Thames Valley Houses

This document contains a Building Performance Evaluation report from the £8 million Building Performance Evaluation research programme funded by the Department of Business Innovation and Skills between 2010 and 2015. The report was originally published by InnovateUK and made available for public use via the building data exchange website hosted by InnovateUK until 2019. This website is now hosting the BPE reports as a research archive. As such, no support or further information on the reports are available from the host. However, further information may be available from the original project evaluator using the link below.

Innovate UK project number	450096
Project author	Low Carbon Building Group, Oxford Brookes University, for Thames Valley Housing Association.
Report date	2014
InnovateUK Evaluator	N/A

No of dwellings	**Location**	**Type**	**Constructed**
2 dwellings	Feltham, Middlesex	House 1: 128 m^2 4-bed, mid-terrace House 2: 146 m^2 5-bed, detached	2012

Area	**Construction form**	**Space heating target**	**Certification level**
128 m^2 and 146 m^2	Timber frame	N/A (has a SAP analysis)	CSH Level 4

Background to evaluation

A two-year in-use BPE study of two social housing dwellings. The social housing scheme of 10 council houses was built to *Code for Sustainable Homes* Level 4, with an average 'as designed' dwelling Target Emission Rate (TER) of 9.01 kgCO_2/m^2 per annum. All dwellings have mechanical ventilation with heat recovery (MVHR) systems with summer bypass mode and thermal sensors. Gas condensing-boilers supply energy for heating and hot water. Electricity is generated by solar PV. The research covered user behaviour in relation to an innovative combination of passive low energy features, the usability and effectiveness of the micro-generation solutions and key control elements and an investigation of the construction costs.

Design energy assessment	**In-use energy assessment**	**Sub-system breakdown**
Yes	Yes	Partial

The envelope consists of external walls with a U-value of 0.21 W/m^{2}K and aluminium windows with double glazing with a U value of 1.6 W/m^{2}K. The envelope was designed to achieve an air permeability of 3 m^3 (m^2.h) @ 50 Pa. In both case study houses, the measured air-permeability values were around 6 m^3 (m^2.h) @ 50 Pa which was double the design target of 3 m^3 (m^2.h) @ 50 Pa, leading to higher ventilation heat losses. Air-leakage pathways identified during the initial walkthrough revealed that design air tightness levels had not been achieved. Mains electricity use in both case study houses was lower than the UK average dwelling, but much higher than the *CSH* level 4 and *Part L* benchmarks.

Occupant survey type	**Survey sample**	**Structured interview**
BUS domestic	8 of 10 (80 % response rate)	Yes

The survey revealed a positive opinion towards the houses, with air quality and comfort being the most appreciated elements. All elements scored high above scale midpoints and above the benchmarks. Respondents felt that the facilities provided meet their needs very well and that the houses were comfortable overall. Temperatures during summer were generally regarded as quite comfortable but less so in winter. Lighting levels appeared to be satisfactory overall. Natural light scored within the benchmark, with the majority of the people finding it adequate (neither too little nor too much).

Contents

1 Introduction and overview

1.1 Scope of the project

The Low Carbon Building Group (LCBG) of Oxford Institute for Sustainable Development (OISD) at Oxford Brookes University in collaboration with Thames Valley Housing Association, has undertaken a two-year building performance evaluation study of two social housing dwellings at Barnlea and Pippin Close during the *in-use* phase, and provide recommendations for future housing design, specification and performance.

The social housing scheme in Barnlea and Pippin Close was designed to demonstrate that affordable housing can be highly energy efficient. It consists of 10 council houses built to Code for Sustainable Homes Level 4, aiming for a low energy performance along with space flexibility and design excellence. A fabric first approach was adopted for all dwellings. All 10 dwellings have a Mechanical Ventilation with Heat Recovery (MVHR) system with summer bypass mode and thermal sensors. Efficient gas condensing boilers supply energy for heating and hot water and electricity is generated by Solar PV. All lighting systems are energy efficient. These houses form the basis for an innovative approach to affordable social housing design, procurement and finance, with large-scale delivery potentials. The dwellings have achieved an average ‘As designed’ Dwelling Emission Rate of 9.01kgCO_2/m²/year and attained a Code for Sustainable Homes Level 4 certification.

The key objectives of the study are to:

- Undertake a comprehensive study of user behaviours in relation to an innovative combination of passive low energy features.
- Concurrently study and compare the *as-designed* and *in-use* performance of two homes with similar architectural design intent.
- Analyse usability and effectiveness of the micro-generation solutions.
- Explore the usability of the housing design and specification in relation to key control elements and comfort levels to ascertain how they might be improved.
- Investigate the impacts of actual costs on user behaviour and construction methods.

The wider benefits of the overall research programme include:

- Supporting a deeper understanding of the performance of very low carbon standards in the affordable housing sector and in general the entire housing sector to enable us meet government’s 2016 zero carbon homes target.
- Helping to unpick the relationships between MVHR systems, modern construction methods and passive low energy measures (e.g. solar gain, natural ventilation).
- Providing valuable insights in terms of the design interfaces of control systems, their usability and how to improve understanding of these through user behaviour studies.
- Improving information giving processes and protocols across the sector through evaluation of the Home Guide in relation to user understanding.
- Providing knowledge transfer through dissemination of case study lessons.

1.2 Project Team

Table 1 Project team

Thames Valley Housing Association (TVHA)	TVHA had overall responsibility of the case study housing development. TVHA as owners, were represented by Tim Preston who was the Project Manager on the case study development. Tim Preston was responsible for overall project management, liaising with householders, evaluators and consultants.
BPTW partnership	BPTW were the project architects. The team provided information on the design decisions, intentions, targets and construction.
Hill Partnership	Hill Partnership was the building contractor for both developments responsible for delivering the scheme and implementing the proposed energy solutions. They were responsible for obtaining the Code for Sustainable Homes pre, design and completion stage assessments for the case study developments.
Low Carbon Building Group (LCBG)	Based at the Oxford Institute for Sustainable Development at Oxford Brookes University, LCBG was the academic subcontractor to TVHA. LCBG undertook testing, survey work, environmental and energy monitoring, analysis and report writing.

1.3 Background to the scheme

The social housing development was completed in March 2012 and is owned by the Thames Valley Housing Association (TVHA). The development is located near Hampton Road, Feltham and frequent bus services connect it to Feltham train station to the North and Richmond to the East.

Two case study dwellings: **Pippin Close** (from now on referred to as House 1) and **Barnlea Close** (from now on referred to as House 2) in the development have been evaluated as part of the BPE study. House 1 is a 128m^2 4-bedroom mid-terrace house and House 2 is a 146m^2 five bed room detached house. Both case studies are occupied by families with young children and have similar occupancy patterns. The dwellings are constructed of timber frame and brick. The envelope consists of external walls with a U-value of 0.21W/m^2K and aluminium windows with double glazing with a U value of 1.6 W/m^2K. The envelope was designed to achieve an air permeability of 3 m^3/h.m^2 @50Pa.

1.4 Summary of findings from the BPE study

- The design and construction audit revealed little deviations from the design. Elevations and plans were executed in line with the architectural drawings with relatively few deviations. However some layout changes were identified in both houses. In House 1 change in use of rooms located on the ground, first and second floors were noted due to family requirements, while in House 2 some changes were made in the storage spaces.

- Air-leakage pathways identified during the initial walkthrough revealed that design air-tightness levels had not been achieved. This was verified by the subsequent air-tightness and smoke pencil tests.

- In both case study houses, the measured air-permeability values were around $6m^3/h.m^2$ which are double the design target of 3 $m^3/(h.m^2)$, leading to higher ventilation heat losses and implying inadequate attention to detail poor workmanship.

- The external walls are well insulated as verified by the in situ U-value tests and thermographic surveys. No significant fabric deterioration was observed. However, thermal bridges across thresholds and ceiling beams, as well as cold spots on ceilings, were identified in the houses. Findings highlight the importance of robust detailing and care to be taken during construction when following a fabric-first approach.

- The design and delivery team aimed to meet the Code for Sustainable Homes Level 4 standards using a fabric first approach, along with mechanical ventilation with heat recovery (MVHR) systems to provide continuous ventilation and solar photovoltaics for generating electricity to achieve the necessary SAP points.

- A key design expectation was to avoid complexity and keep maintenance costs low, which is why the heat system comprised conventional condensing gas boilers and radiators. The MVHR system was considered to be a ‘fit and forget’ system. However, given the high measured air-permeability rates of the case study dwellings, the use of electricity-driven MVHR systems is questionable. In addition due to lack of familiarity of the contractor with installation and commissioning of MVHR systems, they were not commissioned properly, and had unbalanced air flow between supply and extract leading to occupant dis-comfort.

- Commissioning review revealed that installation and commissioning of MVHR system was not up to standard. Additionally poor accessibility to the MVHR unit and controls further hindered maintenance and operation. This was confounded by poor occupant understanding which resulted in system imbalance leading to noise and draughts coming from the system. To address this, occupants in both houses closed the supply terminals thus further unbalancing the system. These findings indicate the interdependency between installation and commissioning of services and systems, with occupant understanding and comfort.

- The evaluation of the handover showed that little of the information provided to the residents during that day was retained by them. Moreover very limited time was allocated to the presentation of the systems and controls, some of which, like the MVHR, were completely new and unfamiliar to the occupants. This has undermined occupant understanding of systems and has resulted in confusion regarding the use and operation of the MVHR system.

- The Home User Guide is well structured and includes useful information. However, discussion with the occupants revealed that they were not eager to read through it as they find it uninviting. The quality of the document could be further improved to make it more visual and easy to read. This can be led by the architect.

- The BUS survey and the occupant interviews revealed that residents are overall satisfied with the houses in terms of space, layout and appearance of the houses, implying that the design quality of the houses has been well-received.

- Occupants are generally satisfied with the room temperatures, quality of heat and system responsiveness and find the heating controls easy to use. Familiarity with heating system and controls has resulted in the occupants feeling they have good control over heating.

- However occupant interviews revealed that occupants in both case study houses are unfamiliar with the purpose and use of the MVHR system and ventilate the houses by opening the windows on a daily basis even when the heating is on leading to energy wastage. This combined with the fact that high measured air permeability of the houses imply that MVHR systems are essentially redundant.

- Moreover occupant habits of keeping the thermostats high (nearly 30^{o}C) and opening the windows while the heating is on has resulted in increased heating loads, thereby widening the discrepancy between the design targets and actual energy use.

- Indoor temperatures in both houses are within comfort levels. Although winter temperatures in House 1 are higher than those recorded in House 2, gas consumption in House 2 was much higher than that of House 1. Investigation revealed that this is due to the House 2 occupants' habit of keeping their windows open for long hours during the day when the heating is on.

- Monitoring data on internal CO_2 levels suggest that the air quality in the houses is within acceptable levels throughout the year as occupants tend to open windows on a daily basis to ventilate the houses. These findings are in accordance with feedback from occupants who also perceive the indoor air quality to be satisfactory.

- Mains electricity use in both case study houses is lower than the UK average dwelling, but much higher than the CSH level 4 and Part L benchmarks. DomEARm analysis showed electricity use per square metre in House 1 is higher than House 2, due to electricity used by appliances most of which are left on or in stand-by mode.

2 About the building: design and construction audit, drawings and SAP calculation review

The social housing development is split into 2 separate sites in Hanworth (Hounslow) comprising of 10 two-storey houses, owned by the Thames Valley Housing Association (TVHA) and built on previously brownfield sites. There are 8 terraced houses in Pippin Close (3 x 4bed, 3 x 3bed and 2 x 2bed houses) and 2 detached 5 bed houses in Barnlea Close. The houses were built over a period of 12 months in one construction phase and completed in March 2012. The development is located near Hampton Road, Feltham and frequent bus services connect it to Feltham train station to the North and Richmond to the East.

The buildings are owned by Thames Valley Housing Association (TVHA), who bought the site from Richmond Borough Council (RBC) which holds the nomination rights over the affordable units. All units are social rented with residents entering into initial Probationary Tenancy for an initial period of 12 months. Assuming the resident completes the period without any breaches, their tenancy agreement becomes an Assured Tenancy.

House 1 is a 128m^2 4-bedroom mid-terrace house and House 2 is a 146m^2 five bed room detached house (Figures 1 and 2). The layout of the houses is similar, with the living areas on the ground floor and sleeping areas on the upper floors. Table 2 presents the background characteristics about the case studies, while Table 3 presents an overview of their design specifications and construction details. Both case studies are occupied by families with young children and have similar occupancy patterns. The houses are occupied 17-19 hours during weekdays, and 24 hours during weekends. The occupancy time in the properties is highly correlated with heating and ventilation interactions and controls. In terms of occupancy and use of space, interviews with occupants have shown that the most occupied area in all properties is the living area whereas bedrooms are mostly used during sleeping hours only.

These dwellings are constructed of timber frame and brick. The envelope consists of external walls with a U-value of 0.21W/m²K and aluminium windows with double glazing with a U value of 1.6 W/m²K. The envelope was designed to achieve an air permeability of 3 m³/h.m^2 @50Pa.

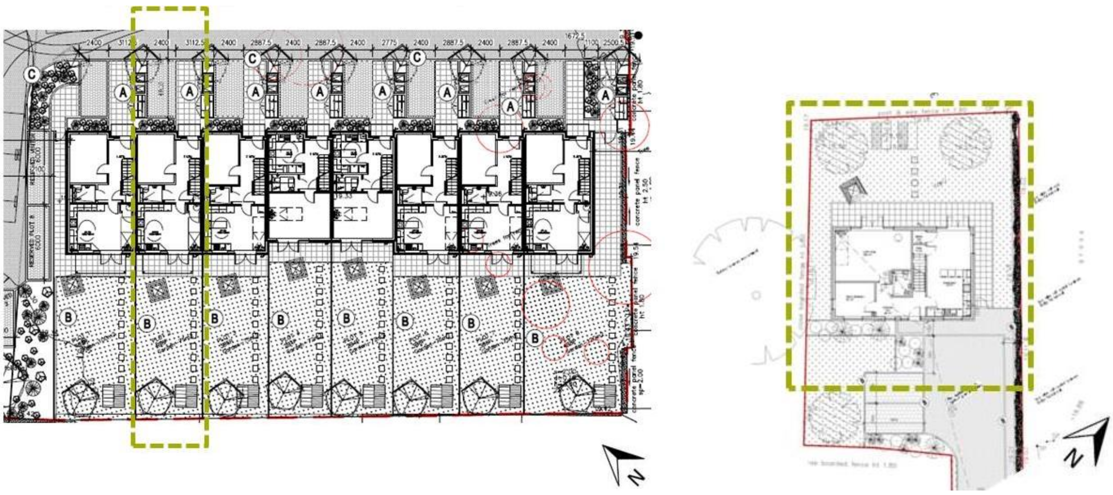


Figure 1 Thames Valley development, plan and elevations. (Left) House 1. (Right) House 2.

Figure 2 (Left) House 1 front elevation (North East). (Right) House 2 front elevation (South East).

Table 2 Case study details

	House 1	House 2
Area m²	128	146
Typology	Four bed Mid-terrace	Five bed Detached
Floors	3	2
Orientation	South	South West
Occupancy patterns	Weekdays: 13:00-8:00 Weekend:24h	Weekdays: 13:00-8:00 Weekend:24h
Occupants	2 adults, 3 children	1 adult, 5 children

Table 3 Construction details and design specifications

Target design rating	CSH Level 4
As-designed SAP Rating	House 1: 90 House 2: 89
Dwelling Emissions Rate (DER)kgCO_2/m^2/yr	House 1: 8.14 House 2: 9.88
Heat Loss Parameter W/K	House 1: 0.87 House 2: 1.32
Main construction elements (as designed) U-values W/m^{2}K	Walls: Timber frame and brick, U-value: 0.21 Roof: Slate roofing, U-value: 0.13 Ground floor: Precast concrete with insulation, U-value: 0.25 Windows: Aluminum frame, double glazing, U-value 1.3
Space heating and hot water system	Efficient gas condensing boilers and radiators
Target air tightness	3 m^3/hm^2 @50Pa

2.1 Building services and energy systems

All dwellings contain Mechanical Ventilation Heat Recovery (MVHR) units for providing background ventilation, and photovoltaic panels to provide electricity. The photovoltaic systems provided are 1.65kWp and 1.8kWp grid connected solar arrays comprising of polycrystalline collectors. The dwellings have also achieved maximum credits for Heat Loss Parameter under the Code for Sustainable homes.

Table 4 Building services and energy systems.

Main heating	Gas condensing boiler and radiators
Heating controls	Time and temperature zone control
Hot water	From primary heating system. Immersion present
Ventilation	MVHR system with summer bypass mode and thermal sensors
Renewables	House 1: Photovoltaics 1.65kWp, SouthWest facing, 30^{o} tilt House 2: Photovoltaics 1.88kWp, SouthEast facing, 30^{o} tilt

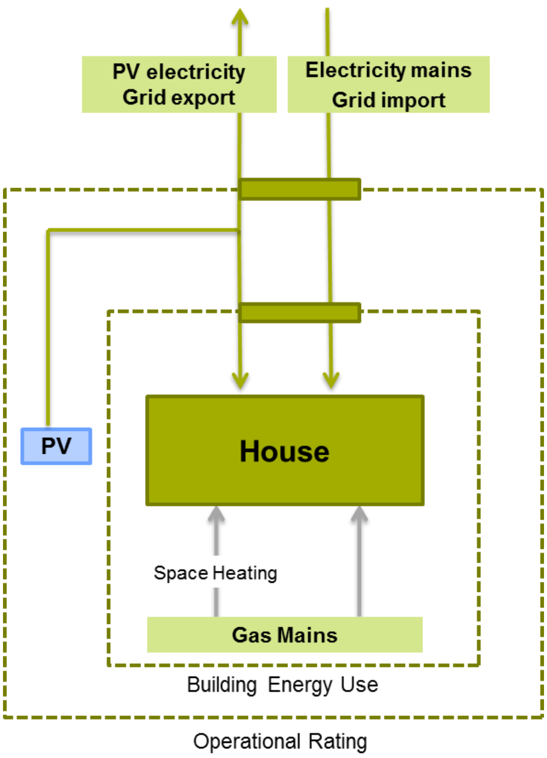


Figure 3 Schematic diagram of the buildings' energy systems.

2.2 Drawings and specifications review

A review of the available drawings and specification documents was undertaken for both case study houses in Feltham. The careful study of the design drawings and specifications in combination with a walkthrough in the dwellings proved to be a valuable experience since it revealed several issues that identify practical arrangements that were implemented during construction and early occupation stage to match the initial design intent of the development and requirements of occupants. The differences were mapped and investigated with the dwelling developers (Section 3) and BPE team in order to establish the reasons for the deviations.

2.2.1 Similarities

- Elevations and plans were found to be executed following the architectural drawings with few deviations as identified below.
- Facilities of both built houses match the specifications held in the O&M manuals which were provided prior to walkthrough.
- Mechanical equipment and pipework are located in intended positions, apart from a minor deviation detected in House 1.

2.2.2 Deviations

<u>House 1</u>

- Several changes of use in ground floor, first floor and second floor spaces were noted (Figure 4) due to family house requirements.
- In particular the living room is located on the ground floor next to the main entrance, whereas the design drawings show it to be on the first floor of the house where the master bedroom is now located.
- Similarly the master bedroom is located in the room previously defined as living room space in the architectural drawings and bedroom 1, which according to plans was located to ground floor, is now located on first floor in the space that was previously defined as Double Bedroom.
- The 2nd floor includes two bedrooms while in the design drawings one bedroom, the loft store and the Hot Water cylinder's space.
- Loft store is now located in the vacant roof space above bedroom 2's ceiling on the second floor.
- The hot water cylinder is located in a store room in the kitchen.
- There is an extra ventilation inlet in the kitchen which is not shown on the MVHR drawings.

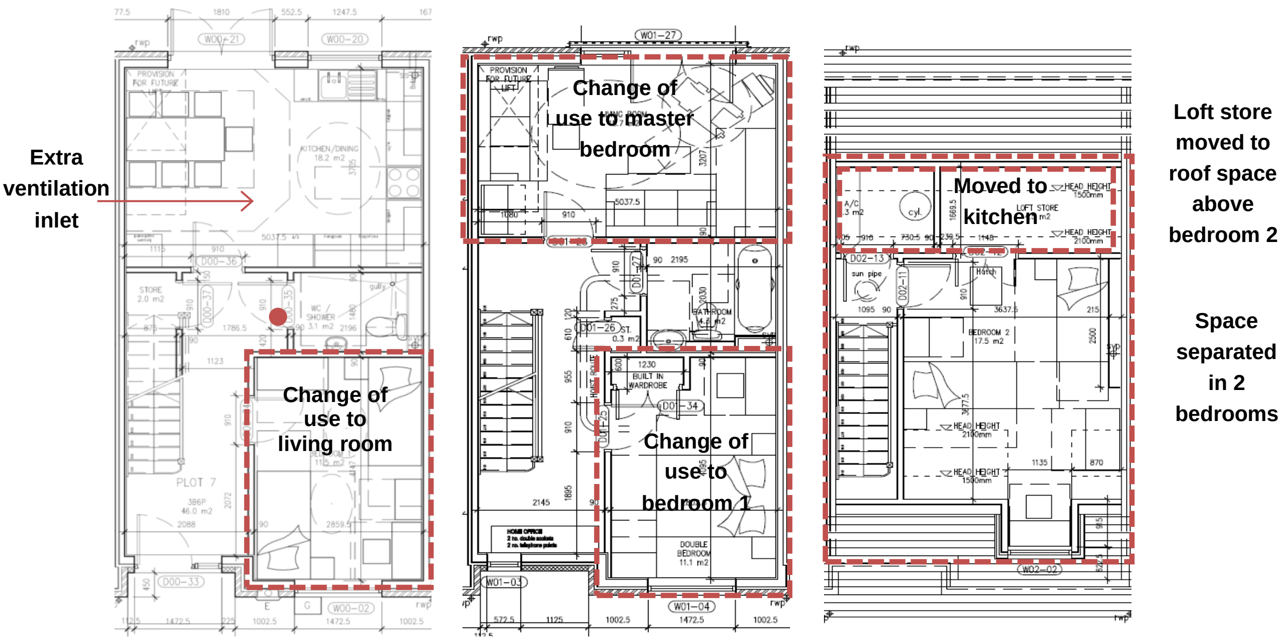


Figure 4 House 1 ground floor, first floor and second floor plans. Spaces where minor deviations were identified are marked in red frames.

House 2

- In contrast to the architectural drawings, the entrance door of the storage space on the ground floor level is located in the kitchen instead of living room.
- The first floor store is separated into two spaces with separate doors (one each), while in the architectural drawings this is shown as one bigger space with double doors (Figure 5).
- Reason for deviations: More convenient access to storage area from the kitchen. In addition two smaller storage spaces might have been considered more practical to allow several occupants to store personal belongings.

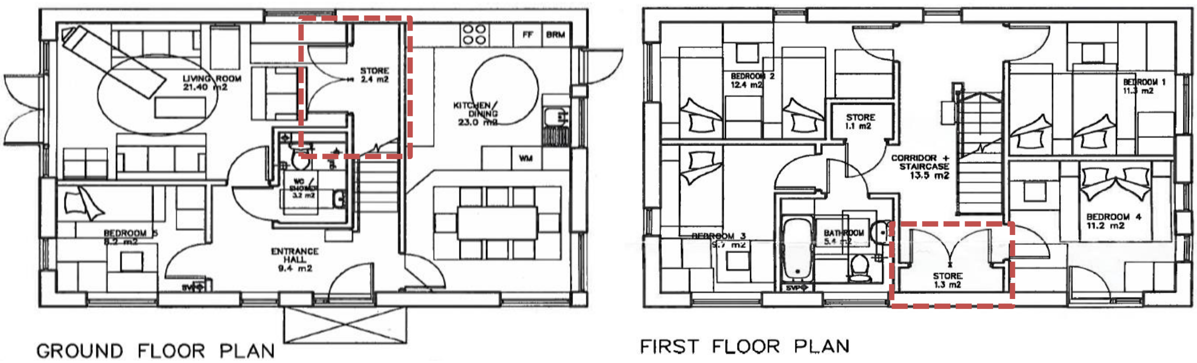


Figure 5 House 2 ground floor and first floor plans. Spaces where minor deviations were identified are marked in red frames.

2.3 Review of SAP calculations

The Standard Assessment Procedure (SAP) is adopted by the Government as the UK methodology for calculating the energy performance and CO_2 emissions of dwellings. The calculation is based on the energy balance taking into account a range of factors that contribute to energy efficiency (BRE, 2009):

- Materials used for construction of the dwelling.
- Thermal insulation of the building fabric.
- Ventilation characteristics of the dwelling and ventilation equipment.
- Efficiency and control of the heating system(s).
- Solar gains through openings of the dwelling.
- The fuel used to provide space and water heating, ventilation and lighting.
- Energy for space cooling (if applicable).
- Renewable energy technologies.

