correcting this for all meters is in hand.

To address shortfall in utility meter data frequent manual readings have been taken.

8.5.3 Broadband

It had been intended to install the three monitoring controllers at high level in the M&E plant rooms to minimise cable runs to the plant meters. The BT Broadband connection was to be located nearby. The contractor recommended that the controllers be relocated to the loft space rather than impinge on the already limited space in the plant rooms. This was accepted and the cables re-run before it was discovered that it was too late to move the broadband socket. It was unacceptable to run a CAT5 cable: for aesthetic reasons as it would have been surfaced fixed, and for air-tightness reasons as it would have been another penetration through the barrier. Therefore, a Wi-Fi connection was used.

This has proven reliable in the houses, but not in the flats. This is probably because of the pre-cast concrete floors that were employed in the flats being an impediment to the signal. After ruling out potential interference, a Netgear range extender was purchased to boost the signal. No data was lost, but it was not always available when desired – for example to see live what was happening during adverse weather conditions.

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9. Other Technical Issues

This section will review the underlying issues relating to the performance of the building and its systems. It will assess the root cause of these issues, considering construction and in use/behavioural aspects.

In this release of the interim report, issues are identified in the preceding sections, and discussed there – the text identifies the continuing activities.

The following questions warrant particular attention in the next few months and will be covered in detail in the final report.

- Overheating – the risk that dissipating gains may prove difficult, leading to uncomfortably high temperatures. Findings to date are covered in section 8.1.3.
- MVHR performance
  - was good practice adhered to
    - Design to minimise pressure loss, including flexible versus rigid pipe
    - Insulation and impermeable barrier on supply duct to avoid condensation
    - Value engineering
    - Re-routing to avoid obstacles
    - Ensuring air reaches into the rooms
    - Avoiding 'short-cut' returns/ providing path for returns
    - Commissioning – settings, balancing and process
    - Maintenance
  - In use:
    - Are residents happy
    - Do they understand how to get the best from the system
    - What are the costs of running the system
    - Is the system the best possible for the residents
- Heat performance
  - Solar thermal
    - is it performing as predicted
    - what portion of the demand is it meeting

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- Distribution and storage losses
  - Are these as predicted
- Usage
  - Split between space and water heating
  - Are the users able to control the temperature

- Electrical performance
  - Where is electricity being used & does this match expectations
  - Why does some usage seem quite high
    - Choice of appliances
    - Frequency of use
- Correlations – the interactions of systems and behaviours is important if the dwellings are to function to their best. Analysis so far has predominantly been of single factors; we should compare and contrast the factors to assess the broadest interaction. For example, by matching what is known of user behaviour and attitudes with their electricity and heat consumption, and the ensuing comfort level.

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10. Key Messages

Messages have been noted in the above sections.

This section will be added in the final report.

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11. Wider Lessons

Wider lessons will be reported in the final report.

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Appendices

A. Monitoring Methods

The primary aim of the quantitative monitoring is to determine whether the Wimbish houses are meeting design expectations of providing a comfortable environment with good air quality, while keeping energy usage to a minimum, thereby resulting in low utility bills. The metric for this is to meet the exacting Passivhaus standards.

A secondary aim is to evaluate the performance of the systems installed in properties to deliver air and heat, especially the MVHR.

The design of the monitoring is intended to comply (subject to budgetary constraints) with Technology Strategy Board and Energy Saving Trust Guidance; in particular, with the EST publication "*CE298 Monitoring energy and carbon performance in new homes*"[46].

For all fourteen properties, the following are logged:

- Electricity, gas and water consumption at the utility meter
- Temperature and humidity in the lounge (these are also logged in the main stairwell in the flats)
- Electricity sub-metering for the kitchen consumption, for small power, and for the M&E systems in the plant room.

The outside temperature, humidity and solar radiation are measured at the Sky mast on top of the flats.

Three properties, one in each block consisting of a flat, a three-bedroom house and a two bedroom house, were selected to be monitored in detail. In addition to the sensors listed above, they have:

- Temperature and humidity in additional rooms – kitchen (where separate) and a bedroom
- CO_2 in the lounge and a bedroom
- Electricity sub-metering: rather than log the M&E systems in the plant room as a whole, these are sub-divided into solar, boiler, and MVHR
- Thermal system – heat flows between sources, the cylinder, and uses:
    - Solar thermal to cylinder
    - Gas boiler to cylinder
    - Cylinder to hot water use

46 http://www.energysavingtrust.org.uk/Publications2/Housing-professionals/Monitoring/Monitoring-energy-and-carbon-performance-in-new-homes-2008-edition

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  - Manifold to towel rail
  - Manifold to MVHR battery
- Ventilation – return, incoming (after the pre-heater) and supply (after the post heater) air temperatures.

Data is logged from 272 sensors.

A wired solution was chosen because we were confident in its reliability. The sensors all connect back to a central 'controller', one in each of the three blocks. The equipment was by Trend Control Systems[47] supplied through ECS Power and Control[48].

Data is collected onto a central server running Trend 963 software over a broadband connection[49]. Jaspersoft iReport Designer is used to connect to the underlying MS SQL Server database to produce reports, or data extracts for further analysis in MS Excel.

47 https://www.trendcontrols.com/en-GB/Pages/default.aspx - Trend Controls being commonly employed in Building Management Systems.

48 www.ecs-anglia.co.uk

49 The site is rural and mobile phone reception is unreliable.