The two case study dwellings were assessed in terms of energy performance through SAP. The SAP calculations took place:

- During design stage in June 2011
- During In-use stage in April 2013 by the BPE evaluators of the project.

The SAP specifications have been matched to provided specification notes, reports, and drawings. The “as built” SAP calculations have been conducted for both case studies using STROMA SAP 2009 software and results have been compared to the “as designed” SAP calculations.

The values in the SAP spreadsheets provided by the project developers (TVHA) and dated in June 2011 were compared to the specifications and available drawings and SAP values obtained by SAP calculations conducted during in-use stage (April 2013) by the BPE team (Table 5). Minor discrepancies were identified in values representing construction elements' net areas (m²), thermal bridges (kJ/m²K) and total fabric heat loss (kJ/m²K). The air permeability values used for SAP calculations in April 2013 were sourced from air pressurisation test average values obtained for both dwellings in spring 2013 by BSRIA (BSRIA, 2013).

Table 5 Deviations between as-designed SAP values and as-built SAP values calcuated as part of the BPE study.

	As-designed SAP		As-built SAP	
	House 1	**House 2**	**House 1**	**House 2**
Thermal Bridges	23.43 kJ/m²K	47.25 kJ/m²K	22.43 kJ/m²K	45.86 kJ/m²K
External Walls Area	39.22m²	130.30 m²	34.23m²	111.6 m²
Party Walls Area	132.71m²	N/A	132.96m²	N/A
Roof Area	55.11m²	71.01m²	46.07m²	73.22m²
Ground Floor Area	45.90m²	71.01m²	46.07m²	73.22m²
Floors Height	2.60m	2.60m	2.40m	2.41m
Fabric Heat Loss	69.59 kJ/m²K	153.65 kJ/m²K	103.94 kJ/m²K	160.97 kJ/m²K
Air permeability value	3 m³/hm² @ 50Pa	3 m³/hm² @ 50Pa	5.87 m³/hm² @ 50Pa	5.97 m³/hm² @ 50Pa
Hot water cylinder volume	52 lt	52 lt	210 lt	250 lt

The "as designed" SAP ratings were found to be higher than the "as built/in-use" SAP calculations (Table 6). Although both dwellings obtained lower SAP rating they still remain in SAP Band B (81-91 SAP points).

Table 6 Discrepancies between provided SAP calculations and recalculated SAP rating by the BPE team.

	As-designed SAP	As-built SAP
House 1	90 (B)	86 (B)
House 2	89 (B)	83 (B)

Finally the estimated annual in-use CO_2 emissions per floor area of both houses as shown in Table 7, have been found to be higher than the estimated carbon emissions during design stage which may be due to different assumed systems efficiency and a large discrepancy in the size of cylinder's volume (52lt in as-designed SAP compared to 210lt for House 1 and 250lt for House 2 in as-built SAP).

Table 7 Discrepancies between estimated CO_2 emissions as calculated in June 2011 and April 2013.

	Estimated CO_2 emissions As-designed	Estimated CO_2 emissions As-built
House 1	8.14 $kgCO_2/m^2year$	15.27 $kgCO_2/m^2year$
House 2	9.88 $kgCO_2/m^2year$	20.84 $kgCO_2/m^2year$

2.4 Conclusions and key findings

- A six point difference in SAP rating was observed between the existing and the revised STROMA rating for House 2 dwelling.
- A four point difference in SAP rating was observed between the existing and the revised STROMA rating for House 1.
- Although both properties achieved lower SAP in-use rating than the one provided during design stage, they have both remained within band B of SAP scale.
- Deviations have mainly been attributed to the discrepancies between values representing the areas of construction elements such as wall, roof and floor areas.
- CO_2 emissions of both dwellings have been calculated to be significantly higher than previous SAP calculations.
- Discrepancies in estimated carbon emissions are due to different sizing of hot water tanks (cylinders) in both houses and assumed heating systems' efficiency.

The following recommendations are made in light of the SAP analysis:

Ensure that 'as-built' SAP assessments are undertaken to capture changes in design and procurement that could affect the energy performance of the dwelling. For instance, this could capture the differences identified in the sizing of sizing of hot water tanks (cylinders) in both houses and assumed heating systems' efficiency.

3 Fabric testing (methodology approach)

The fabric performance of the case study dwellings was tested using diagnostic field tests which include: **air permeability test**, **in situ U-value test** and **infrared thermography**. Air permeability tests help establish the air permeability and the heat loss due to air infiltration and exfiltration through the building fabric alone. In-situ U-value tests measure the heat loss of construction elements by means of heat flux sensors that provide a direct measure of flux from a surface into and through a construction element. They can be used to determine the actual u-value of individual constriction elements. Infra-red thermography provides an infra-red image which gives an indication of surface temperatures and can enable thermal anomalies (air leakage, thermal bridges, missing insulation) in construction to be identified, which can affect indoor environmental conditions.

3.1 Air tightness test

An important parameter of the heat loss in a dwelling is the air exchange rate through the building envelope. A part of this rate is necessary in order to provide adequate ventilation, however, the amount of the incoming fresh air should be controlled by a well-designed ventilation system. In some cases this air movement is uncontrolled and additional to the designed ventilation causing an unnecessary increase to the total heat loss.

To quantify the air-leakage rate through the building envelope two standard air leakage tests were carried out during depressurisation and pressurisation (at 50 Pa) (Appendix 12.1).

Two surveys were undertaken, one at the beginning of the study (February 2013) and one towards the end of the study (August 2014) to establish any changes to fabric performance during the study period. The surveys were undertaken whilst the properties were occupied. The testing kit was placed on the main door of each dwelling. During testing the internal doors were open, the windows were closed and the ventilation terminals were sealed.

The measured average air-permeability rate of both dwellings when tested using the method contained in ATTMA standard TS1 failed to meet the initial design criteria of $3m^3/(h.m^2)$ and was found to be around 6 $m^3/h.m^2$ for both houses. However, they were both significantly less than the national building standard of 10 $m^3/(h.m^2)$ (Table 8)(Figure 6). The gap between designed and actual air tightness in the houses is one of the key parameters leading to the discrepancy between the 'as designed' and 'as built' SAP discussed in the previous chapter.

Table 8 Air permeability measurements

Air-permeability values $m^3/(h.m^2)$ @ 50Pa	House 1	House 2
Design air permeability	3	3
Test 1 - Average measured air permeability	**5.86**	**5.97**
Test 2 - Average measured air permeability	**6.00**	**6.17**
Energy Saving Trust for CSH Level 5	3.00	3.00
UK Building Regulation Best practice	5.00	5.00
UK Building Regulation Good practice	10.00	10.00

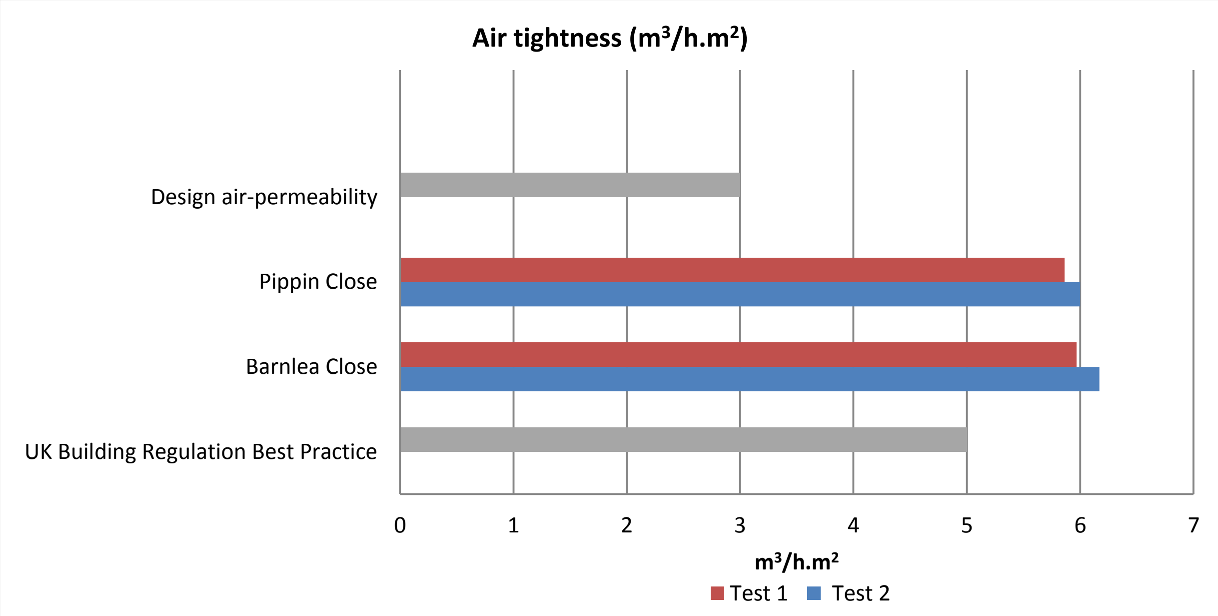


Figure 6 Comparison of target and measured air permeability rates

Comparison between the two tests reveals that the air-tightness levels of both houses have slightly fallen during the monitoring period. This is likely to be a result of fabric deterioration and appears to be quite a common phenomenon.

A fan pressurisation test is a useful quantity assessment indicator of air leakage in a building although it does not directly identify its location. In order to attain an overall image of air leakage paths in the building envelope it can be combined with visualization methods such as **smoke visualization**.

The smoke pencil tests revealed several air leakage paths, for both houses around:

- Windows/doors frames
- Window hinges
- Patio doors
- Ceiling roses
- Electrical outlets
- Bathrooms: Bath panel, wc boxing, light fitting and pull switch, saver point.

These findings indicate that the detailing and workmanship during construction did not comply with the necessary standards to achieve the design air-tightness specification standards. Better air tightness would have resulted from a higher quality of detailing and careful implementation at key junctions, skirtings and service penetrations, and detailed care around door and window thresholds and seals.

Furthermore, air-tightness tests show that the houses have an air-permeability higher than 5 $m^3/h.m^2$, thus questioning the need for always-on MVHR systems. Higher heat loss through the fabric not only results in higher heating demand but also leads to higher electricity use by the MVHR system.

3.2 In situ U-value measurement

The U-values were determined by placement of Hukseflux HFP01 sensors on north facing walls using the “Average method” detailed in ISO 9869:1994, Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance (Appendix 12.2). For calculation purposes internal/external air temperatures were recorded within the dwelling adjacent to the sensors and outside adjacent to the corresponding wall space. Measurements were recorded over a two week period whilst the properties were occupied. The data reported are from the final seven days of measurement, with the first seven days data excluded to allow for stabilisation of the instrumentation.

Heat flux measurements were taken at 1 minute logging intervals. The Hukseflux sensors were positioned on the construction elements using custom built sprung clamps that allowed free flow of air around the sensor (Figure 7). A proprietary thermal compound was used to ensure good thermal contact.

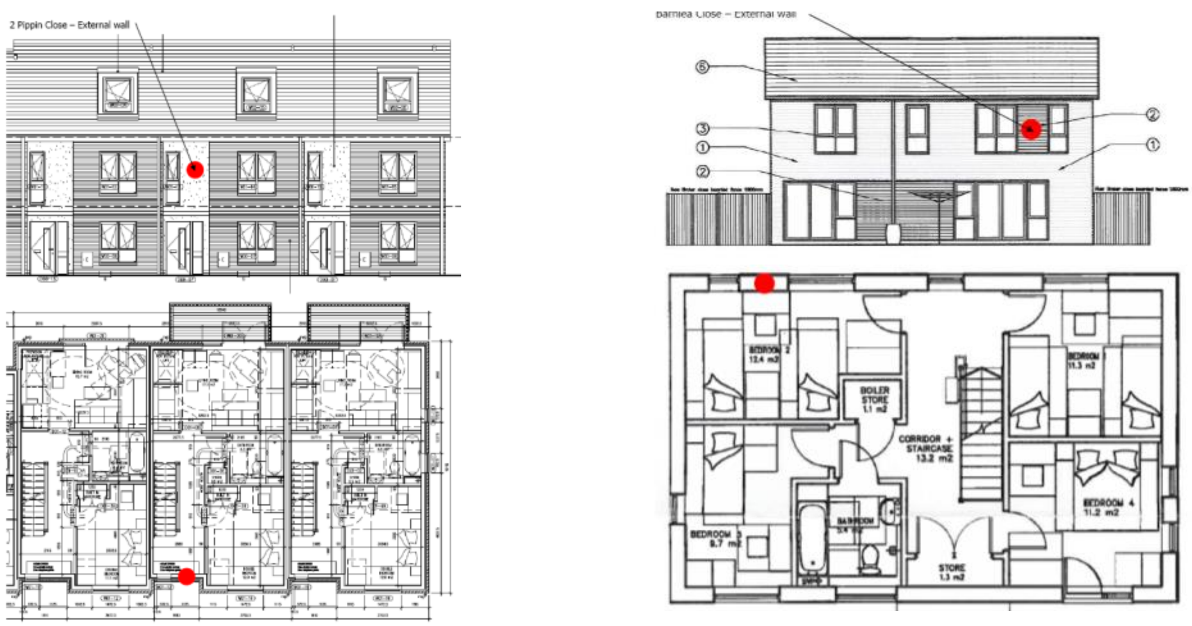


Figure 7 Location of heat flux meters in House 1 (Left) and House 2 (Right)

The in situ measurements of the wall U-values showed values lower than those intended at the design stage (Table 9). This indicates that the walls are well-insulated and that design aspirations were met. The findings suggest that familiarity of the construction team with the materials and wall construction can lead to good results making the fabric-first approach more reliable.

Table 9 Comparison of design U-values and in situ U-value measurements

Wall detail	**House 1** NorthEast facing external wall	**House 2** North facing external wall
Design specification wall U-Value W/(m^{2}K)	0.21	0.21
Measured final averaged wall U-Value W/(m^{2}K)	**0.18**	**0.14**

3.3 Thermographic survey

A series of thermograms[1] were taken of the various elevations of the buildings and for the purposes of this survey, images were primarily taken of the external walls and internal surface that exhibited any thermal anomalies. Two surveys were undertaken during two different winter seasons to establish any potential fabric deterioration. The first survey was undertaken in March 2013 and the second one in February 2014. The environmental conditions and building fabric properties were entered into the thermal imaging reporting software and the relevant corrections were made. The surveys were undertaken late afternoon. Findings in both surveys were similar and no significant deterioration of the envelope was observed.

The thermograms of this report show a number of thermal anomalies, and more detail is supplied against each image; including spot and area temperatures (minimum and maximum). In general terms these anomalies were considered to be as a result of the build process and further investigation of the areas identified is recommended.

3.3.1 House 1

No significant thermal anomalies were observed on the external walls (Figure 8). This is in accordance with the findings of the in situ U-value tests. However, several cold spots and thermal bridges were identified on the top floor ceiling and across thresholds, as a result of floor and ceiling detailing. Lack of drawings specifically showing the light tube detail as well as poorly fitted loft insulation have resulted in the cold spots shown in Figures 10 and 11. The steel beams of the roof construction were not fully insulated, as shown in Figure 12, thus creating the thermal bridge identified in Figure 11 and other areas of the house. The lower temperatures in the bedroom walls, shown in Figure 13, result from air movement in the unheated space behind the wall shown in Figure 14.

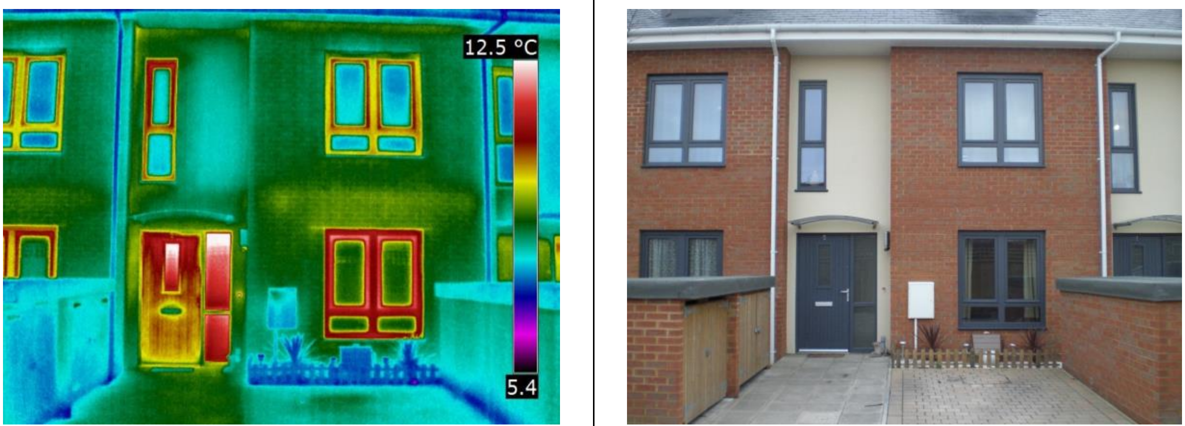


Figure 8 (Left) Front elevation thermogram. Note: There are no significant thermal abnormalities evident in the walls due to thermal bridging, but there are signs of a temperature difference above the lower lounge windows which stops at the next floor level. The elevated temperature of the window surrounds and the front door are likely to be due to the change in material and are unlikely to be indicative of heat transfer anomalies. (Right) Front elevation digital photograph.

[1] The details contained in this report are in accordance with the simplified testing requirements of BS EN 13187:1998 Thermal Performance of Buildings – Qualitative detection of thermal irregularities in building envelopes – Infrared method (ISO 6781:1983 modified). In accordance with the TSB requirements all thermographic images are in the full colour rainbow-hi pallet, and the work was undertaken whilst the properties were occupied.

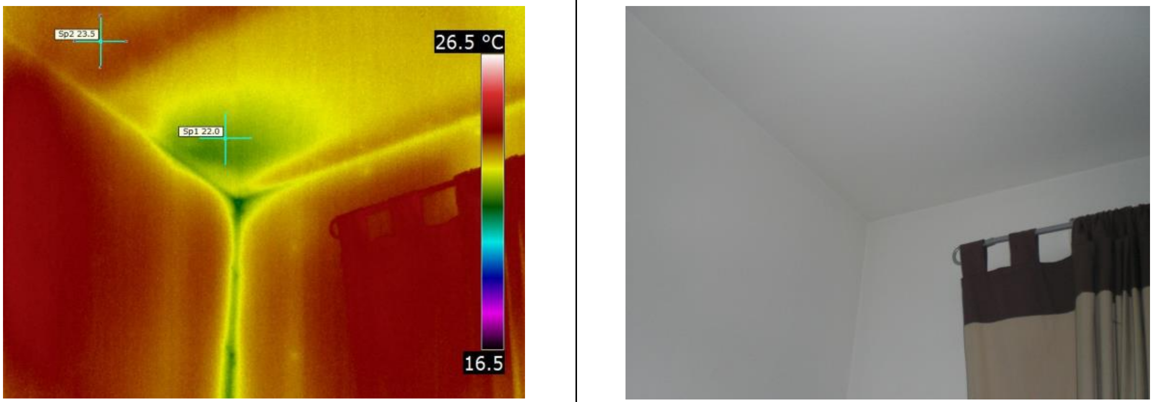


Figure 9 (Left) Living room left window thermogram. Note: Area of reduced temperature on ceiling is likely to be due to external air infiltration into the structure and possibly related to area of temperature difference identified in Figure 8. (Right) Living room left window digital photograph.

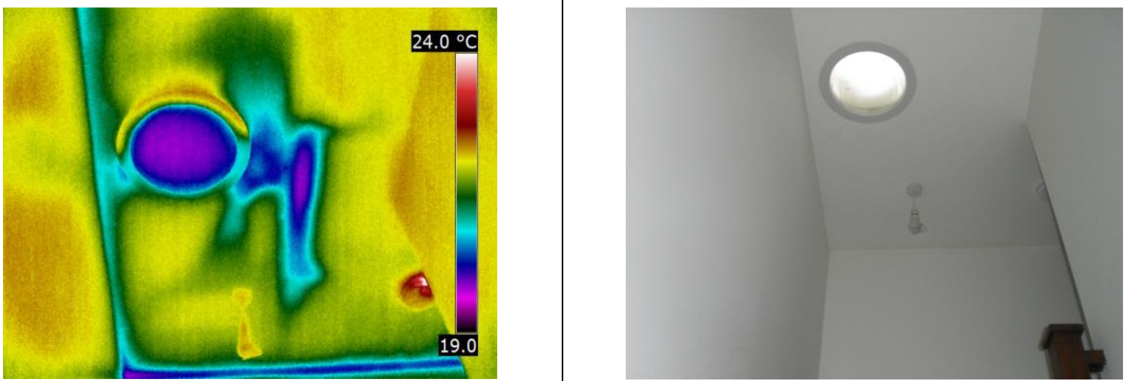


Figure 10 (Left) Top floor landing light tube thermograph. Note: Area of reduced temperature to right of light tube is likely to be due to poor insulation in the roof space. (Right) Top floor landing light tube digital photograph.

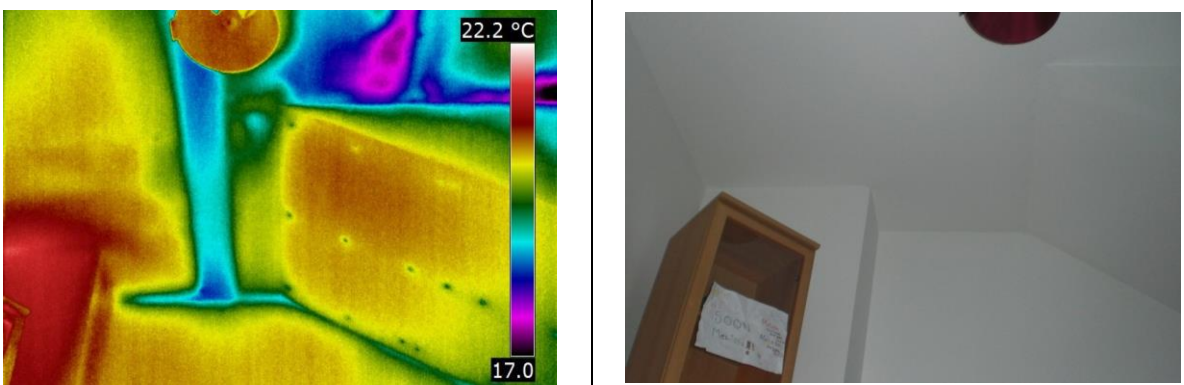


Figure 11 (Left) Top floor front bedroom ceiling thermogram. Note: The vertical area of reduced temperature is typical of a steel beam in the roof structure that has not been insulated. Similar findings also identified in other areas. The area of reduced temperature to right of light fitting is likely to be due to poor insulation in the roof construction. (Right) Top floor front bedroom ceiling digital photograph.

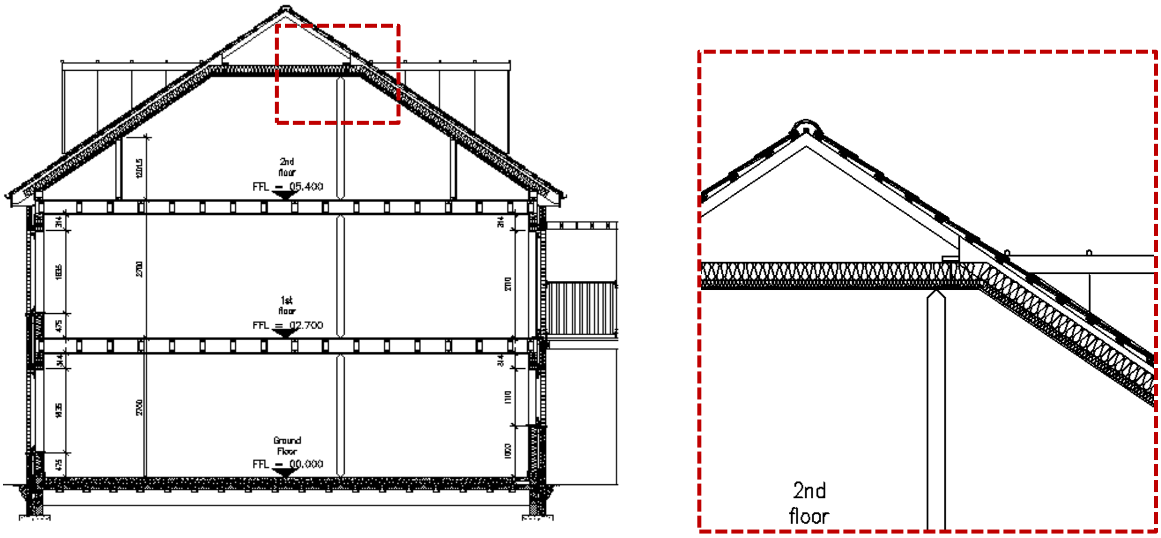


Figure 12 Section and roof detail showing that the top of the steel beam in the roof structure is not insulated creating the thermal bridge shown in Figure 11.

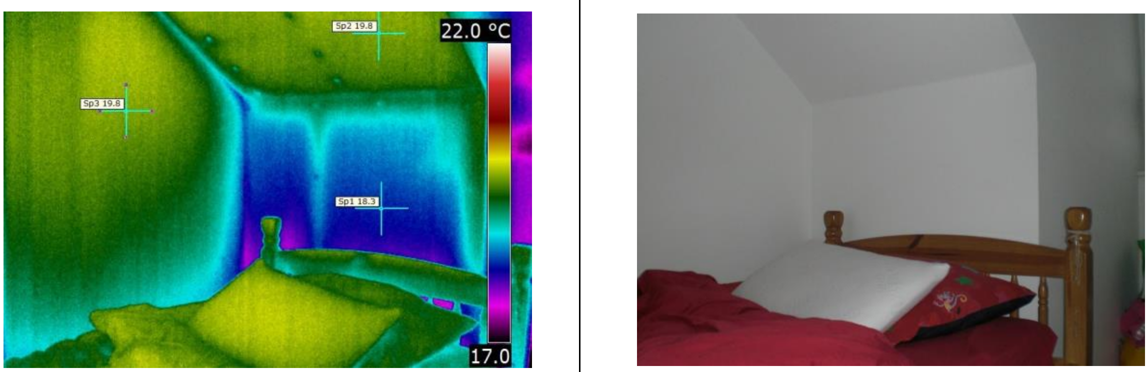


Figure 13 (Left) Top floor front bedroom wall thermogram. Note: Area of reduced temperature behind bed is likely to be due to poor fitting of insulation within the wall / ceiling construction. A similar finding was also identified in other top floor walls. (Right)Top floor front bedroom wall digital photograph.

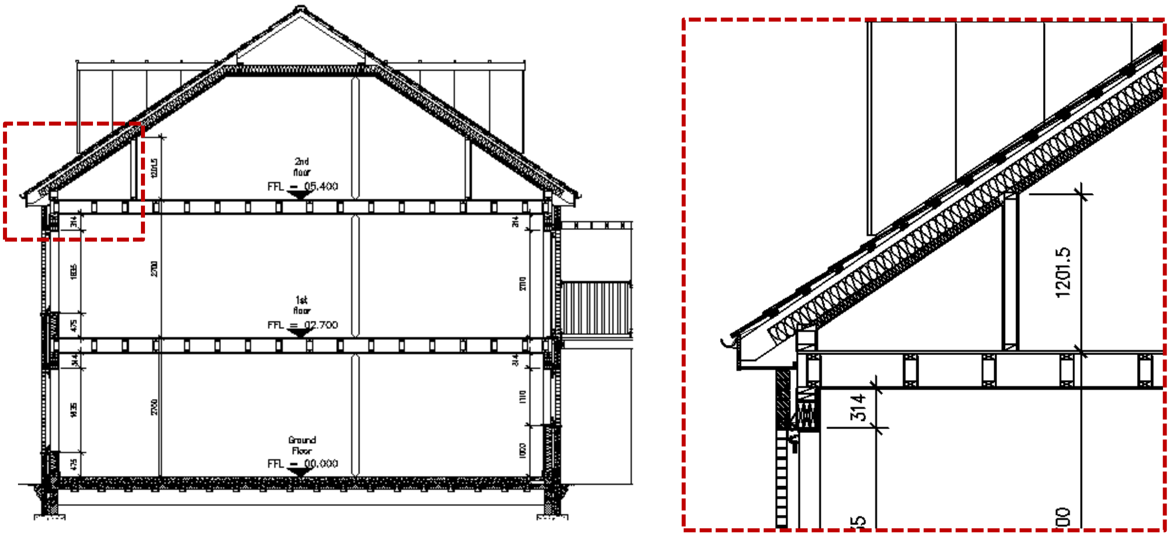


Figure 14 Section and wall detail showing unheated space behind bedroom wall.

3.3.2 House 2

No thermal anomalies were evident on the external walls (Figure 15). However, as in House 1, thermal bridges and cold spots were identified across thresholds and top floor ceilings (Figures 16-19). These issues are mainly related to the design of floor and wall details. As shown in Figure 16, thresholds have not been designed with a thermal barrier thus forming a thermal bridge. Additionally, roof insulation detailing is not considered robust (Figure 19), resulting to the insulation not being well fitted around the edges and creating the cold spots shown in Figure 18.

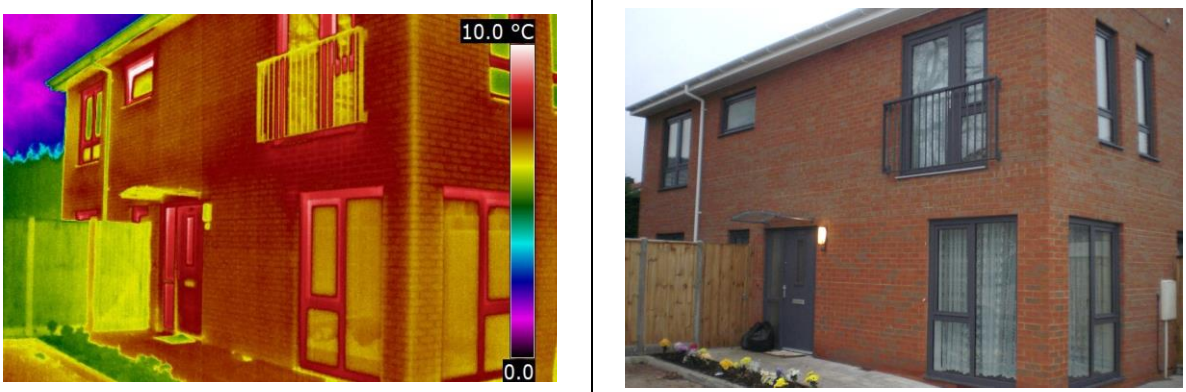


Figure 15 (Left) Front elevation thermogram. Note: No thermal abnormalities are evident in the walls. The elevated temperatures of the window surrounds and the front door is likely to be due to the change in material, whilst the elevated temperatures in the upper centre bathroom window could either be due to poor fitting or simply that the window has been left open. (Right) Front elevation digital photograph.

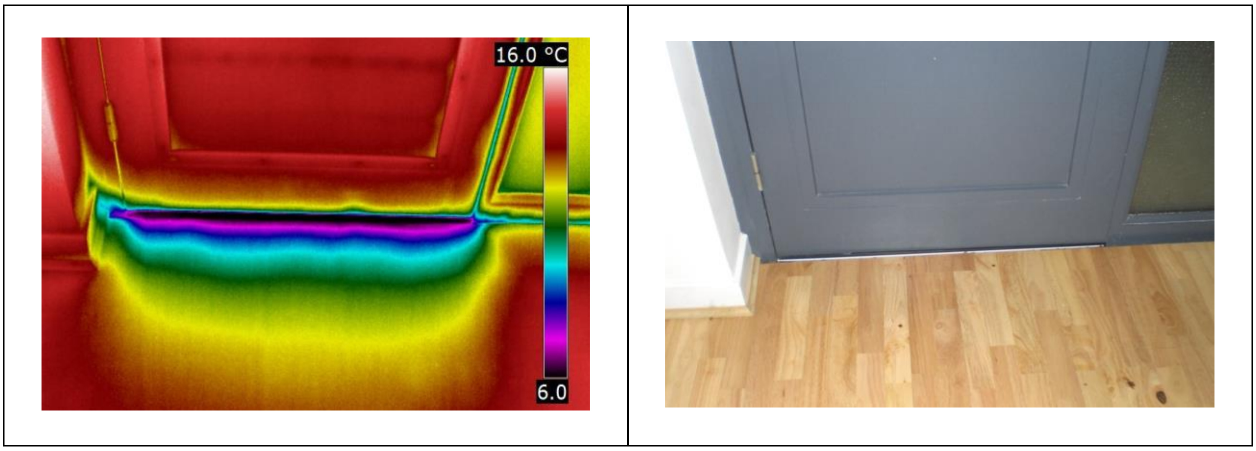


Figure 16 (Left)Front door threshold thermogram. Note: Reduced temperatures due to air ingress beneath door. At the time of the visit all the supply air inlet terminals within the dwelling on the MVHR system were closed, and all the extracts in the kitchen / bathrooms were open. This resulted in the property being depressurized in relation to the external environment and excessive levels of unheated external air entering the property through the opening. (Right) Front door threshold digital photograph.

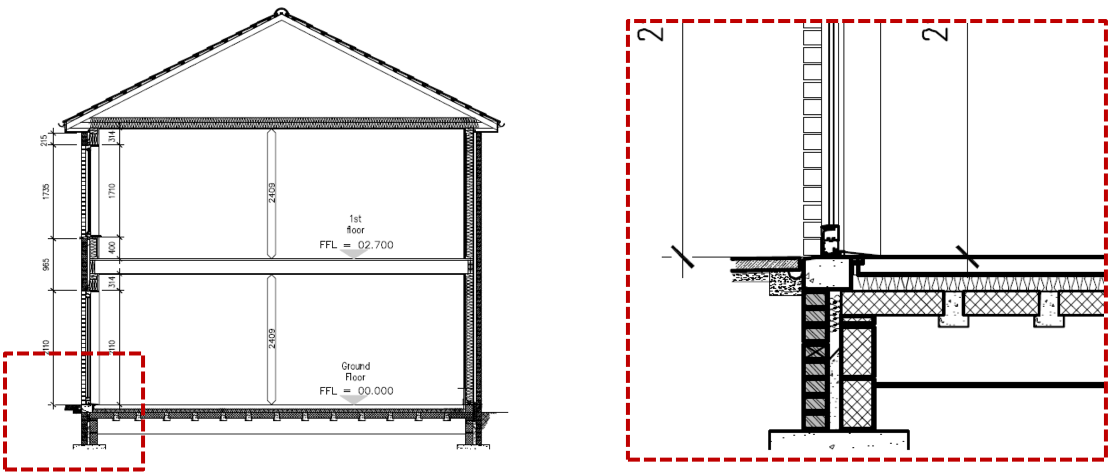


Figure 17 Section and floor detail. Door and window thresholds are not insulated and section shows no thermal barrier resulting in cold bridges as shown in Figure 16. It is recommended that threshold details are reconsidered for future developments.

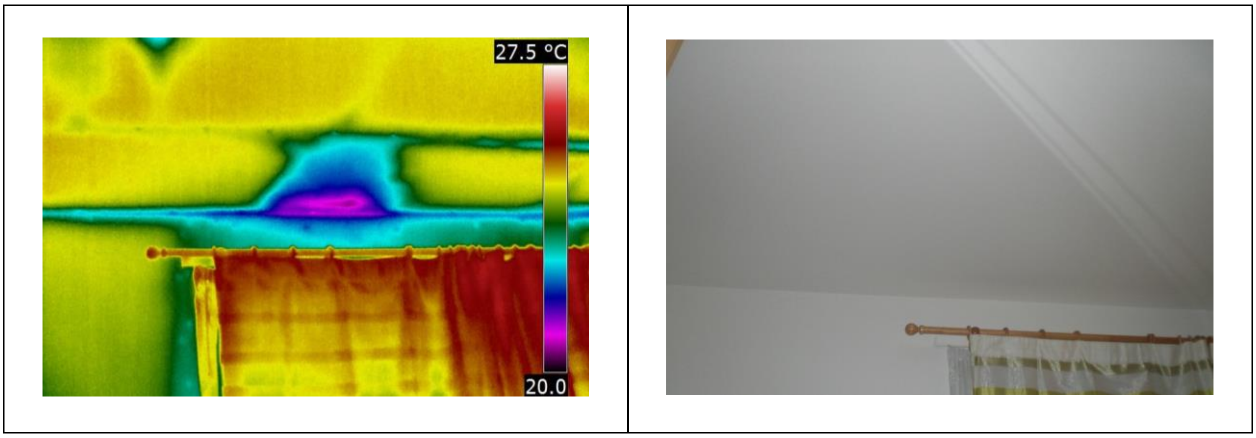


Figure 18 (Right)Bedroom 2 ceiling thermogram. Note: The area of reduced temperature on the ceiling is probably due to poorly fitted or missing loft insulation. Similar findings were also evident in bedrooms 3 and 4 around the external wall perimeter. (Left) No.2 front upper (east) digital photograph.

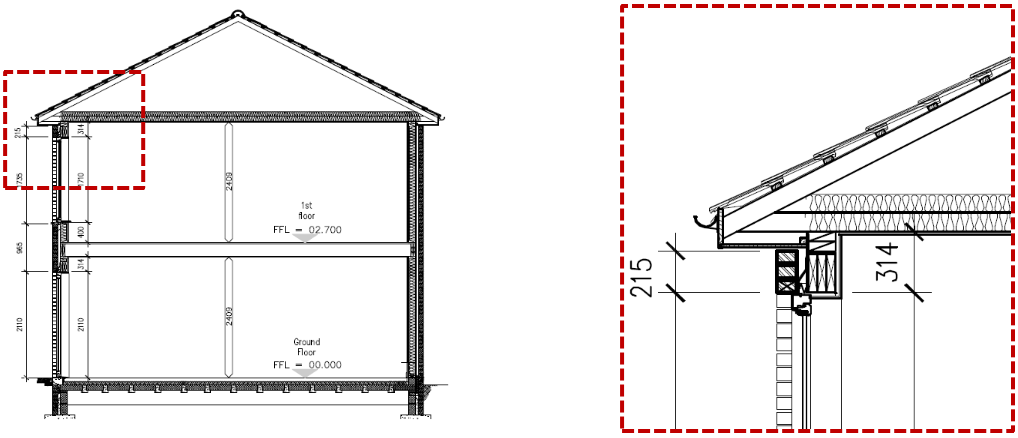


Figure 19 Section and wall-ceiling detail. Poorly fitted insulation at the corner of the roof possibly resulted in the cold spot identified in Figure 15. More robust detailing is recommended for future developments.

3.4 Conclusions and key findings

- The air tightness tests performed showed that the houses did not meet the design air permeability target. In both cases, the measured air-permeability values were around 6 $m^3/h.m^2$, double the design target of 3 $m^3/h.m^2$, indicating heat losses due to air leakage paths and also questioning the need for having always-on MVHR systems which are usually installed in houses with air permeability rates less than 3 $m^3/h.m^2$.
- Several air-leakage paths were identified across both houses, indicating that the detailing and workmanship during construction was not up to standard to achieve the design air-permeability targets. It is recommended that both the designers and the developers familiarise themselves with robust/accredited construction details to achieve such low air-tightness levels.
- The gap between designed and actual air tightness in the houses is one of the key parameters leading to the discrepancy between the ‘as designed’ and ‘as built’ SAP. In addition to increasing heating demand, higher heat loss through the fabric also leads to higher electricity use of the MVHR system.
- No significant fabric deterioration was observed. This was confirmed by both air permeability tests at the beginning and end of the study, and the thermographic surveys undertaken during two different heating seasons.
- The external walls are well insulated as confirmed by in-situ measurements of the wall U-values that showed values lower than those intended at the design stage (0.21 W/m^2K) and the thermographic survey that did not show any thermal anomalies in the external walls.
- Thermal bridges across thresholds and ceiling beams as well as cold spots on ceilings identified in the houses are a result of poor detailing and workmanship. Images showed thermal bridging across the threshold of the front and back doors in both houses. Thermal bridges due to ceiling beams in top floors that have not been insulated were also highlighted. Additionally, areas of reduced temperature on top floor ceilings are likely to be due to poorly fitted insulation within the wall / roof construction. More robust floor and roof detailing is recommended in order to avoid similar issues in future developments.

4 Key findings from the design and delivery team walkthrough

4.1 Design and delivery team interview and walkthrough

Both the designer and developer were interviewed in order to gain good understanding of the design intent and explore the degree to which the design intent was followed through in terms of delivery and adoption by the occupants. The interview and walkthrough with the developer was conducted on 17th April 2013. The interviewee was the head of project delivery at Thames Valley Housing Association. The interview with the designer of BBTW partnership was conducted over the telephone on 19th April 2013. The same set of questions were asked of both interviewees.

4.1.1 Design intentions and comparison with the built outcome

The main intention of both parties was to create high performing social housing that would meet CSH Level 4 standards. The developer's intention was to regenerate sites that were of no particular use and to provide a high standard family accommodation. The architect's intention was to provide generous and well-designed housing that would satisfy the requirements of the client (TVHA) and respond to the particular site. Both parties are satisfied with the design product and would be happy to use the same design strategy in future projects. Both the designer and developer are pleased with the space planning, public space, appearance, space quality, flexibility and size of the properties. The developer has also received positive feedback from the occupants.

While the design specifications have met the CSH Level 4 standards, the built outcome succeeded in providing the occupants with high quality accommodation. The buildings were well integrated within their surroundings and interviews with the occupants revealed that they are satisfied with their homes (See Section 6).

4.1.2 Strategies to achieve design intentions

In order to achieve the design intentions a fabric first approach was followed. The developer was aiming to limit the construction complications as much as possible in order to ensure that the homes would be easy to use. To achieve this, the technologies used in the house were tested in order to ensure that the systems chosen for the scheme were simple and effective. Evaluation of the fabric performance (Section 3) as well as the usability of systems and controls (Section 9) revealed that both these strategies were only partly successful. The low design air-tightness targets and the use of an MVHR system proved to be more complicated than expected as the developers were not so well familiar with them.

Regarding the design and layout, the designers started with analysing the sites, their orientation and accessibility and then followed an inside out approach in order to develop the layout. Occupants have expressed satisfaction with the layout, space, appearance and outdoor space of the houses.

4.1.3 Learning from past projects

The developer knew from past experience that in order to achieve CSH Level 4 low carbon technologies would have to be incorporated in the design in conjunction with the fabric first approach. However, they were not well familiar with the MVHR system which has resulted in a series of commissioning and operation issues (Sections 7 and 9) that have undermined the reliability of the system. The designers were not well familiar with the CSH Level 4 standards which resulted in some applications not being approved during the application stage. They then revised the options based on feedback from the previous applications in order for the development to meet standards of internal spaces and environmental criteria of CSH Level 4.

4.1.4 Design intentions related to sustainability and costs

Cost appraisal methods were used during the design process of the scheme and costing was decided through the collaboration of both parties. A fabric first approach was promoted by both parties as it was considered a 'fit and forget' option. In order to achieve compliance with CSH Level 4 different low-carbon systems were taken into consideration (GSHP, ASHP, PV). The developer's aim of reducing long term maintenance cost whilst achieving code compliance was pivotal in the selection of the heating system (gas boilers with radiators) and the decision to incorporate photovoltaic panels. MVHR systems were also used to achieve code compliance and were considered a low maintenance system. The maintenance cost of technology was the key in decision-making for both parties as TVHA intended to invest within the scheme's budget to meet CSH requirements.

4.1.5 Aspects that should be done differently

Both parties agree that the fabric first approach is successful but that it could be further enhanced. The need for better detailing and care during construction was highlighted by the air-tightness testing and thermographic surveys. The designer believes that the external appearance could also be further improved but finds the materials used suitable for the particular residential area.

The developer reported that energy and sustainability consultants were not involved from the beginning of the design process and feels their contribution would have been useful in order to allow for adequate space provisions for smart metering and other monitoring devices. Another aspect that the developer would reconsider is the use of MVHR system. The study has revealed that lack of familiarity of both the developers and the occupants with the system has resulted in poor commissioning and operation. The developer reported that the systems were considered to achieve CSH compliance and that they would have avoided them if the design target could be achieved without it. The developer also believes that the tenants' familiarisation with the technologies would have to be improved and is looking for ways to improve handover and occupant training in future projects. Lack of occupant understanding of the MVHR system was highlighted during the interviews with the occupants of the case study houses (Section 6).

4.1.6 Comfort and control

The developer is satisfied with the heating strategy but has some reservations regarding the ventilation strategy and expressed concerns that the quality of installation and commissioning of MVHR systems in the UK is not up to standard. Provision of usable and accessible controls for the MVHR system was also found to be problematic (Section 9). Poor occupant understanding of the system in addition to poor commissioning has led to system imbalances that affect the energy use of the houses (Section 7).

On the other hand, the lighting strategy is considered successful. Feedback from occupants reveals they have been very satisfied with the daylighting approach used to provide circulation spaces with natural lighting.

4.1.7 Operation and usage patterns

As reported by the developer, the operation of systems and controls was not prioritised compared to other topics during handover undermining occupant understanding in some cases (Section 5). The developer is looking for ways to improve the familiarisation of occupants with controls. Especially in the case of the MVHR system, the developer would re-consider its implementation due to the lack of clear information and industry guidance on how to operate it properly.

Additionally, the developer believes that high occupant expectations raise actual energy use and have a negative effect on the performance of the houses. Findings from the energy monitoring show the effect of occupant behaviour on the energy use of the houses. The study however has revealed that occupant behaviour is a result of occupant expectations, understanding and ease of use which are in turn directly related to handover, guidance, controls and commissioning of systems.

4.1.8 Maintenance

There was a one year's defect period alongside an extension in terms of the built contract. During the second year the sub-contractors could be contacted either by the occupants directly or through TVHA for any defects arising. TVHA has a 24h access line and a logging system indicates what defects have occurred within the contractor timescales.

The developer stated that no major maintenance, reliability or breakdown issues have been reported. However, the BPE study has helped reveal problems in the operation and performance of the MVHR systems in both the case study houses (Section 7).

4.1.9 Communication and learning

Both parties agree that there was good level of communication and collaboration achieved between the different members of project team (designers, constructors and developer). A 'keep it simple' approach was advocated from the beginning of the design process; with developers aiming to ensure the homes would meet the needs of the people without being experimental. The architect, however, appears sceptical of the way the building process responds to the checklist way of achieving target and the procurement process.

Regarding learning, the fabric first approach and the photovoltaic panels are two strategies that were considered successful and would be used again. Both parties also point out the importance of enhancing familiarisation and education of occupants on low carbon technologies and controls in houses in order to achieve good environmental performance in reality.

4.2 Documentation available to the developers

Documentation available to the developers (TVHA) as part of the houses handover process was reviewed as part of the BPE study. The documentation includes:

- O&M manuals (plumbing and heating systems only)
- Both properties were accompanied by an O&M manual specific to each development containing operational instructions, information and specifications of building systems and other installed items
- O&M manuals for each property includes:
    - Easy User Guides
    - Operational Instructions
    - Location of Valves and Equipment

- Manufacturers User Guides
- Specification of Sanitaryware
- Specification of heating units
- Specification of Plumping units
- Sanitaryware Care recommendations
- O&M manual for Solar PV systems
- Specification and Warranty of PV system

The O&M manuals have a good contents list overall but key information appears to be missing:

- No commissioning data are available in handover documentation available to the developer.
- Not all features of the properties were discussed in detail. Information on plumbing and heating systems and fittings is included but information on MVHR and ventilation strategy is missing.
- No explanation of PV system or capacity specific to each property; general product information sheet was only available to the developer together with system's warranty.
- Information on energy saving light bulbs, energy saving measures and responsible purchasing is also not provided.

In addition, the presentation and format of the O&M manuals could also be improved. Scattered black and white schematics accompany the text in sections with operational instructions and location of valves and equipment, but are not explained properly.

4.3 Conclusions and key findings

- The main design intention of the developer and designer was to create high performing social housing that would meet CSH Level 4. Both parties were satisfied with the design outcomes in terms of space, appearance, size and flexibility, and would be happy to use the same design strategy in future projects. Occupant feedback from surveys and interviews have revealed that occupants are also satisfied with their homes especially in terms of space, appearance and flexibility.
- The developer aimed to keep things simple by using tried and tested construction methods, technologies and controls. In order to achieve the design intentions a fabric first approach was followed and PV panels and MVHR system were implemented. However, the design and delivery team was not well familiar with achieving low air-tightness targets and was not experienced in the implementation of MVHR systems, both of which proved to be more complicated than expected as revealed through the evaluation of fabric performance and usability of controls (Sections 3 and 9). Lack of familiarity with the MVHR system in particular has resulted in a series of commissioning and operation issues (Sections 7 and 9) that have undermined the reliability of the system.
- As a result of the study, the developer would like to reconsider the use of MVHR system against their air-tightness and ventilation standards.
- The developer reported it would have been beneficial to have sustainability consultants involved from the beginning of the design process in order to avoid complexity and ensure good space provisions for systems and technologies.
- The developer's aim of reducing long term maintenance costs whilst achieving code compliance was pivotal in the selection of the heating system (gas boilers with radiators) and the decision to incorporate photovoltaic panels.
- MVHR systems were used to achieve code compliance and were regarded as a 'low maintenance' system by the designer and the developer. This has not been the case in reality given the issues

with commissioning, operation and maintenance. The maintenance cost of technology was the key in decision-making for both parties.

- Both parties agreed that the fabric first approach is successful but think it could be further enhanced through better detailing and care during construction.
- The design and delivery team pointed out the importance of enhancing familiarisation and education of occupants about the use, operation and maintenance of low carbon technologies and controls. The team believes that the tenants' familiarisation with the technologies could be improved through re-training and is also looking for ways to improve handover and occupant training in future projects. Lack of occupant understanding of the MVHR system was highlighted during the interviews with the occupants of the case study houses (Section 6). This has been confounded by inadequate commissioning, which has in turn led to system imbalances that affect the energy use of the houses (Section 7).

5 Evaluation of guidance offered to the occupants and the physical handover process

5.1 Overview of handover process and guidance offered to the occupants

The handover process of both case study houses was conducted by a specialist of Thames Valley Housing Association as soon as occupants had signed up to the properties. During handover:

- Residents signed up to properties.
- Residents completed a procedure which included a large level of housing management information, including:
  - Rent details
  - How to report repairs
  - Demonstration how to use the equipment within the property.
  - What to do in the event of ASB (Anti - Social Behaviour)
- A demonstration on technologies was provided by a specialist explaining controls, the operation of the boiler and the benefits of the MVHR units and PV panels. The demonstration took place in both houses and the benefits of low carbon technologies and building services available in the properties were presented to the occupants.
- A residents' manual was also provided.
- Residents were familiarised with Ewgeco smart meters available on-site that were connected to the electricity and gas meters.

Six months after handover, occupants were contacted by TVHA representatives to report any defects that may have occurred in the properties during early occupation.

During handover residents were provided with a lot of information ranging from details on the tenancy agreement and rent payment to demonstration of building systems and technologies. Due to the large amount of information provided on a single day there was a risk that little information would be retained. This has in fact been verified through discussion with occupants during the semi-structured interviews and walkthroughs (Section 6). Occupants have demonstrated a lack of understanding of the MVHR and PV system. The occupant in House 1 also pointed out that they do not remember all the information provided during the induction tour and has expressed the need for a follow-up presentation of systems.

As mentioned in Section 3, the operation of systems and controls was not prioritised compared to other topics during handover thus undermining occupant understanding of systems. The MVHR system has proven to be the one creating most confusion to the occupants due to lack of proper training and guidance regarding its purpose and operation. Poor occupant understanding of the system in addition to poor commissioning has led to system imbalances that affect the energy use of the houses (Section 7).

Smart meters installed for gas, water and electric would allow residents to monitor their energy consumption on remote devices. However, these were found to be disconnected and in the case of gas meters completely removed. As a result, occupants do not have a clear understanding of their energy consumption only relying on monthly or quarterly bills. In some cases occupants have set up monthly direct debits and will only be able to find out their actual energy consumption at the end of the year.

5.2 Review of the Home User Guide

Occupants were provided with a Home User Guide during handover, among other documentation such as tenancy agreements, rent payment instructions and other supporting information.

The home user guide covers a thorough list of topics:

- A general welcome note and introductory description of the development scheme.
- Operation instructions for doors and windows.
- List of options to enhance security within the home, including information on external security, PID lighting.
- Insurance policy information.
- Fire and CO_2 safety instructions and equipment description.
- Information about communal and individual facilities (i.e. bin collection, bicycle storage).
- Information on electricity, central heating, water, gas systems and controls including guidance on check procedures in case of a problem.
- Information about the MVHR system.
- Information on bathroom facilities, telephone connections and TV aerial.
- List of how to prevent and/or condensation within the properties.
- Description of wall fittings and partitions.
- Guidance on actions that should be undertaken in case of blockages in kitchen, baths and basins, WCs and bathrooms.
- Cleaning advice for different types of surfaces.
- Redecorating instructions.
- List of the environmental design features of houses.
- Energy and water saving tips.
- Fault reporting procedures.
- Information on what to do in the event of an emergency.
- Full list of local amenities and useful contacts.

The home user guide is considered to be satisfactory. It contains comprehensive information about all the energy systems in the dwelling and a full list of contacts to be reached in case of a defect or an emergency, but its overall quality could be further improved. Colour illustrations with useful information on the sustainability features and energy systems, could make the user guide easier and more pleasant to read. The user guide is well-organised with each section describing the item under discussion and how it works and including information on who to contact in case of defects The section that describes defects and procedures to be followed in case of a problem identified in the property is easy-to-follow and provides very detailed information on what is a defect, how to report defects and who to contact, defects procedures, response times and end of defects inspection.

Semi-structured interviews with the occupants have shown that residents are not eager to read through the document as they find it too-detailed and uninviting, thereby leading to unfamiliarity with the mechanical ventilation system. TVHA has been informed of these findings and is thinking of ways of improving occupant training by introducing a more interactive Home User Guide using online video clips.

5.3 Conclusions and key findings

- Due to the large amount of information provided during the one-day handover not all information was retained by the occupants. Also not enough time was allocated to describing and demonstrating the operation of (heating and ventilation) systems and controls. This has undermined occupant understanding of systems and has resulted in confusion regarding the use, operation and maintenance of MVHR system. Findings from the semi-structured interviews and walkthroughs with occupants have shown that occupants are not well familiar with the MVHR system and even the solar PV panels (Section 6). The need for a follow-up training and presentation of the working of the various energy systems in the homes, was further expressed.

- It is therefore recommended that the handover should follow a more phased approach providing occupants with more time to digest information:
    - An initial handover session with residents can provide information regarding rental agreement and other tenancy particulars.
    - Another training session should be organised to familiarise occupants with the features and services of their new home through demonstrations, walkthroughs and familiarisation with the content of home user guide. The training session should also take into account the age and technical ability of residents.
    - Thereafter follow-on sessions (typically a month after move-in and then after 3 months and 6 months) between occupants and the housing officer could address any emerging queries and issues that arise during the first year of occupation.

- It is also recommended that feedback from occupants about the quality and usefulness of the handover sessions should be collected through workshop sessions and questionnaires in order to improve these for future projects.

- In-home displays (Ewgeco) installed for providing real-time feedback to residents on their gas, water and electricity consumption, were not operational as their clamps were found to be disconnected by the utility companies, thereby limiting the occupants understanding and management of energy and water consumption. To avoid such situations, it is recommended that utility companies are made aware of any smart metering and display arrangements that are set up in housing developments.

- The home user guide is considered satisfactory, but its overall quality could be further improved especially in terms of overall length, appearance and graphics. Other ways of communicating the user guide through online video clips is being explored by the developer (social housing provider).

6 Occupant surveys using standardised housing questionnaire (BUS) and other occupant evaluation

6.1 BUS survey

The BUS questionnaire method was used to map the reactions of the occupants in Thames Valley, Feltham. Eight responses were received out of ten questionnaires that were distributed, giving a response rate of 80%. The questionnaires were distributed on 13th December 2013.

The purpose of the survey is to understand how well the dwellings meet the occupants' needs, the perceived level of comfort within the dwellings and the degree of control the occupants feel they have over the energy and water-saving features of their home. The questionnaire prompted occupants to comment on the building's image and layout, the control and daily use of the energy and water-saving features and any lifestyle changes since moving to the property. Their responses were then rated in terms of effectiveness and additional comments were made where needed. The survey also collects comments made by the respondents under each of the categories. The summary of these comments are shown in tables.

The questionnaire variables are compared with their respective scales midpoint and BUS benchmarks to provide a slider showing green/amber/red lights depending on the comparison with upper and lower limits of the scale midpoint and benchmark. The benchmark used is the UK 2011 domestic benchmark which is formed of multiple domestic sites (i.e. multiple dwellings) in the UK. The benchmark includes dwellings of various typologies and age.

According to the demographic data collected, the majority of the people who responded to the questionnaires were women (6 out of 8). All of the participants have lived in their house for more than one year and most of them are over 30 years of age. The development comprises of eight terraced houses and two detached houses. A good spread of both house types (terraced and detached) was covered in the survey: Six terraced, Two detached. Most of the houses are occupied by families with young children.

6.1.1 The building overall

The overall picture of the survey (Figure 20) revealed a positive opinion towards the houses, with the air quality and comfort being the most appreciated elements. All elements scored high above the scale midpoint, with most elements scoring above the benchmark. Participants feel that the facilities provided meet their needs very well and that the houses are comfortable overall. Temperatures during summer are generally regarded as quite comfortable but less so in winter. Lighting levels appear to be satisfactory overall. Natural light scored within the benchmark, with the majority of the people finding it adequate (neither too little nor too much).

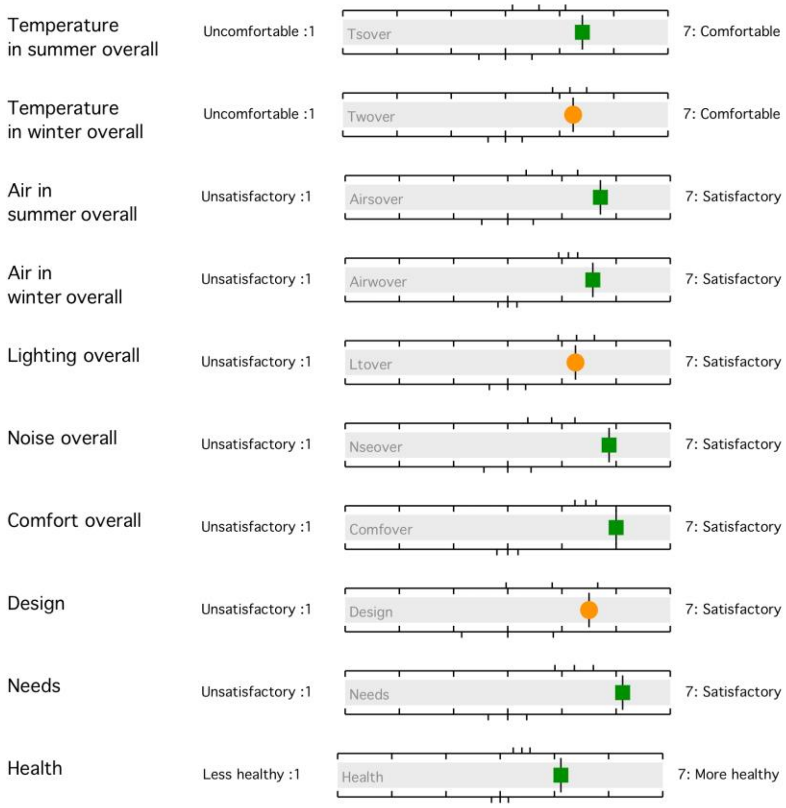


Figure 20 Overall findings

6.1.2 Appearance, layout and location

Respondents rated the building's appearance favourably with 6 out of 8 finding the appearance 'good' (Figure 21). The location is also appreciated with the majority of the respondents being satisfied with it. The layout was rated as good on average, scoring higher than the benchmark, with the majority of the occupants finding it 'good'. Respondents rated the space of the houses as satisfactory with the majority finding it enough overall. Space and building storage scored above the benchmark. Contradictory answers were received regarding the amount of storage space with 3 of the respondents finding it more than enough and another 3 finding it below adequate. This might be related to the number of occupants living in each property.

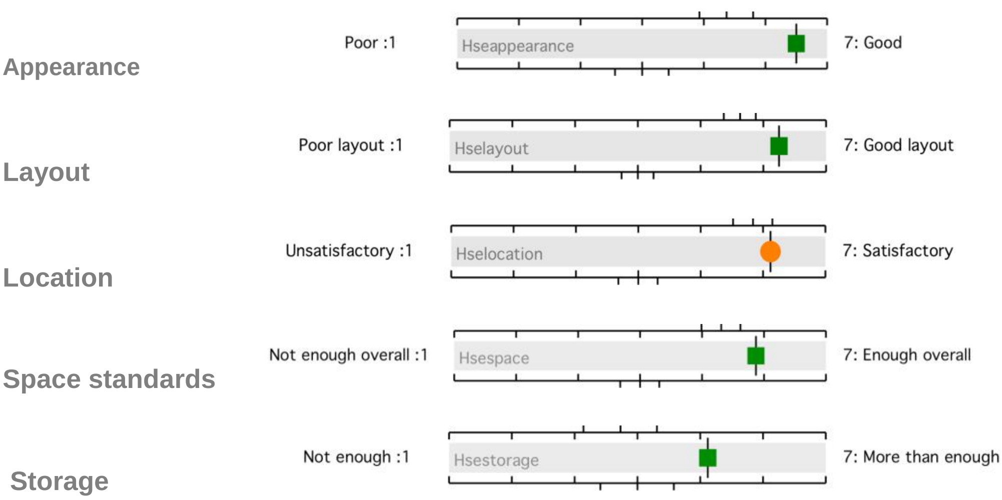


Figure 21 Findings on appearance, layout, location, space and storage

6.1.3 Air temperature and quality

In general, the summer and winter temperature conditions are perceived as comfortable but less so in winter than summer (Figure 22). Overall winter air temperature score sits within the benchmark with 4 of the respondents finding them comfortable. Overall summer air temperatures scored higher than the benchmark with 7 of the respondents finding them quite comfortable. Comments received mention unpleasant draughts and noise from the MVHR system.

Figure 22 Temperatures in winter and summer overall

In winter, air is perceived as satisfactory by the majority of the respondents (Figure 23). Air quality in winter scored higher than the benchmark. These findings, however, cannot be directly related to the performance of the MVHR system as occupants tend to open the windows to ventilate the houses even during winter (Section 6.2).Air quality in summer was also rated favourably with 3 of the respondents being fully satisfied.

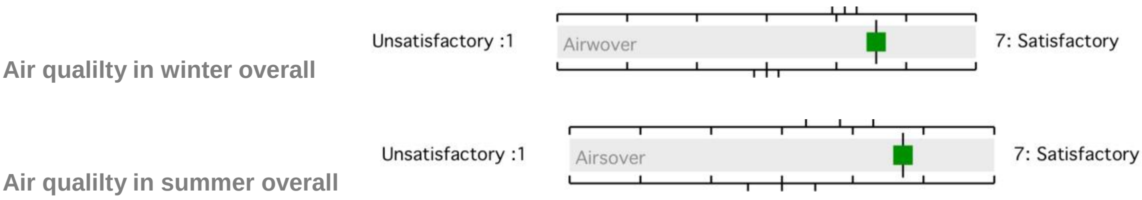


Figure 23 Air quality in summer overall, slider and histogram

6.1.4 Personal control

Control over cooling was rated positively on average, with 3 respondents feeling that they have full control and 1 respondent feeling they have no control over it. Control over heating, ventilation, lighting and noise scored higher than the benchmark. 4 out of 8 feel they have full control over heating and 1 out of 8 feels they have no control (Figure 24). As regards to ventilation, 6 of the respondents feel in good control. Control over lighting was rated positively on average with the majority of the respondents feeling in full control.

However, interviews with occupants from the two case study dwellings indicated that the occupants do not fully understand the purpose of the MVHR system and normally open the windows to ventilate the houses. Walkthroughs also revealed that the occupants do not make good use of the heating system, setting the thermostat at 30^{o}C and leaving the windows open when the heating is on.

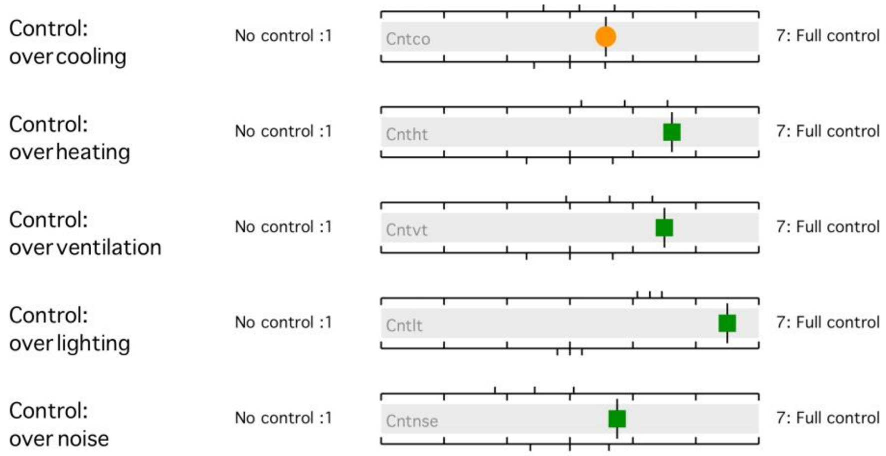


Figure 24 Personal control

6.1.5 Utilities costs

Respondents generally felt that utilities costs are higher to those in their previous accommodations, with the score sitting much below the benchmark (Figure 25). Comments received point out that *heating costs were high*. One occupant pointed out that no one had shown them how to use the energy meter.

Figure 25 Gas and electricity costs

6.1.6 Lifestyle

The majority of the occupants felt that living in the house has changed their lifestyle (Figure 26). Occupants commented that the use of the garden and the amount of space was welcomed by both kids and parents. Other comments point out the importance of good connections and proximity to work.

Figure 26 Effect of houses on lifestyle

6.2 Interviews and walkthroughs with occupants

This section summarises the findings of the occupant interview and walkthrough in House 2, conducted on Friday 13th December 2013 and House 1, conducted on 18th February 2014. Each occupant interview lasted approximately 20 minutes and was followed by a walkthrough with the tenant.

The purpose of the interview is to find out the occupant's level of satisfaction with the handover process and the appeal of the house, to check how they feel about the comfort and control of the different systems in their home (space heating and hot water, ventilation, daylight and lighting) and what they think about the space standards and their flexibility. The walkthroughs go through specific items in each of the rooms of the house looking at the best and worst features of each space.

6.2.1 General satisfaction

- Occupants are very satisfied with the houses, the amount of space, the layout and appearance and are very appreciative of the gardens.
- The spaces are easy to clean and maintain.
- Occupant in House 1 is not satisfied with windows opening towards the inside as they are not safe for children. Also, they do not like the fact that the external door can be opened from the outside if not locked.

6.2.2 Home User Guide & Induction process

- Occupants in both houses appear to be satisfied with the induction process and find the home user guide easy to use. However, when asked about the purpose and operation of the MVHR system both occupants appeared to be unfamiliar with it. The occupant in House 2 also appeared to be unfamiliar with the PV system. The occupant in House 1 pointed out that they do not remember all the information provided during the induction tour and has expressed the need for a follow-up presentation of systems.
- These findings indicate that the induction process was not completely successful and that it did not help the occupants gain full understanding of the technologies implemented. This is probably due to the fact that little information was retained by the occupants during the one-day handover (Section 5). Additionally, these findings point out that the occupants do not read the home user guide and are not well familiar with it. This might be due to the fact that the guide includes information in a technical way that is uninviting for the occupants.

6.2.3 Heating system: operation, comfort and control

- Both occupants are satisfied with the room temperatures, quality of heat and system responsiveness and find the heating controls easy to use. Heating is achieved through a gas boiler and radiators which is a system the occupants are well familiar with. Such familiarity with systems and controls has resulted in the occupants feeling that they have good control over heating and thus has a positive effect on their perception of comfort.
- Temperatures are controlled by one thermostat located next to the main entrance. In both houses, the thermostats were found to be set as high as 30°C even though the occupants had reported having the thermostats around 15-20°C. This indicates a strong difference between what the occupants are reporting and what they are actually doing.
- Occupants in House 2 do not adjust the thermostat or radiator valves but prefer to open the windows when spaces get warm but keep the heating on. This pattern increases heat loss and leads to an increase in gas consumption. This explains the elevated heating energy demand shown in the monitoring data collected (Section 8).
- On the contrary, the occupant in House 1 reported heating the house in the morning and afternoon, turning the heating off during the night. The radiator valves are used by the occupants to control temperatures in individual rooms. However, the occupant likes to keep their windows open throughout the day when in the house. This practice can substantially increase heating demand.

6.2.4 Renewable energy systems

- The occupant in House 2 was not aware of the existence of PV panels and did not have any information about them.
- The occupant in House 1 believes that the PV panels are working well because their electricity bill is low compared to the amount of electricity used in the house.

6.2.5 Lighting

- The occupant in House 2 is satisfied with the daylight house but the occupant in House 1 pointed out that the living room and bedrooms located in the north side of the house are dark at times.
- The sky light in House 1 is successful in providing plenty of natural light to the staircase and landing.
- Lighting controls were reported to be easy to use.

6.2.6 Hot water

- Hot water is provided from the boiler and is always sufficient for the occupants' daily needs. The hot water temperatures are acceptable and overall the system works well.
- The immersion heater is not being used.

6.2.7 Acoustics

- No noise issues were reported in the houses.
- Outside noise is blocked when the windows are closed.

6.2.8 Ventilation system

- Occupants in both houses are unfamiliar with the purpose and use of the MVHR system and ventilate the houses by opening the windows on a daily basis. This combined with the fact that the measured air permeability of the houses is higher than $3m^3/m^2h$ -which is considered to be the threshold for installing MVHR systems- may imply that MVHR system is essentially redundant.
- Occupants are satisfied with the air quality of the houses but always open the windows after cooking or after using the bathroom.
- Particularly in House 1, the occupant is used to keeping the windows open at all times when in the house. Such habits are hard to shake and occupants need to be trained well to gain a good understanding of how the house operates as a whole and how to use the house in different seasons.
- The MVHR system in House 1 is not performing well and has broken down several times. The MVHR system was out of operation for three months and was re-commissioned in mid-November 2013 but broke down again shortly after. Currently, the supply terminals in the top floor blow cold air whereas both the supply and extract terminals in the ground and middle floors do not seem to be working.
- The several breakdowns of the MVHR system in House 1 have undermined its reliability and have confused the occupant who in turn has got used to operating the house without it.
- Furthermore, the first two MVHR tests conducted in each of the houses had shown that the both MVHR systems were very unbalanced supplying air much above the design values. The MVHR systems were re-commissioned in mid-November 2013 and since then, the amount of supply and extract air flow rates have been reduced. However, there is still a discrepancy between supply and extract rates.
- As a result of the system imbalance, noise and draughts have been reported in both houses. Occupants in both houses have actively tried to stop the 'annoying' cold draughts by shutting the supply terminals thus further unbalancing the system and potentially undermining indoor air quality. This finding also points out that the occupants were able to tamper with the MVHR system balance because the terminals had not been locked in fixed positions as per the specifications.

6.2.9 Maintenance, reliability and breakdowns

- The heating system in House 2 had broken down over the summer (July-August 2013) resulting in the heating being constantly on. This is evident in the energy monitoring data that show unusually high heating energy demand during the summer months (see further section).
- The MVHR system in House 1 has broken down in the past and is currently not performing well. Breakdown was due to a manufacturing fault.

6.2.10 Flexibility and storage

- Occupants find the houses to be flexible and suitable for large families because of their overall size and room dimensions.
- Storage space is considered adequate for the needs of the occupants. Occupants use the under stair and airing cupboards, the garden and bike shed and have fitted large closets in the bedrooms.

6.2.11 Energy and water consumption

- The occupants in House 2 find their gas bills high (£125/month) but manageable. Interestingly in their previous house, which was a smaller 3-bedroom flat, the gas bill was lower (£100/month). Electricity bills are £80/month (monthly debit) and water bills are £40/month (monthly debit).
- The occupant in House 1 is satisfied with their bills: £50 per week on gas and £10-15 per week on electricity.
- It should be noted that occupants are used to paying high bills because of the size of their families, needs and daily activities (Section 6.3).

6.3 Monitoring of occupant activities and comfort

Occupancy patterns and activities were monitored in order to help gain a clear understanding of the daily and seasonal operation of the houses and of the causes that affect their energy and environmental performance (Tables 10, 11).

Both houses share similar occupancy patterns with occupants leaving the house in the morning and returning in the afternoon. Daily space heating, cooking and washing patterns and occupant window habits, shown in Table 11, help explain the high energy use in both case study houses.

Table 10 Occupancy patterns in House 1 and House 2

		9:00-13:00	14:00-17:00	18:00-21:00	22:00-1:00	2:00-8:00
House 1	Weekdays	Not occupied	Partly occupied	Fully occupied	Fully occupied	Fully occupied
	Weekends	Fully occupied	Partly occupied	Partly occupied	Fully occupied	Fully occupied
House 2	Weekdays	Not occupied	Partly occupied	Fully occupied	Fully occupied	Fully occupied
	Weekends	Fully occupied	Fully occupied	Fully occupied	Fully occupied	Fully occupied

Legend: Not occupied (white); Partly occupied (light blue); Fully occupied (blue)

Table 11 Schedule of activities in House 1 and House 2

	Space Heating (hours/day)	Cooking (hours/day)	TV (hours/day)	Windows open (in winter)	No. of showers/day	No. of washing & drying/week
House 1	2 -4h	1h (wday) 3h (wknd)	4h (wday) 10h (wknd)	Kitchen	5	8
House 2	2-4h	1h (wday) 2h (wknd)	3-5 h	Bedroom - Kitchen when cooking	2-5	8-12

6.3.1 House 1

Winter week

During a typical winter week in House 1, the occupant was 'comfortably neither warm nor cool' for most the time, never reaching the 'too warm' or 'too cold' end of the scale. Activity levels usually involve sitting or walking in the house. Regarding adaptive opportunities, during the week the occupant mostly wore long sleeve shirts and long trousers, switching to a T-shirt when feeling warm. Windows were mostly closed and internal doors were open while heating was on four days during the week.

According to the activity logging sheet, during weekdays all five occupants gather in the house in the afternoon. During weekends the house is continuously occupied. On a daily basis:

- The heating is on for about 2 hours/day during weekdays and between 2-4 hours/day during weekends.
- The kitchen window is left open during weekdays and the backdoor is open during weekends when the occupants are home. It should be noted that the back door is left open to accommodate the family dog.
- The hob/oven(gas) is used for cooking 1hour/day during weekdays and 2-3hours/day during weekends.
- About 5 showers are taken every day.
- Washing and tumble drying involves two loads four times a week.
- TVs are on for about 4 hours or more per day during weekdays and for more than 10hours during weekends.

Summer week

During a typical summer week in House 1, the occupant was 'comfortably neither warm nor cool' for most the time, reaching the 'too warm' end of the scale at times. Activity levels usually involved sitting or walking in the house. Regarding adaptive opportunities, during the week the occupant mostly wore short sleeve shirts or vests with shorts. Windows and doors were opened at all times in an attempt to get rid of excessive heat.

According to the activity logging sheet, during weekdays all occupants gather in the house in the afternoon. During weekends the house is continuously occupied. On a daily basis:

- All the windows and the back door are open throughout the day.
- The hob/oven (gas) is used for cooking 1hour/day during weekdays and 2-3hours/day during weekends.

- About 4-5 showers are taken every day.
- Washing involves one load three times a week.
- TVs are on for about 6 hours or more per day during weekdays and for more than 10hours during weekends.

6.3.2 House 2

Winter Week

During a typical winter week the occupant in House 2 reported feeling 'comfortably cool' at all times and rated the overall comfort as acceptable. Occupant activity mainly involved standing. The occupant wore long sleeve shirts and sleeved robe throughout the week. The internal doors were open as well as some windows. The curtains were kept closed.

According to the activity logging sheet all occupants gather in the house usually after 13:00. On a daily basis:

- The heating is on between 2-4hours per day.
- The bedroom windows are usually open and the kitchen windows when cooking.
- The hob/oven is used for cooking 1hour/day
- About 2-5 baths are taken every day
- Washing and tumble drying involves 2-3 loads four times per week
- TVs are on 3-4 hours or more per day.

These patterns clearly explain the large amounts of electricity and domestic hot water used in the house.

Summer week

During the summer week the occupant in House 2 reported feeling 'comfortably cool' and rated the overall comfort as 'very comfortable'. The occupant wore short sleeve shirts throughout the week. The internal doors and windows were kept open.

Summer occupancy patterns are similar to the winter ones.

On a daily basis:

- Heating is off.
- Extract fan is used when cooking.
- The hob/oven is used for cooking 1hour/day
- About 2-5 baths are taken every day
- Washing and tumble drying involves 2-3 loads four times per week
- TVs are on 3-4 hours or more per day.

6.4 Conclusions and key findings

- Overall the BUS survey and interviews have revealed a positive opinion towards the houses, with the air quality and comfort being highly-rated. Occupants are very satisfied with the houses, the amount of space, the layout and appearance and are very appreciative of the gardens.
- Occupants find the houses to be flexible and suitable for large families because of their overall size and room dimensions.
- Occupants are not well familiar with the purpose and operation of the MVHR system and PV panels. Little information was retained from the handover and occupants are reluctant to read through the

Home User Guide. These findings indicate that the induction process and guidance has not helped the occupants gain full understanding of the technologies implemented.

- Occupants are generally satisfied with the room temperatures, quality of heat and system responsiveness and find the heating controls easy to use. Heating is achieved through a gas boiler and radiators which is a system the occupants are well familiar with. Such familiarity with systems and controls has resulted in the occupants feeling that they have good control over heating and thus has a positive effect on their perception of comfort.
- In both case study houses, the thermostats were found to be set as high as 30°C even though the occupants had reported having the thermostats around 15-20°C. This indicates a strong difference between what the occupants are reporting and what they are actually doing.
- Individual space heating and ventilation patters in the houses lead to increased heating loads as shown in the energy monitoring analysis (Section 8)
- Air quality in winter and summer scored higher than the benchmark. Control over ventilation is also rated positively. However, these findings cannot be directly attributed to the MVHR system as he occupants do not rely on it for the ventilation of their homes but tend to open the windows frequently.
- Interviews have revealed that occupants in both case study houses are unfamiliar with the purpose and use of the MVHR system and ventilate the houses by opening the windows on a daily basis. This combined with the fact that the measured air permeability of the houses is higher than $3m^3/m^2h$ may imply that MVHR system is essentially redundant.
- Poor commissioning of the MVHR system in combination with poor occupant understanding has resulted in system imbalance which in turn resulted in noise and draughts coming from the system. Occupants in both houses have actively tried to stop the 'annoying' cold draughts by shutting the supply terminals thus further unbalancing the system and potentially undermining indoor air quality. These findings strongly indicate the relationship between proper installation and commissioning and occupant comfort and control. Extra care needs to be given to innovative systems especially because occupants are used to operating their homes without them and can easily by-pass them.
- Participants in the BUS survey generally feel that utilities costs are higher to those in their previous accommodations, with the score sitting below the benchmark. This is against the design intent which was about developing Code level 4 houses with low fuel costs. Interestingly, occupants in the case study houses are more or less happy with their bills as they are used to paying high bills because of the size of their families, needs and daily activities.
- The positive feedback from residents regarding air quality, comfort, and perceived control is likely to be due to their familiarity in using conventional gas condensing boilers, the primary source of space and water heating in these houses. On the other hand MVHR systems have led to issues with air flow, balance and occupants closing off the terminals. It is vital for TVHA as the social housing provider to keep the heating and ventilation systems simple.

6.5 Recommendations

- The induction and handover process should be reviewed to provide more detailed and hands-on experience to new tenants and possibly re-training of existing tenants. In addition to demonstrations of the operation of the energy system (heating, ventilation etc) by the design team member, also let occupants try out the energy systems themselves to ensure they understand how to operate them. Follow this up through subsequent visits to ensure that the information presented has been absorbed by the occupants.
- The Home User Guide should be revised to provide concise and useful information to occupants on how to operate their homes in summer and winter and how to operate the heating system effectively

to reduce their energy consumption. Consider the use of videos clips to make the Home User Guide easier to follow.

- Take measures to improve the performance of the MVHR system by training the occupants, re-balancing the system and addressing breakdowns.
- Since the design intent of achieving low energy homes with low running costs has not been met and is likely be due to the imbalanced and constantly on MVHR systems combined with higher air permeability rates, TVHA needs to review the strategies for air-tightness and ventilation. MVHR should be introduced only if necessary as there are alternate solutions available such as natural ventilation, passive stack ventilation or even demand controlled ventilation.
- Build in seasonal commissioning (to avoid breakdowns, leaks etc) of ‘unfamiliar’ energy systems and specify that only calibrated equipment be used for commissioning and re-commissioning of systems.
- Improve customer care and help service for rapid trouble-shooting. Make occupants and housing maintenance team aware of the maintenance requirements of ventilation systems.
- Ensure the installers and maintenance technicians are appropriately trained.
- Consider re-training of existing occupants to the use, operation and maintenance of the ventilation system.
- Take advantage of south orientation to allow for solar gains during winter and increase daylight.
- Promote the use of systems and controls that are easy to operate and intuitive. Good occupant control improves energy performance as well as the perception of comfort.

7 Installation and commissioning checks of services and systems, services performance checks and evaluation

The building services and energy systems are summarised in Table 12. Space heating and domestic hot water are provided through the condensing gas boilers connected to radiators as heat emitters. The developers preferred to avoid complexity and use a conventional system which both they and the occupants were familiar with (Section 4). Immersion heaters are present but the study has shown that they are not being used by the occupants. Space heating and hot water settings are controlled by a masterstat located in the kitchen and a thermostat located in the ground floor. The masterstat offers the option to set up space heating and hot water to switch on and off during seven days of the week and offers three settings per day. It also offers a boost button and summer mode. Radiator valves allow for individual room control over temperatures.

Electricity is provided by the grid and part of it is generated by solar PV panels. The photovoltaic systems provided are 1.65 kWp and 1.8 kWp grid connected solar arrays comprising of polycrystalline collectors in House 1 and House 2 respectively. All lighting systems are energy efficient.

As already mentioned, all houses have MVHR systems with summer bypass mode for providing background ventilation as they were designed for high air-tightness ($3m^3/h.m^2$).

Table 12 Building services and energy systems.

Main heating	Gas condensing boiler and radiators
Heating controls	Time and temperature zone control
Hot water	From primary heating system. Immersion present
Ventilation	MVHR system with summer bypass mode and thermal sensors
Renewables	Photovoltaics 1.65kWp & 1.88kWp

A review of installation and commissioning of services and systems was carried out on 18th March 2013 for House 1 and House 2. The review looked at ventilation systems, heating and hot water systems, and lighting. Several issues were discovered during the commissioning review and were reported to the building owners. Most of the problems were common in both houses, suggesting that the same could be encountered in more houses across the development.

7.1 Space heating and hot water systems

The review revealed that in both houses:

- The space heating and hot water system has been installed in accordance with the manufacturer's requirements.
- A discrepancy in the hot water cylinder's volume was observed between the actual system installed and the as-designed SAP specification (52 lires in as-designed SAP compared to 210 litres for House 1 and 250 litres for House 2 in as-built SAP) (Section 2).
- The benchmark commissioning sheet was not left with the end user along with the user guide.
- The space heating and hot water circuits have fully pumped circulation and all pipework emanating from the cylinder has been insulated.

7.2 Lighting

The review revealed that in both houses:

- Mainly low energy lighting is used in the house.
- Low energy lighting includes CFL and low voltage halogen. This is according to specifications.

7.3 Ventilation systems

7.3.1 House 1

- The MVHR unit is located in the loft space that is accessible through the loft hatch. The unit is not easily accessible by the occupants. This suggests that there is not sufficient access for routine maintenance repair and replacement of components.
- The commissioning review revealed that the system has not been installed in accordance with the manufacturer's requirements. The ductwork is not properly insulated even though it is located in an unheated space.
- Controls have not been set in accordance with the manufacturer's recommendations.The review showed that the correct number of grills had been installed, however, none of the extract and supply grills were locked in a fixed position, thus allowing the occupants to open or close them at will; and unbalancing the system.
- All internal doors have sufficient undercut to allow air transfer between rooms.
- All protection/packaging had been removed and the system was fully functional.
- During the commissioning test, air flow measurements were taken from both the extract and supply grills.

7.3.1.1 First MVHR test

The MVHR test conducted during the commissioning review indicated that there was a discrepancy between design and measured extract rates and that the system needed to be re-commissioned as some supply vents were shut closed (Table 13).

Table 13 Air flow measurements taken during commissioning review - Test 1

Location of terminals	Design air flow high rate (l/s)	Measured air flow low rate (l/s)	Measured air flow high rate (l/s)
Extract			
Kitchen	13	8.9	Not functioning
Bathroom	8	12.3	Not functioning
WC	6	8.5	Not functioning
Supply			
Living room	13	6.5	Not functioning
Bedroom 1	6	6.1	Not functioning
Bedroom 2	13	0 (valve closed)	Not functioning
Bedroom 3	5	7.4	Not functioning
Bedroom 4	5	5.2	Not functioning
Kitchen Diner	13	5.9	Not functioning

7.3.1.2 Second MVHR test

Following the 1st test, the system was re-commissioned by the BPE team and a second MVHR test was performed on 16th January 2014 (Appendix 12.3). In House 1 total extract after the second test is 10.7 l/s and total supply is 12.4 l/s. The discrepancy between supply and extract is 13% (Table 14). Energy consumption of the MVHR unit is also 11.8 W. Monitoring data has shown that the re-commissioning has had a great impact on the total monthly electricity consumption of the MVHR (Section 8).

It should be noted that during the test the filters were found to be dirty. Additionally, the boost switch did not appear to be operational.

Table 14 Air flow measurements - Test 2

Location of terminals	Design air flow high rate (l/s)	Measured air flow low rate (l/s)	Measured air flow high rate (l/s)
Extract			
Kitchen	13	4.5	4.5
Bathroom	8	4.6	4.5
WC	6	1.6	1.7
TOTAL		**10.7**	**10.7**
Supply			
Living room	13	2.4	2.4
Bedroom 1	6	1.9	1.9
Bedroom 2	13	1.6	1.7
Bedroom 3	5	2.4	2.3
Bedroom 4	5	2.1	2.1
Kitchen Diner	13	2.0	1.9
TOTAL		**12.4**	**12.3**

7.3.2 House 2

- The MVHR unit is located in the loft space that is accessible through the loft hatch. The unit is not easily accessible by the occupants. This suggests that there is not sufficient access for routine maintenance repair and replacement of components.
- The commissioning review revealed that the system has not been installed in accordance with the manufacturer’s requirements. The ductwork is not properly insulated even though it is located in an unheated space.
- Controls have not been set in accordance with the manufacturer’s recommendations. The review showed that the correct number of grills had been installed, however, none of the extract and supply grills were locked in a fixed position, thus allowing the occupants to open or close them at will, and unbalancing the system.
- Not all internal doors have sufficient undercut to allow air transfer between rooms.
- All protection/packaging had been removed and the system was fully functional.
- Three MVHR tests were conducted in 2013-2014 in House 2 to measure the performance of the MVHR system.

7.3.2.1 First test

The first test indicated that all supply vents in the house were shut creating a big imbalance in the system. The results are shown in Table15. The occupants appear to have closed the grilles as they were not fully aware of the purpose of the MVHR system and were trying to avoid cold draughts coming from the grilles. In addition to this, the boost button was not working.

Table 15 Air flow measurements taken during commissioning review – Test 1

Location of terminals	Design air flow high rate (l/s)	Measured air flow low rate (l/s)	Measured air flow high rate (l/s)
Extract			
Kitchen	13	13.1	Not functioning
Bathroom	8	2.4	Not functioning
WC	6	12.1	Not functioning
Supply			
Living room	13	0	Not functioning
Bedroom 1	13	0	Not functioning
Bedroom 2	6	0	Not functioning
Bedroom 3	6	0	Not functioning
Bedroom 4	6	0	Not functioning
Kitchen Diner	13	0	Not functioning

7.3.2.2 Second test

- The test indicated that the MVHR system was unbalanced (Appendix 12.3).
- The total air extract was measured at 25.6 l/s (low rate) and the total supply at 35.9 l/s (low rate) indicating a 28% discrepancy between supply and extract (Table 16). Energy consumed by the unit rate was measured at 80.7W and 100W in low and high rate respectively.
- These results, coupled with on-site inspection, indicated that the system needed to be re-commissioned before an accurate test could be performed.

Table 16 Air flow measurements – Test 2

Location of terminals	Design air flow high rate (l/s)	Measured air flow low rate (l/s)	Measured air flow high rate (l/s)
Extract			
Kitchen	13	12.10	12.20
Bathroom	8	0.4	0.80
WC	6	13.10	13.50
TOTAL		25.60	26.50
Supply			
Living room	13	3.8	5.4
Bedroom 1	13	6.1	9.5
Bedroom 2	6	5.9	8.6
Bedroom 3	6	10.6	15.2
Bedroom 4	6	3.5	7.8

Bedroom 5	6	0.0	0.0
Kitchen Diner	13	6.0	8.2
TOTAL		35.9	54.7

7.3.2.3 Third test

- TVHA had the MVHR systems in both properties re-commissioned.
- The MVHR test following the re-commissioning gave completely different values than before.
- In the case of House 2 total extract was reduced to 11.5 l/s (low rate) and total supply was reduced to 17.4 l/s (low rate) (Table 17). The discrepancy between supply and extract was calculated at 33% but the total amount of cold air entering the house had been reduced by 51% compared to the situation before the re-commissioning.
- Additionally, the energy consumption of the unit fell to 11.9W (low rate), which is 85% lower than the previous rate.

It should be noted that during the test the filters were found to be dirty. Additionally, the boost switch did not appear to be operational.

Table 17 Air flow measurements – Test 3

Location of terminals	Design air flow high rate (l/s)	Measured air flow low rate (l/s)	Measured air flow high rate (l/s)
Extract			
Kitchen	13	4.6	4.5
Bathroom	8	3.2	3.3
WC	6	3.7	3.7
TOTAL		11.5	11.5
Supply			
Living room	13	1.6	1.5
Bedroom 1	13	2.4	2.4
Bedroom 2	6	3.5	3.4
Bedroom 3	6	3.0	2.9
Bedroom 4	6	2.0	2.1
Bedroom 5	6	1.1	1.1
Kitchen Diner	13	3.8	3.7
TOTAL		17.4	17.1

7.4 Conclusions and key findings

- The MVHR units are located in the loft space that is accessible through the loft hatch. The units are not easily accessible by the occupants. This suggests that there is not sufficient access for routine maintenance repair and replacement of components.
- The commissioning review revealed that the MVHR system has not been installed in accordance with the manufacturer's requirements. The ductwork is not properly insulated even though it is located in an unheated space.
- Additionally, the fact that the vents are not locked in a fixed position, allowed the occupants to close them off completely, thereby unbalancing the extract and supply air flow in the system.
- The MVHR tests revealed great discrepancy between the supply and extract rates:

- In House 1 total extract after the second test was 10.7 l/s and total supply 12.4 l/s showing. a discrepancy between supply and extract as 13%. Energy consumption of the MVHR unit as about 11.8 W.
- In the case of House 2, before the re-commissioning, the total air extract was measured at 25.6 l/s (low rate) and the total supply at 35.9 l/s (low rate) indicating a 28% discrepancy between supply and extract. Energy consumed by the unit rate was measured at 80.7W and 100W in low and high rate respectively.
- After the re-commissioning total extract was reduced to 11.5 l/s (low rate) and total supply was reduced to 17.4 l/s (low rate) in House 2. The discrepancy between supply and extract was calculated at 33% but the total amount of cold air entering the house has been reduced by 51% compared to the situation before the re-commissioning. Additionally, the energy consumption of the unit fell to 11.9W (low rate), which is 85% lower than the previous rate.

These findings indicate that the MVHR installation and commissioning was not up to standard and even after re-commissioning of the systems, the systems were still not operating to expected levels. This raises an important question for the industry - *how can commissioning quality be improved*? Installation and commissioning procedures need to be robust and be carried out by qualified technicians. It is also important that appropriate documentation is compiled and provided to the building owners. As mentioned in Section 4, some documents, including the commissioning data, were missing from the O&M manuals. It is recommended that maintenance personnel are properly trained and have good understanding of the maintenance requirements of low-carbon technologies and systems especially MVHR. It is recommended that all the mechanical ventilation systems in the case study development are rebalanced by expert technicians using calibrated equipment. Extract and supply grilles would need to be locked in fixed positions and occupants re-trained regarding the purpose and seasonal operation of the system, as well as reporting of breakdowns.

8 Monitoring methods and findings

8.1 Metering and sub-metering arrangements

In May 2013 monitoring equipment (Figures 27, 28) was installed in both case study houses. Tables 19 and 18 list the type of monitoring equipment and the variables monitored for each house and the date at which data commenced coming through the Oxford Brookes University (OBU) web-portal without significant interruption, apart from solar radiation sensors which started transmitting to OBU on 28 June 2013.

Figure 27 Examples of energy monitoring equipment installed in properties in Feltham.

Figure 28 Environmental and occupants' behaviour monitoring: Location of equipment.

Table 18 Pippin Close: Complete list of energy and environmental monitoring equipment installed in the property, type of variables measured, location of installed equipment and date from which the data was available on the OBU web-portal.

Energy monitoring equipment	Type of data	Location	Date (1st day of data in OBU)
2x electricity meters with 2x pulse transmitters	Electricity (mains) supply kWh PV electricity export kWh	Electricity external utility box	13 May 2013
1x Pulse transmitters connected with installed meters	Gas (mains) supply m^3	Gas external utility box	13 May 2013
2x Heat flux meters with 2x pulse transmitters	DHW energy kWh (t) Heating energy (t)	Kitchen cupboard	13 May 2013
6x Electricity meters with 6x pulse transmitters	Downstairs lights kWh Downstairs electrical circuit kWh Upstairs lights kWh Upstairs electrical circuit kWh MVHR supply kWh	Hallway	13 May 2013
1 x Pulse transmitter	PV total generation kWh	Hallway	13 May 2013
1x Wi5 data hub	Transmission of 5 min data	Loft space	13 May 2013
2x Duct temperature transmitters	MVHR supply temp °C MVHR extract temp °C	Loft space	13 May 2013
1x pyranometer with 1x pulse transmitter	Solar radiation W/m^2	South facing roof and loft space (transmitter)	28 June 2013
Environmental monitoring equipment	**Type of data**	**Location**	**Date (1st day of data in OBU)**
5x Temperature / Relative Humidity transmitters	Temperature °C & Relative Humidity %	Kitchen, Living room FF bedroom SF front bedroom DF rear bedroom	13 May 2013
2x CO_2 transmitters	CO_2 levels ppm	Living room FF bedroom	13 May 2013
5x Open / closed window transmitters	Frequency of window opening	Kitchen, Living room FF bedroom SF front bedroom SF rear bedroom	13 May 2013
1x PIR transmitter	Frequency of door opening / occupancy levels	Hallway	13 May 2013

Table 19 Barnlea Close: Complete list of energy and environmental monitoring equipment installed in the property, type of variables measured, location of installed equipment and date from which the data was available on the OBU web-portal.

Energy monitoring equipment	Type of data	Location	Date (1st day of data in OBU)
9x electricity meters with 9x pulse transmitters	Electricity (mains) supply kWh PV total generation kWh PV electricity export kWh Downstairs lights kWh Downstairs electrical circuit kWh Upstairs lights kWh Upstairs electrical circuit kWh MVHR supply kWh	Kitchen cupboard Loft space	14 May 2013
2x Heat flux meters	DHW energy kWh (t) Heating energy (t)	First floor cupboard	14 May 2013
1x Wi5 data hub	Transmission of 5 min data	Loft space	14 May 2013
2x Duct temperature	MVHR supply temp °C	Loft space	14 May 2013

transmitters	MVHR extract temp °C		
1x pyranomenter with 1x pulse transmitter	Solar radiation W/m^2	South west facing roof and loft space (transmitter)	
Environmental monitoring equipment	**Type of data**	**Location**	**Date (1st day of data in OBU)**
4x Temperature / Relative Humidity transmitters	Temperature °C Relative Humidity %	Kitchen Living room FF bedroom 1 FF bedroom 2	14 May 2013
2x CO_2 transmitters	CO_2 levels ppm	Living room FF bedroom	14 May 2013
3x Open / closed window transmitters	Frequency of window opening	Kitchen Living room FF bedroom SF front bedroom DF rear bedroom	14 May 2013
1x PIR transmitter	Frequency of door opening / occupancy levels	Hallway	14 May 2013
1x Radio-Tech External Temperature / Relative Humidity transmitter	External Temperature °C & Relative Humidity %	External/fence/kitchen window	14 May 2013

8.2 DomEARM analysis and comparison with benchmarks

The DomEARM spreadsheet was used to compare the annual energy performance of the case study houses with current benchmarks. Actual grid electricity use in both case study houses is lower than the UK average housing but much higher than the CSH level 4 (CHS level 5 is not available in DomEARM) and Part L compliant benchmarks (Figures 29, 30). Electricity use per m^2 in House 1 is higher than that in House 2, whereas gas use is lower. This discrepancy between benchmarks and actual energy use is related to occupant heating patterns and appliance's schedule (See Chapter 8.5).

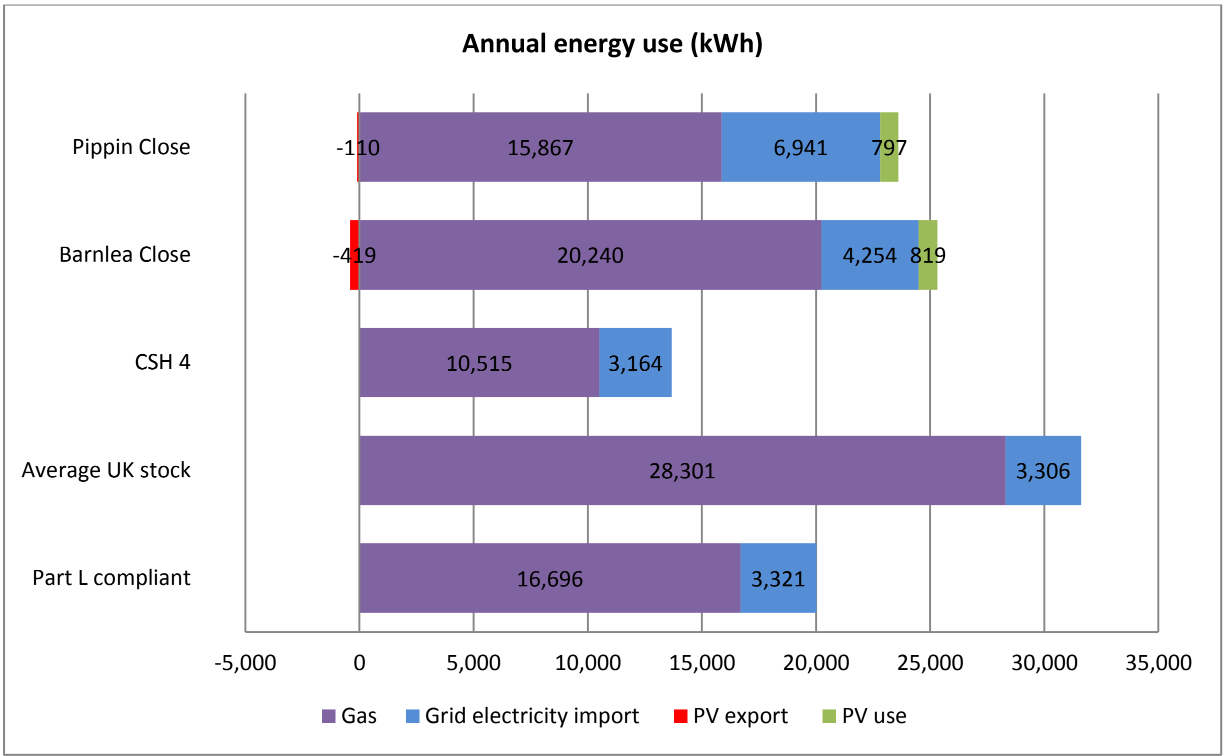


Figure 29 Annual energy use (kWh)from October 2013 to September 2014 and comparison with DomEarm benchmarks.

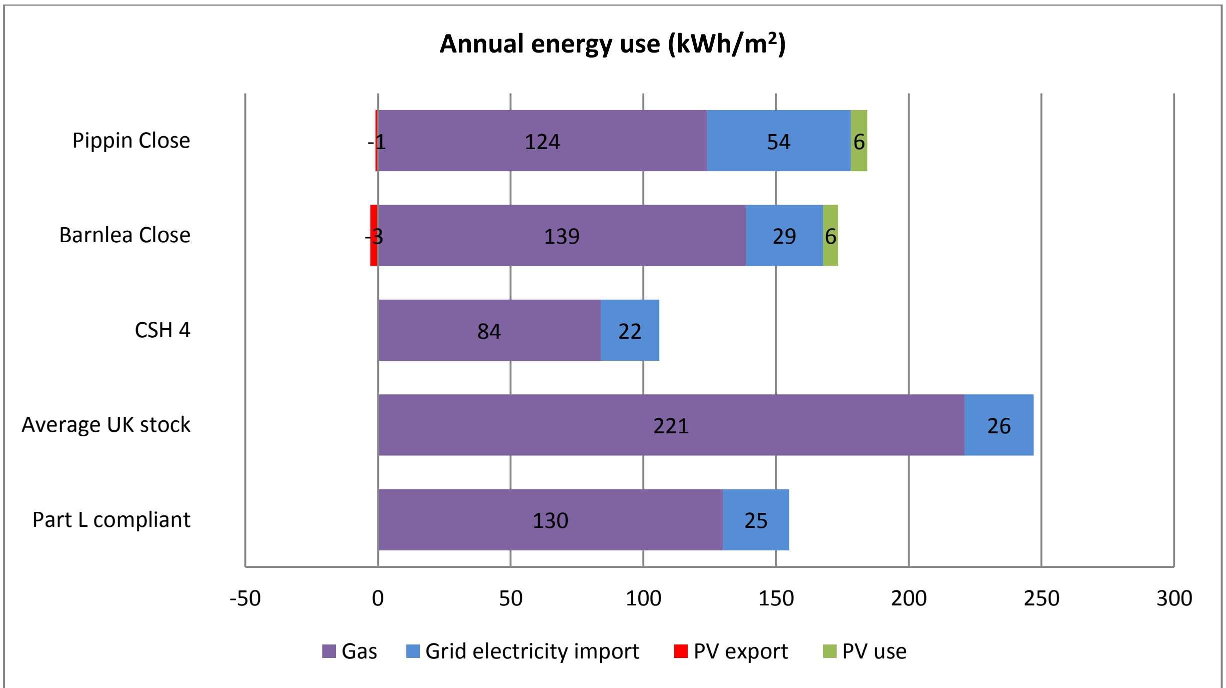


Figure 30 Annual energy use (kWh/m^2) from October 2013 to September 2014 and comparison with DomEarm benchmarks.

CO_2 emissions from gas use are higher than the CSH Level 4 benchmark and similar to the Part L compliant benchmark. CO_2 emissions from electricity use are higher than the average UK stock in both houses (Figure 31).

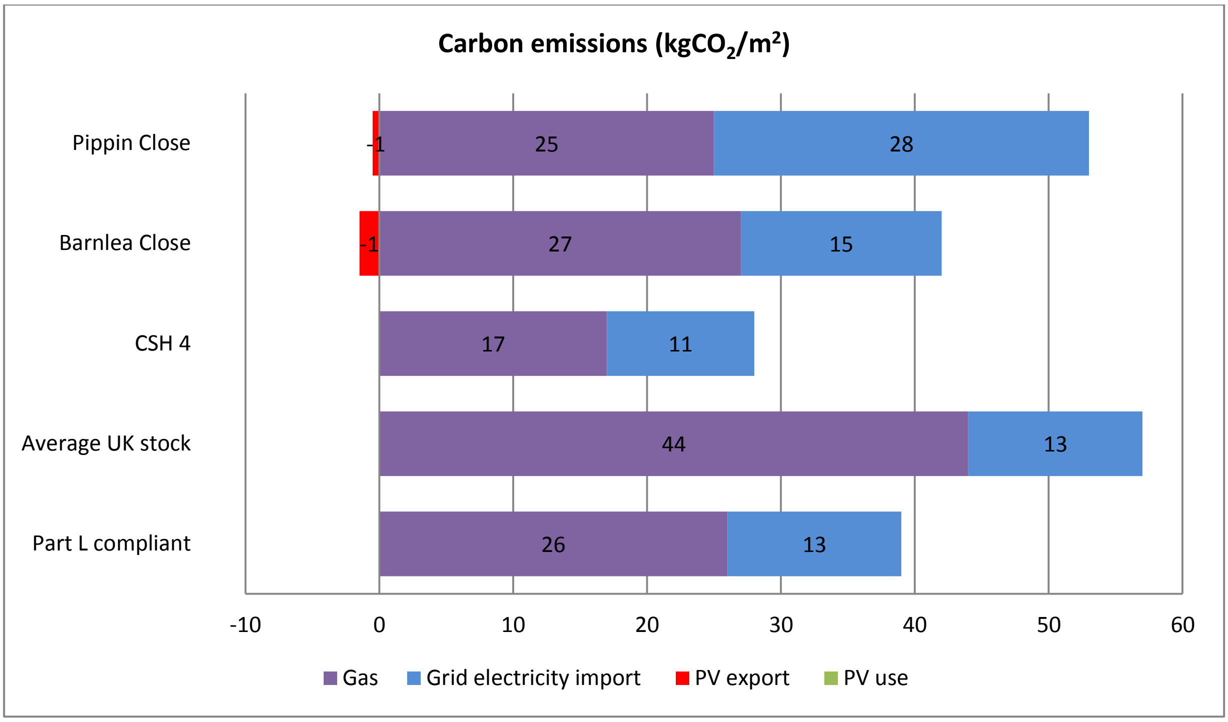


Figure 31 Annual carbon emissions from October 2013 to September 2014 and comparison with DomEarm benchmarks. Carbon emissions factors: Electricity 0.517 $kgCO_2e$, Gas 0.198 $kgCO_2e$.

Additionally, energy costs in both houses are high and are comparable to a UK average dwelling (Figure 32). These findings indicate that the houses are not cost efficient despite being designed for CSH Level 4 and support occupant claims of electricity bills being high.

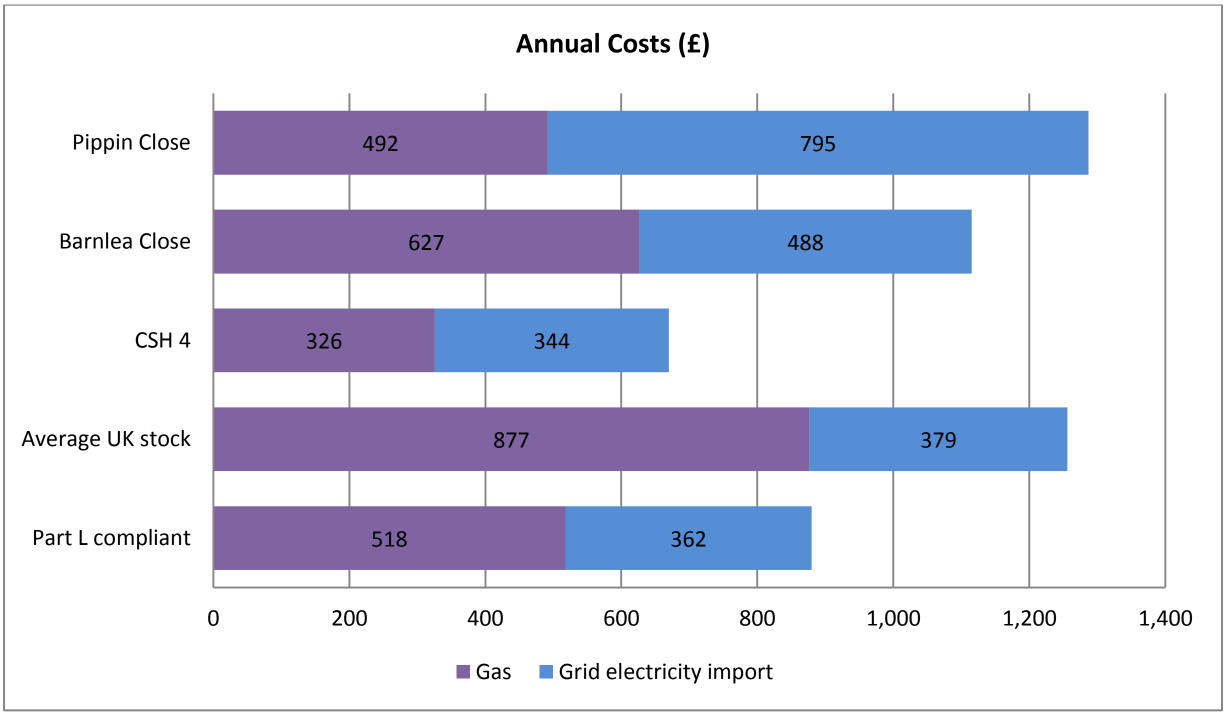


Figure 32 Annual costs from October 2013 to September 2014 and comparison with DomEarm benchmarks. Estimated price 0.11p/kWh.

8.3 Monitoring data

8.3.1 House 1

8.3.1.1 Energy balance

The total electrical energy from the grid used in the home during the monitoring period is 6,941kWh. This equates to an average of 19kWh/day (365 days). The amount of photovoltaic generated electricity (PV) used in the house and grid electricity import are shown in Figure 33. PV systems capacity is 1.65kWp. PV generation (use and export) from October 2013 to September 2014 is 907kWh. As-designed SAP indicates that the PV panels would generate 937 kWh/year; a figure that was nearly achieved. Gas consumption during that period is 15,867kWh.

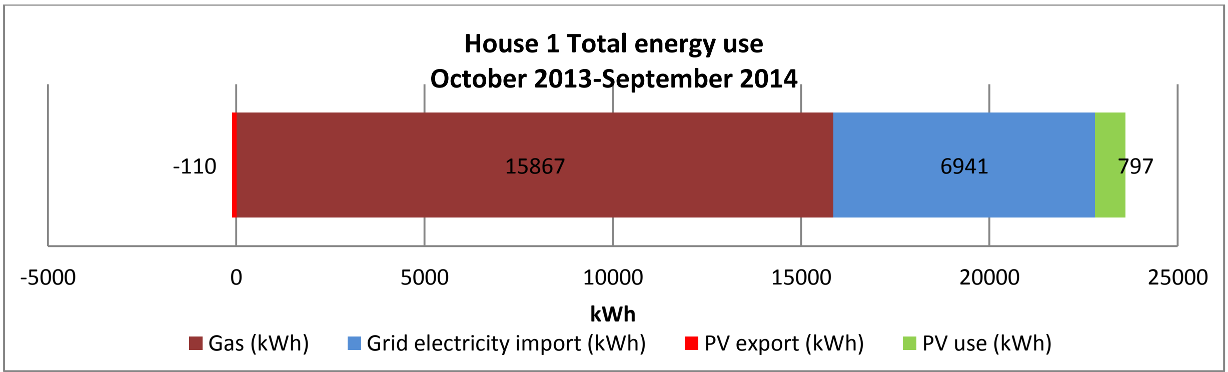
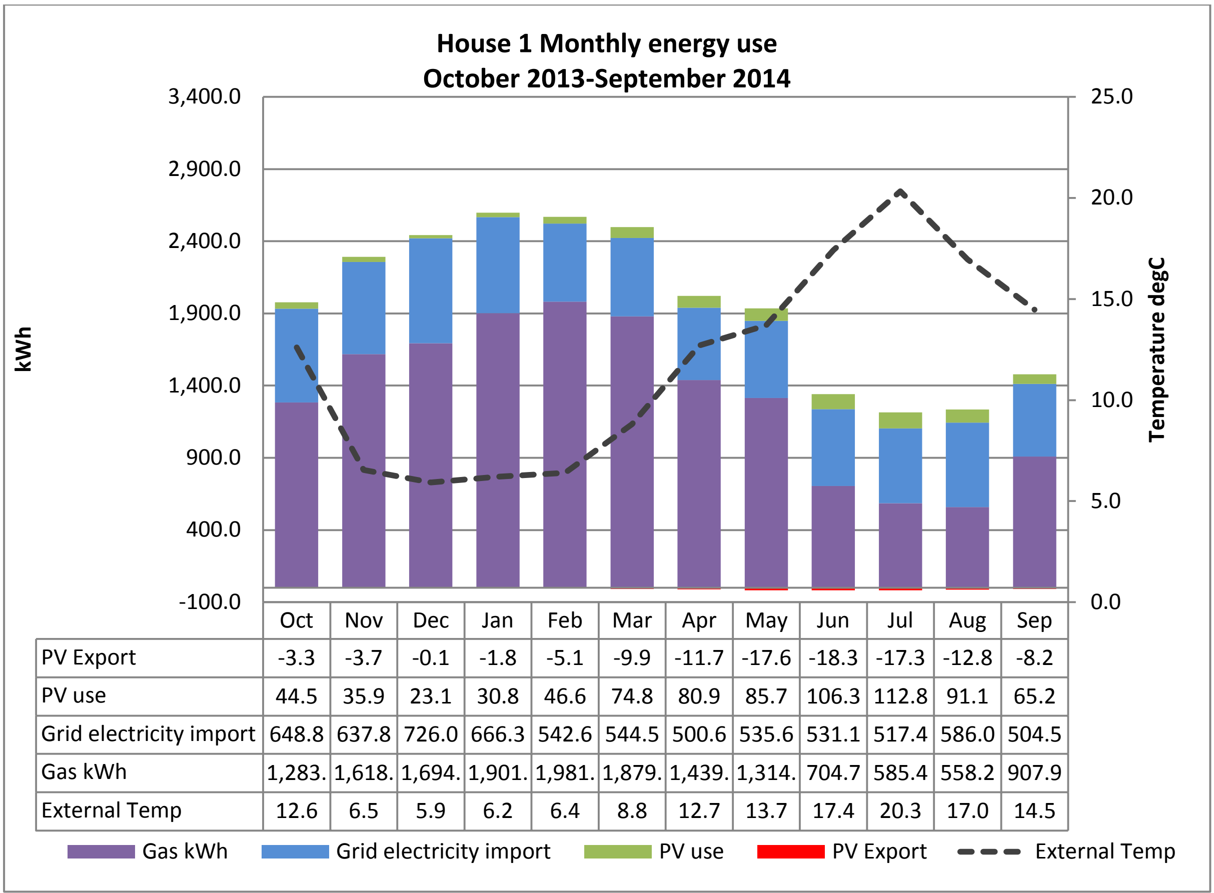


Figure 33 Total energy used in House 1 from October 2013 to September 2014

	kWh	kWh/m^2
Gas	15,867	123
Grid Import	6,941	54
PV Export	797	6
PV total	907	7

Figure 34 shows the monthly electricity use in House 1 from October 2013 to September 2014. Electricity import in June is close to 400kWh and reaches 700kWh in December. Gas consumption varies from 560kWh in August to 2000kWh in December.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
PV Export	-3.3	-3.7	-0.1	-1.8	-5.1	-9.9	-11.7	-17.6	-18.3	-17.3	-12.8	-8.2
PV use	44.5	35.9	23.1	30.8	46.6	74.8	80.9	85.7	106.3	112.8	91.1	65.2
Grid electricity import	648.8	637.8	726.0	666.3	542.6	544.5	500.6	535.6	531.1	517.4	586.0	504.5
Gas kWh	1,283.	1,618.	1,694.	1,901.	1,981.	1,879.	1,439.	1,314.	704.7	585.4	558.2	907.9
External Temp	12.6	6.5	5.9	6.2	6.4	8.8	12.7	13.7	17.4	20.3	17.0	14.5

Figure 34 Monthly electricity use in House 1 from October 2013 to September 2014.

Total annual energy use by end-uses is shown in Figure 35 and the percentage of energy use is shown in Figure 36. Energy used for space heating is 44% of the total energy used in the house, while appliances consume 31% of the total. Findings indicate that space heating and hot water consume more than half of the total energy used in the house.

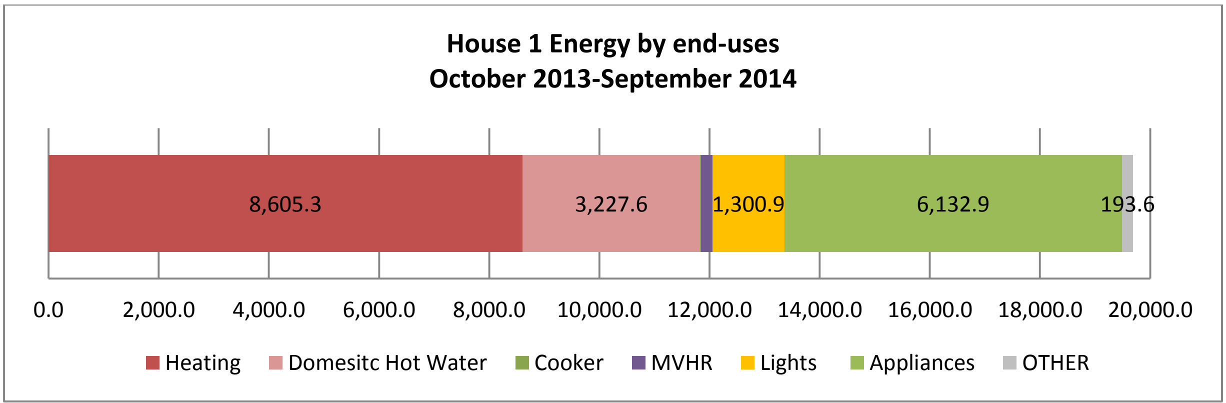


Figure 35 Total annual energy by end-uses from October 2013 to September 2014

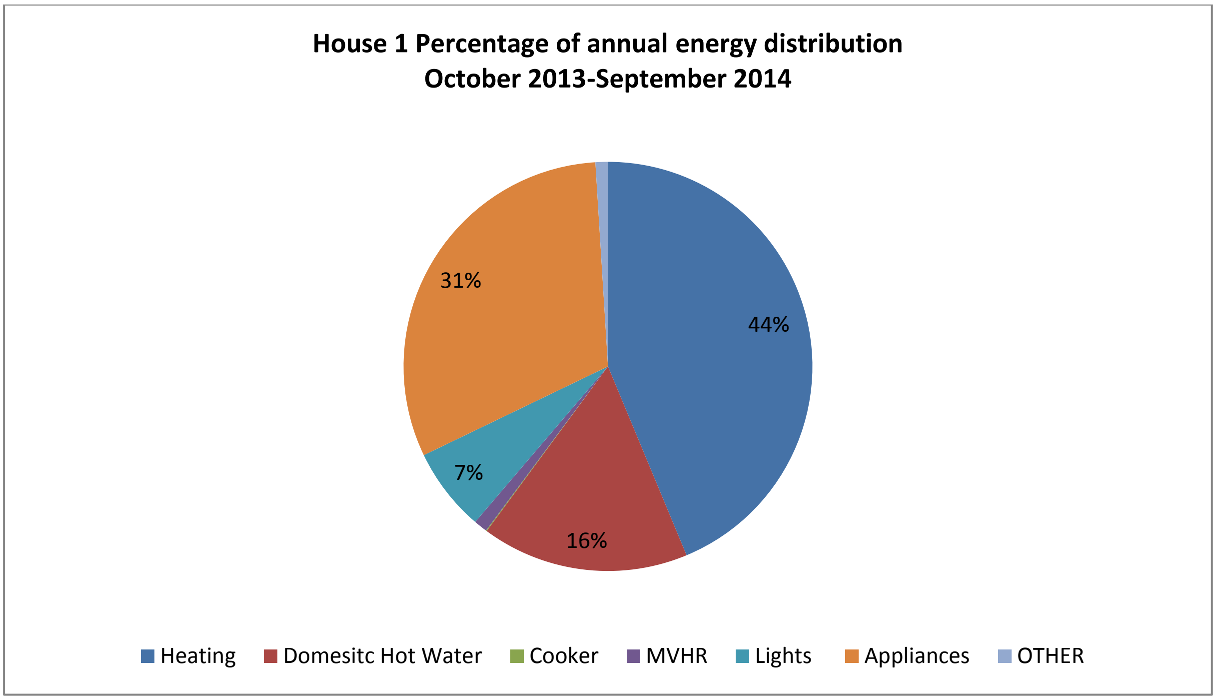


Figure 36 Percentage of annual energy distribution from October 2013 to September 2014.

Figure 37 shows the monthly energy use by end-uses in House 1 from October 2013 to September 2014. Appliances consume the highest amount of electricity in the house ranging from 350kWh in June to 570kWh in December. Lights consume around 120-140 kWh per month.

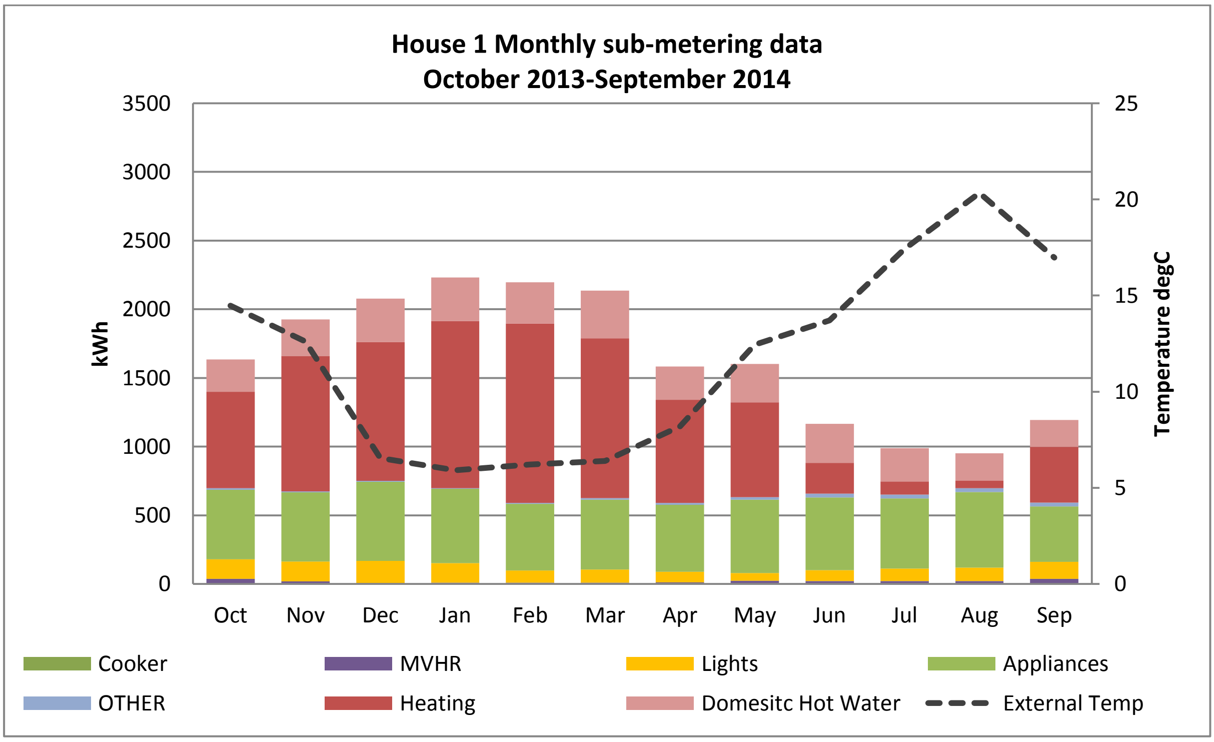


Figure 37 Monthly electricity use by end-uses in House 1 from October 2013 to September 2014.

Figure 38 shows the average hourly electricity profile over a day. Electricity import throughout the night ranges between 0.4-0.6kWh per hour. During the day grid electricity import drops as PV generated electricity is used instead. Grid electricity import peaks during the afternoon, reaching 1.2kWh at 17:00, when all the family is gathered in the house.

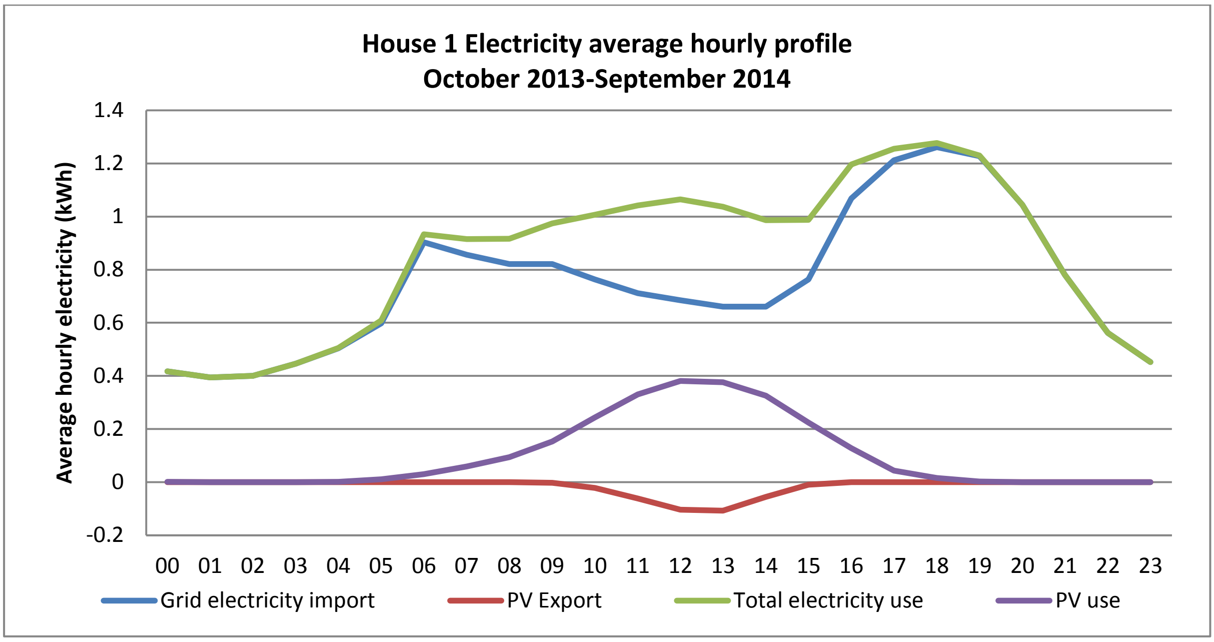
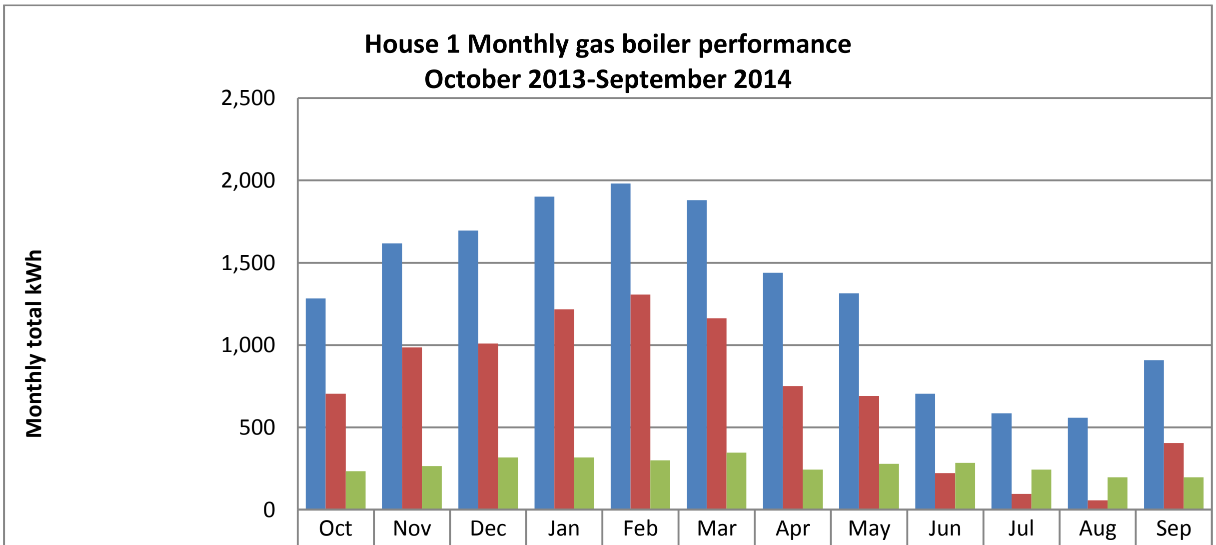


Figure 38 Average hourly electricity profile from October 2013 to September 2014.

Figure 39 shows the monthly gas boiler performance. During the monitoring period space heating energy ranges from 55kWh in August to 1300kWh in February. Domestic hot water energy is steady throughout the monitoring period ranging between 190-318 kWh per month, being slightly higher than the respective SAP values ranging from 140-200kWh.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Gas kWh	1,283	1,618	1,694	1,902	1,981	1,879	1,440	1,314	705	585	558	907.874
Heating Energy kWh	704	986	1,010	1,217	1,307	1,162	750	690	222	95	57	404.345
Domesitc Hot Water kWh	234	265	318	317	300	348	243	279	285	243	197	197.378

Gas kWh   Heating Energy kWh   Domesitc Hot Water kWh

Figure 39 Monthly gas boiler consumption from October 2013 to September 2014

8.3.1.2 Internal and external temperature

Over the two-year monitoring period the average daily external temperature drops significantly from 17°C in September 2012 to 5°C in December 2012. From December 2012 to April 2013 it ranges between -2 to 0°C and from mid-April 2013 it starts rising again reaching 25°C in July 2013 (Figure 40). The lowest temperatures were observed during December and January.

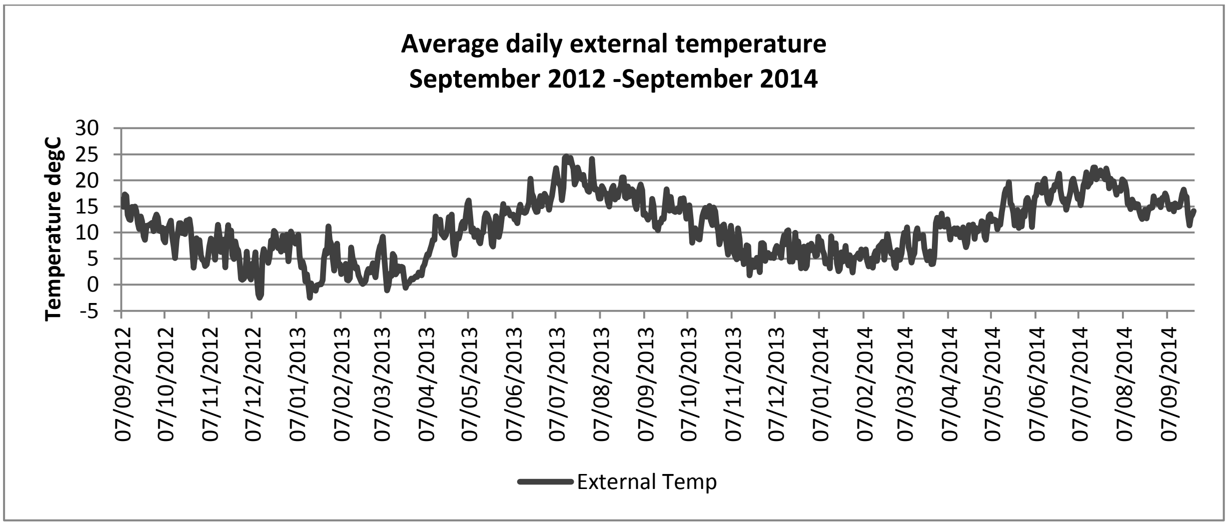


Figure 40 Daily average external temperatures from September 2012 to September 2014.

Figure 41 shows the average daily internal temperatures of the living room, the kitchen, and south bedroom. The temperatures for each space are close to the upper part of the comfort band of 20-25°C with the kitchen temperatures reaching 27°C even during winter months indicating that the house is overheated during winter and that there is great energy saving potential by re-adjusting the thermostat settings. During July 2013 temperatures were high above the comfort band reaching 30°C as the external temperature was around 25°C.

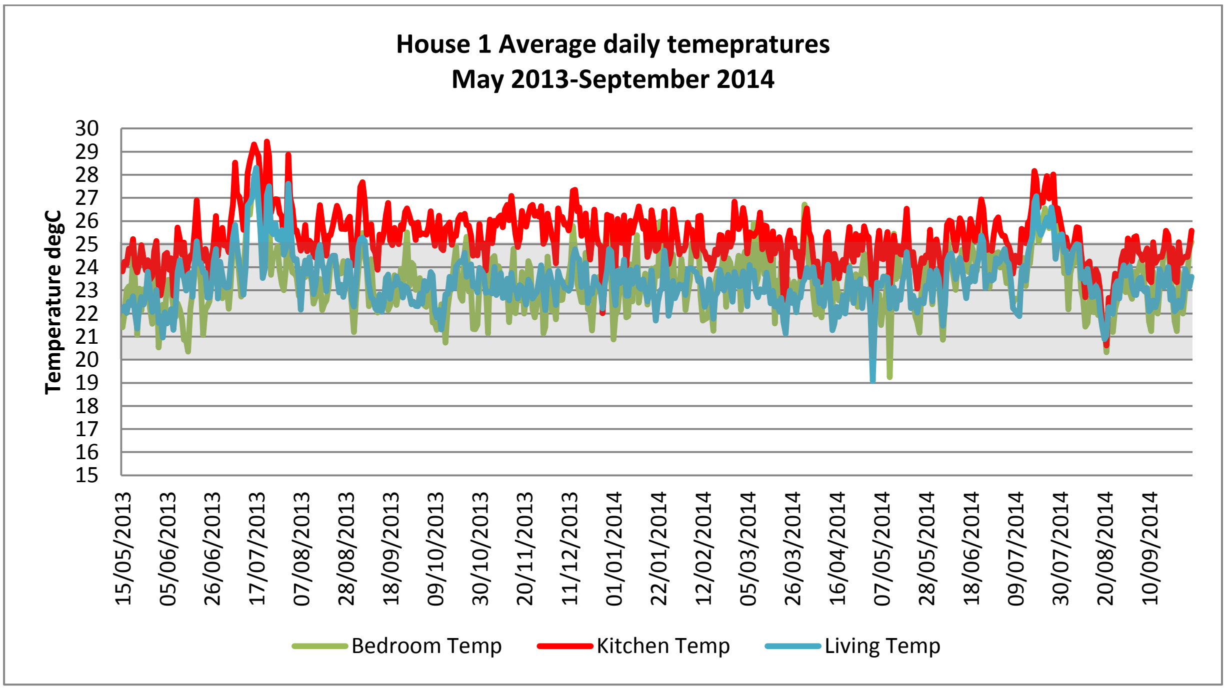


Figure 41 Average daily internal and external temperatures from May 2013 to September 2014.

Figure 42 shows the monthly mean, maximum and minimum temperatures recorded in the living room during the monitoring period. Monthly mean temperatures are close to the upper part of the comfort band. Mean temperatures in July and August are to the upper limit of the comfort band (25°C) and maximum temperatures reach 31°C suggesting that the house overheats during summer. However, these temperatures are related to the high external temperatures recorded during the July 2013 heat wave. Maximum winter temperatures show that the house is being overheated and clearly indicate that gas consumption could be reduced by adjusting the thermostats settings.

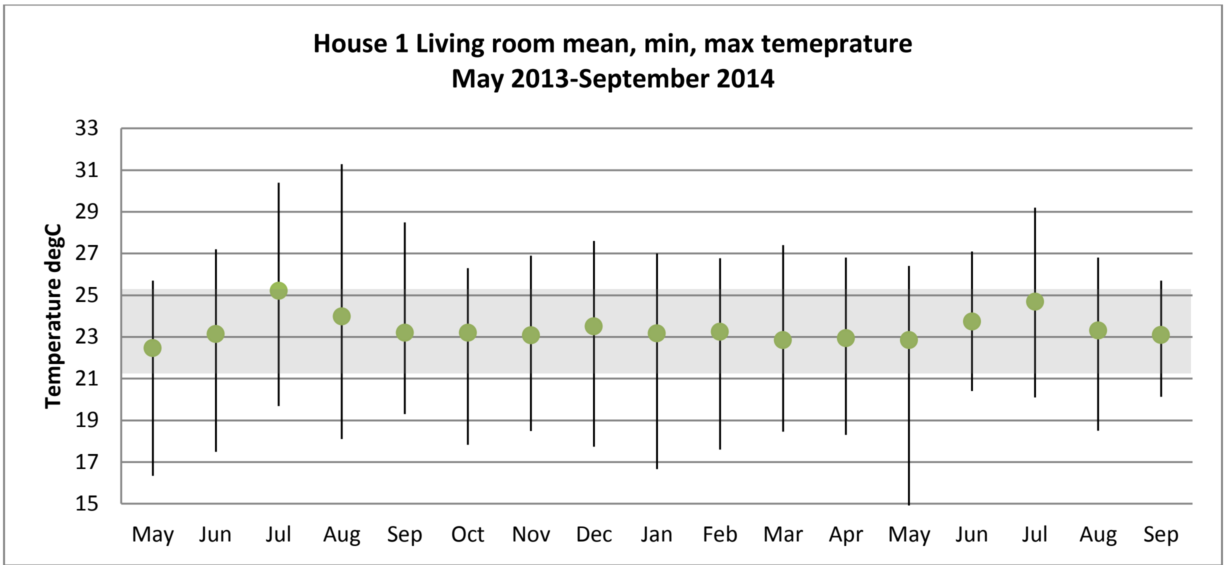


Figure 42 Living room temperatures: monthly mean, max, min from May 2013 to September 2014.

Temperatures in the living room and bedroom are between 22-24°C for 47-48% of the time and between 24-26°C for 26-29% of the time. Kitchen temperatures are high, remaining between 24-26°C for 48% of the time and above 26°C for almost 33% of the time (Figure 43).

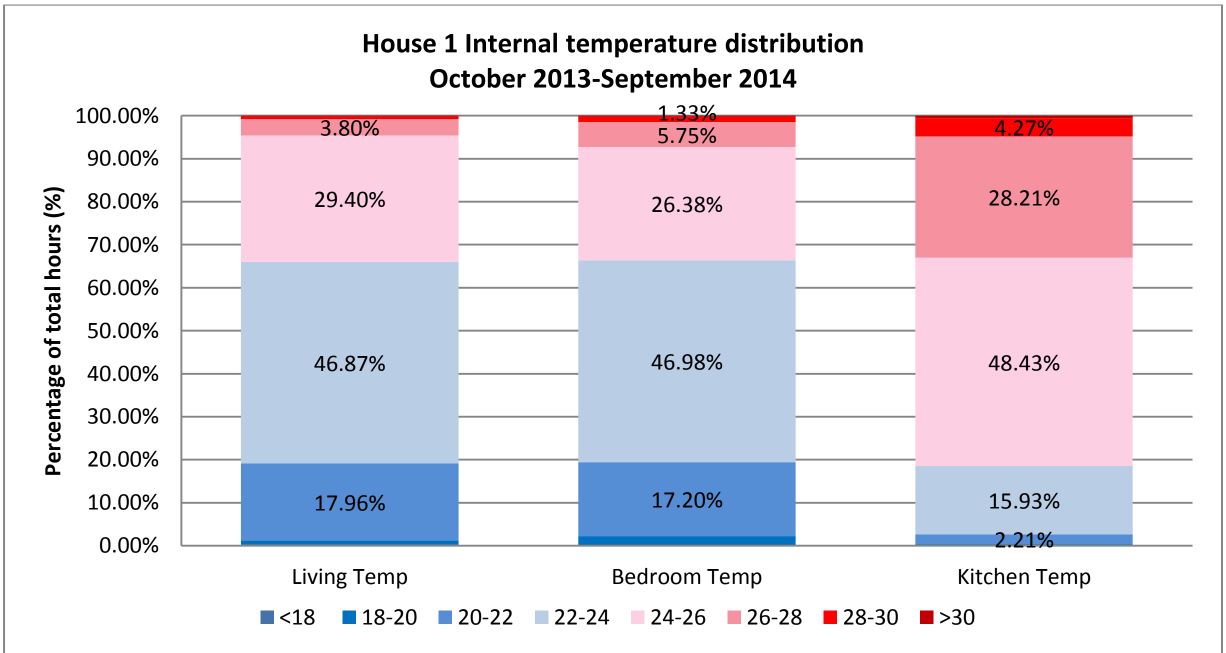


Figure 43 Internal temperature distribution from October 2013 to September 2014.

8.3.1.3 Internal and external relative humidity

Average daily RH levels reach 60%RH in September and fall to 40-50%RH during the winter months when the heating is turned on (Figure 44). RH levels follow the same pattern in all spaces. Of all the rooms, the kitchen appears to have the lowest RH levels, reaching 30%RH during winter, which are linked to the high temperatures recorded in that space.

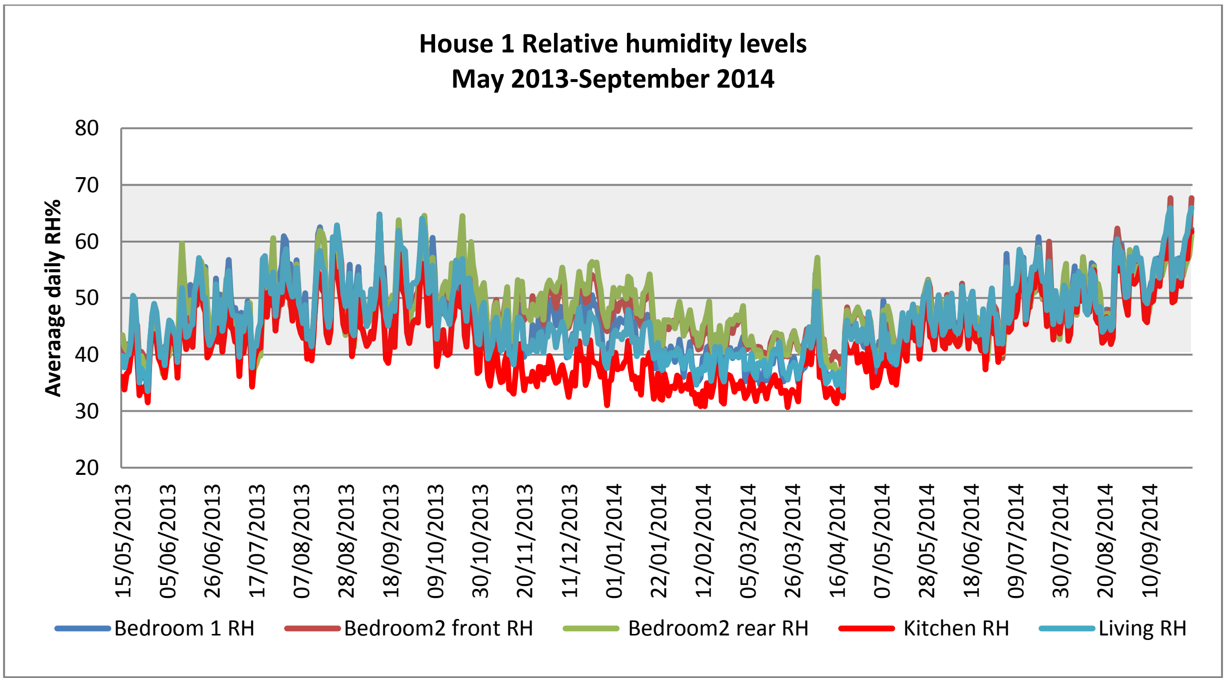


Figure 44 Internal and external RH with CIBSE recommended from May 2013 to September 2014.

Figure 45 shows the monthly mean, maximum and minimum relative humidity levels recorded in the living room. It is noticeable that RH levels gradually rise from May (40%) to September (50%). Maximum RH levels recorded are usually below 70%. Mean RH levels during winter months are around 40%.

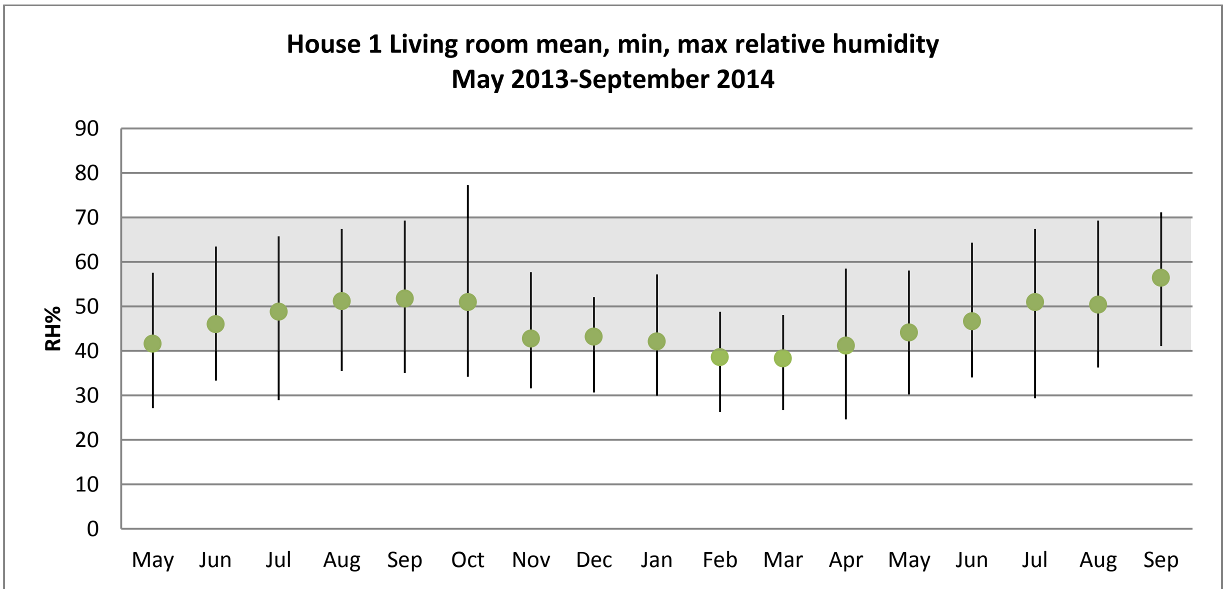


Figure 45 Living room relative humidity: monthly mean, max, min from May 2013 to September 2014.

Winter temperatures range between 20-27°C, while summer temperatures are higher; ranging between 22-29°C. Comfort conditions are achieved most of the time during winter and half of the time during summer (Figure 46). Relative humidity levels rise during summer as a result of increased ventilation.

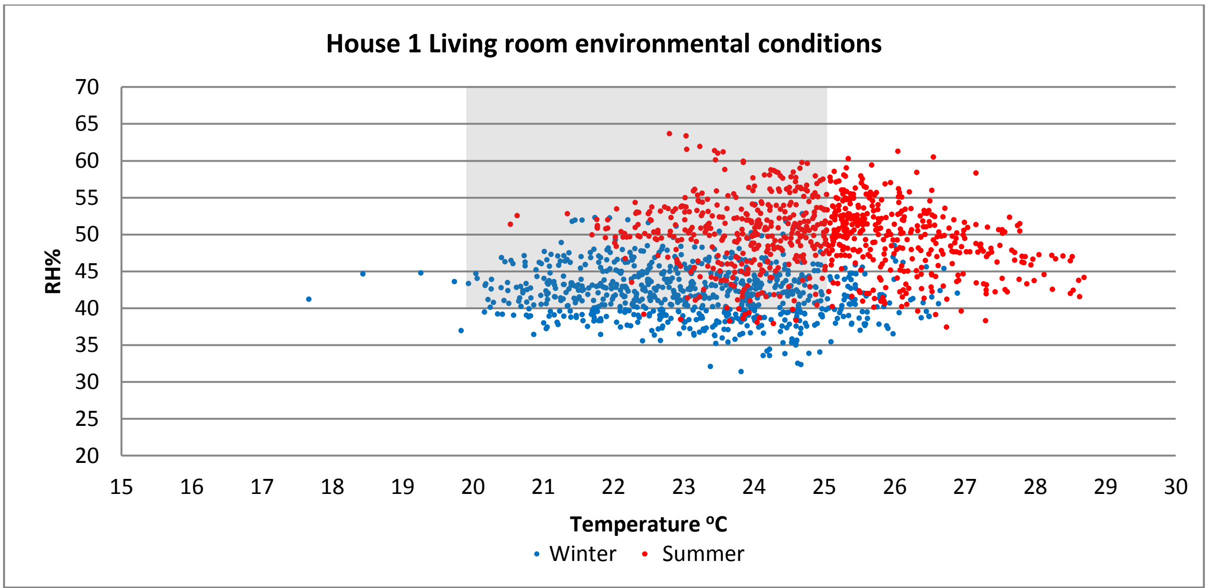


Figure 46 Environmental conditions in living room during winter (January 2014) and summer (August 2014).

8.3.1.4 Internal CO_2 as a proxy of air quality

Figure 47 shows the monthly mean, maximum and minimum CO_2 concentration in the living room from May 2013 to March 2014. The graph indicates that the CO_2 levels in the space are within acceptable levels as mean monthly values range between 400-700ppm. Maximum values can exceed the ASHRAE recommended limit of 1000ppm but rarely exceed 1500ppm. Mean and maximum CO_2 levels have risen since mid-November when the MVHR system was re-balanced.

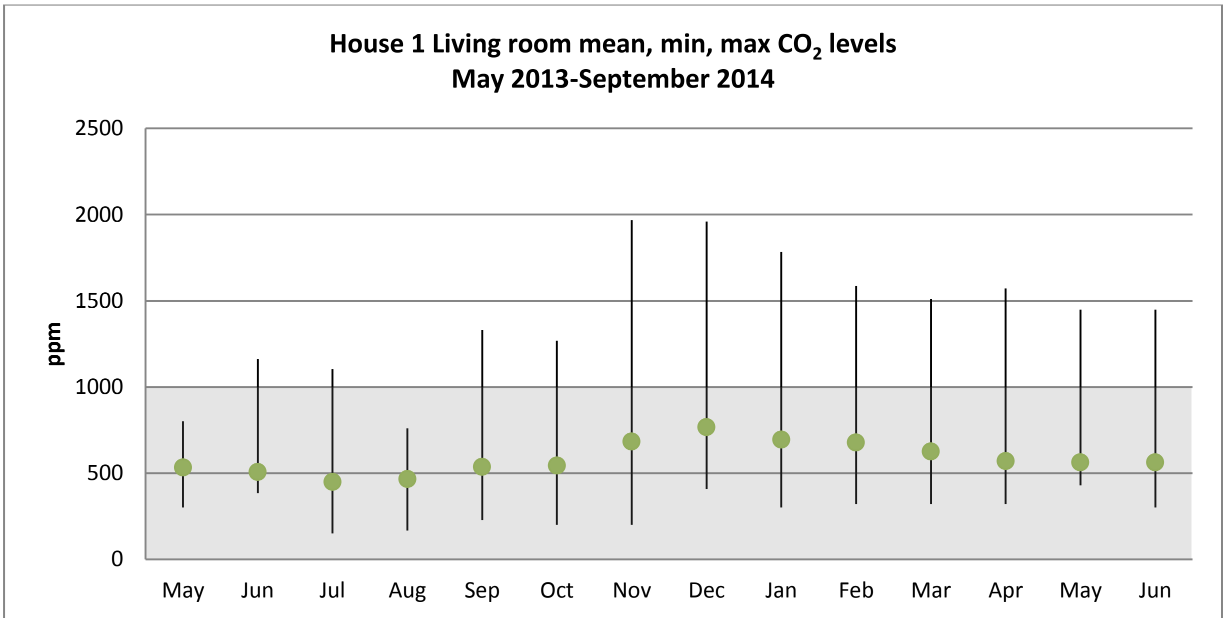


Figure 47 Living room CO_2 concentration levels: monthly mean, max, min from May 2013 to September 2014.

CO_2 concentration in the living room remains between 500-1000ppm for 55% of the time. Bedroom CO_2 levels remain between 500-1000ppm for 65% of the time and above 1500ppm for 7% of the time (Figure 48).

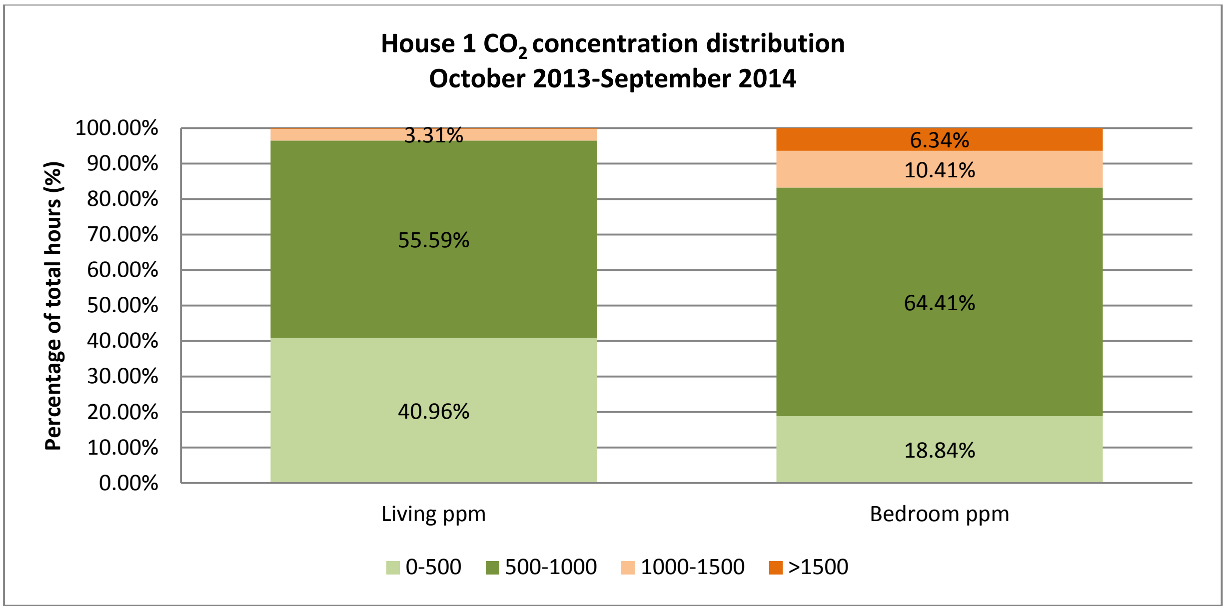


Figure 48 CO_2 concentration distribution from October 2013 to September 2014.

CO_2 levels during summer rarely exceed 500ppm, whereas during winter CO_2 levels range between 500-1000ppm (Figures 49, 50). These findings indicate that the air quality in the houses is good during both seasons.

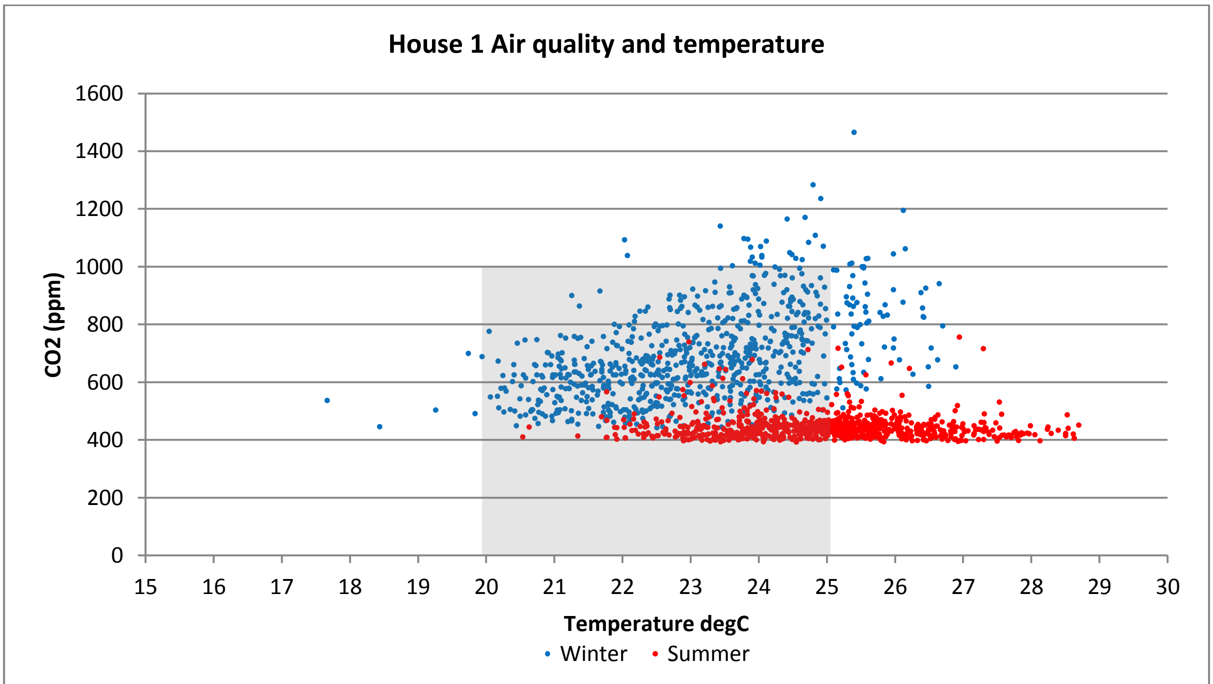


Figure 49 Living room air quality and temperature during winter (January 2014) and summer (August 2014).

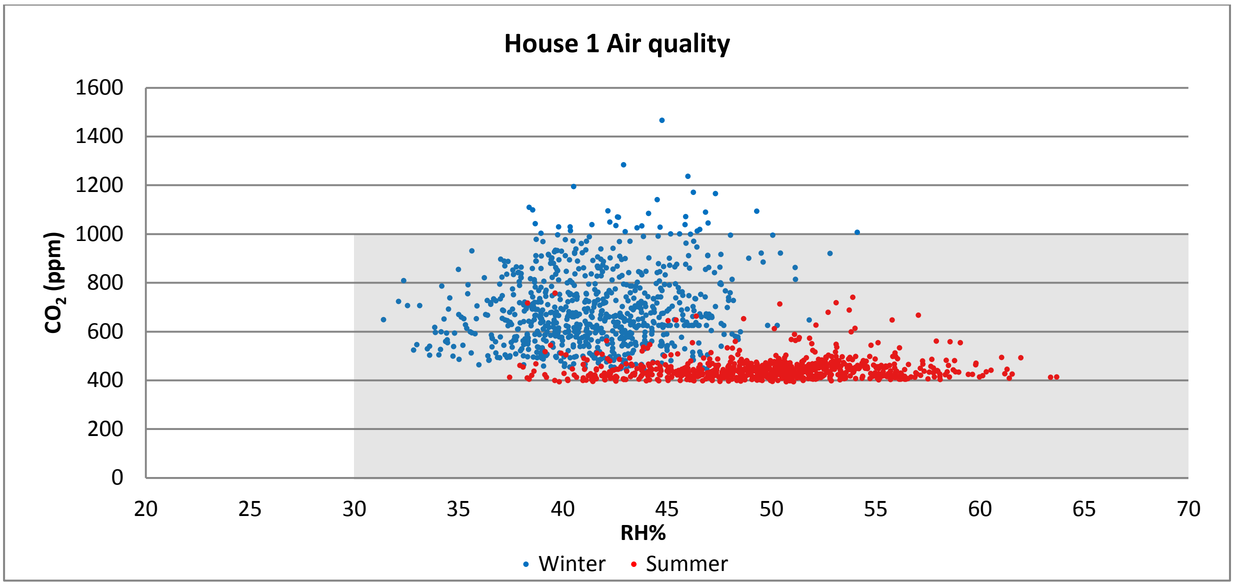


Figure 50 Living room air quality during winter (January 2014) and summer (August 2014).

8.3.2 House 2

8.3.2.1 Energy balance

The total electrical energy from the grid used in the home during the monitoring period is 4,254 kWh. This equates to an average of 11kWh/day (365 days). The amount of photovoltaic generated electricity (PV) used in the house and grid electricity import are shown in Figure 51. Total electricity generated by the PV panels is 1,238kWh, out of which 819kWh was used in the house. The as-designed SAP estimate for annual PV generation in the house is 1351kWh.

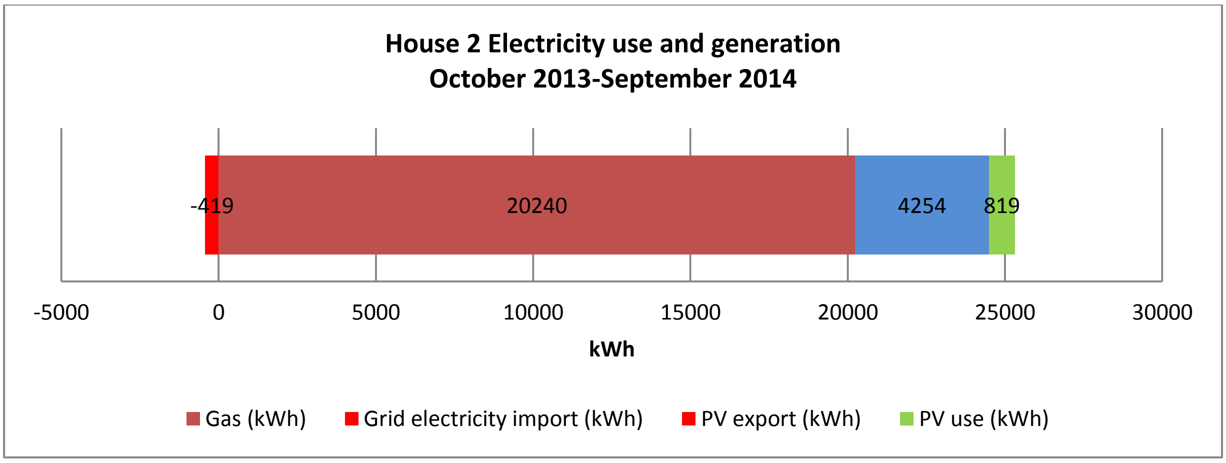
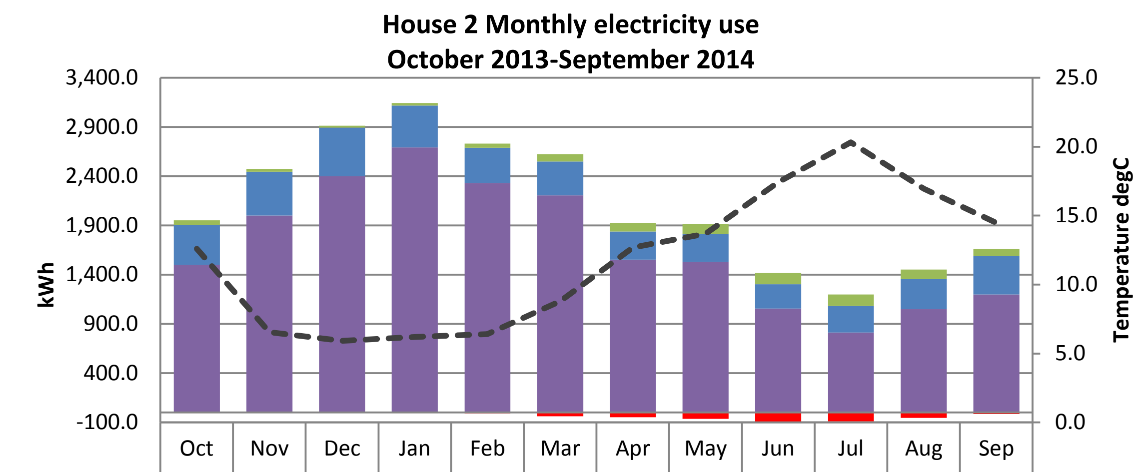


Figure 51 Total electricity used and generated in House 2 from October 2013 to September 2014.

	kWh	kWh/m^2
Gas	20,240	138
Grid Import	4,253	29
PV Export	-419	2.8
PV total	1,238	8.5

Figure 52 shows the monthly energy use and PV generation in House 2 from October 2013 to September 2014. Electricity import in June is 250kWh and reaches 500kWh in December. PV electricity generation peaks in July reaching 200kWh, whereas in December it drops to 20kWh.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
PV use	43.4	28.9	19.3	26.2	41.9	74.0	88.1	99.1	112.0	115.6	97.2	73.6
PV Export	-5.1	-2.0	-1.2	-4.59	-8.78	-36.8	-47.6	-63.5	-92.4	-89.1	-53.3	-15.0
Grid Electricity import	408.4	445.1	494.4	425.6	357.6	344.4	284.7	285.6	246.5	270.4	303.2	388.3
Gas kWh	1,500	2,000	2,400	2693	2333	2206	1554	1532	1057	812.2	1051	1,200
External Temp degC	12.6	6.5	5.9	6.204	6.4	8.8	12.69	13.7	17.42	20.33	16.96	14.5

Figure 52 Monthly electricity use in House 2 from October 2013 to September 2014.

Total annual electricity use by end-uses is shown in Figure 53 and the percentage of energy use is shown in Figure 54. Electricity used by appliances is 72% of the total energy used in the house, while the cooker consumes 15% and the lights and MVHR consumes 5% and 6% respectively.

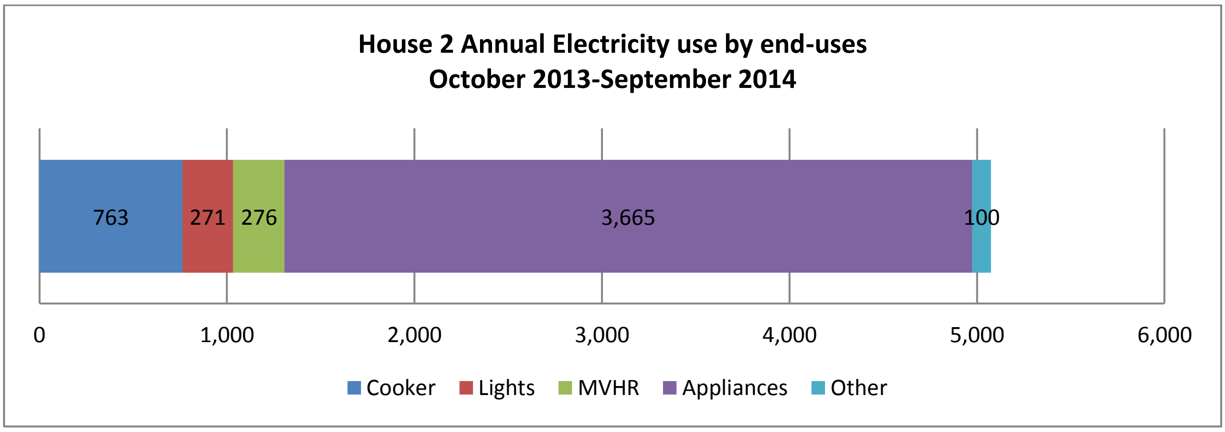


Figure 53 Total annual electricity use by end-uses from October 2013 to September 2014

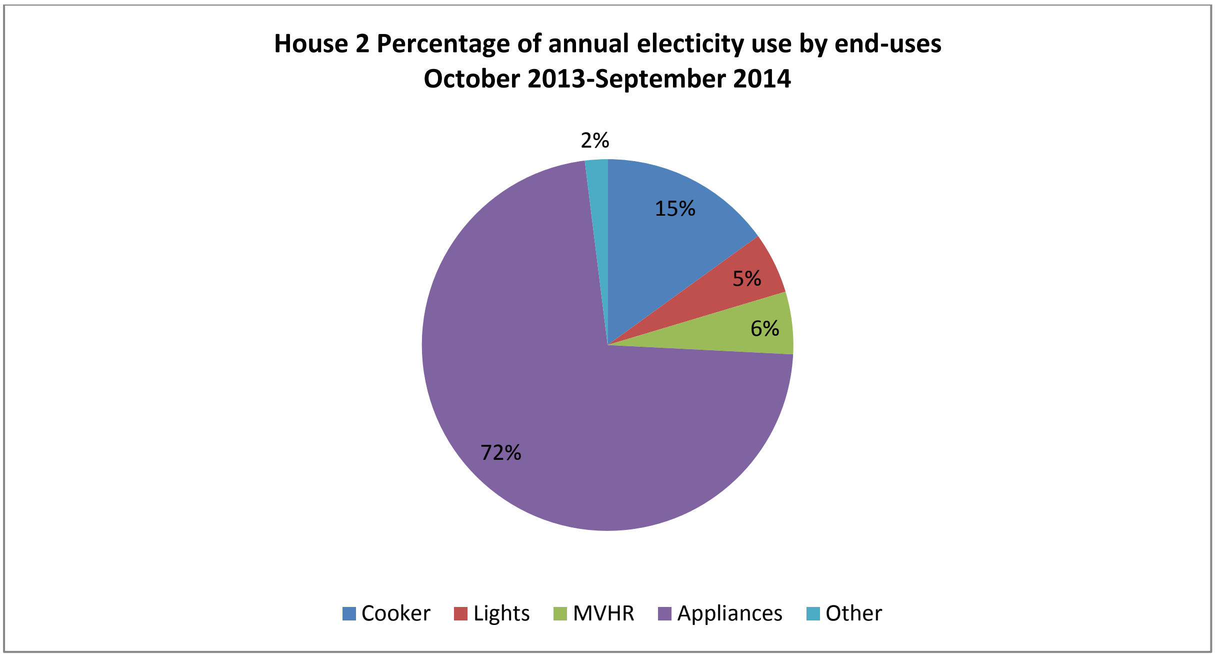


Figure 54 Percentage of annual electricity use by end-uses from October 2013 to September 2014.

Figure 55 shows the monthly electricity use by end-uses in House 2 from October 2013 to September 2014. Appliances appear to consume the highest amount of electricity in the house ranging from 250-350 kWh per month. The MVHR system consumed around 60kWh per month but since it was re-balanced in mid-November that figure went down to 11kWh/month. However, it is considered problematic that the MVHR system was on during the summer months. Lights consume between 10-40 kWh per month. Cooker electricity consumption is around 60-90kWh per month.

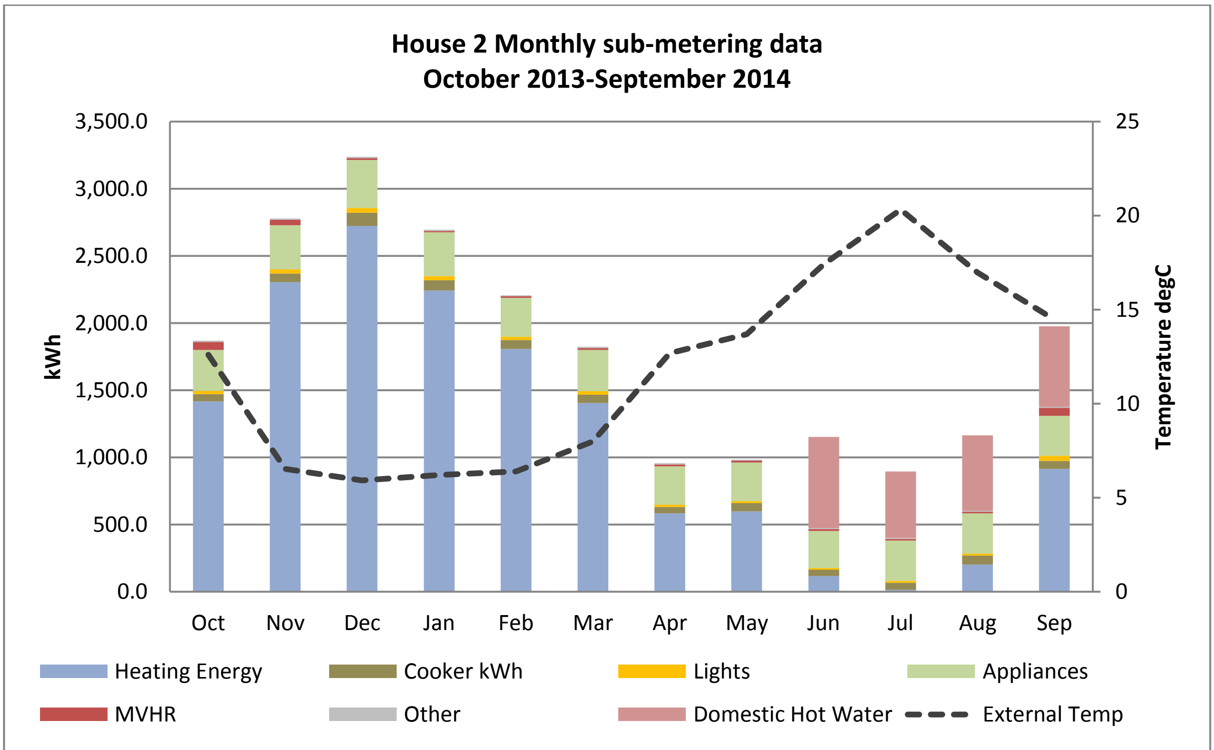


Figure 55 **Monthly electricity use by end uses in House 2 from October 2013 to September 2014.**

Figure 56 shows the average hourly electricity profile during a day. Electricity import is steady throughout the night (0.3-0.4kWh per hour) and starts dropping during the day as PV generated electricity rises. PV generated electricity use peaks at midday and then gradually drops. Grid electricity import peaks during the afternoon, reaching 1.2kWh at 18:00, when the occupants return in the house and more appliances are being used.

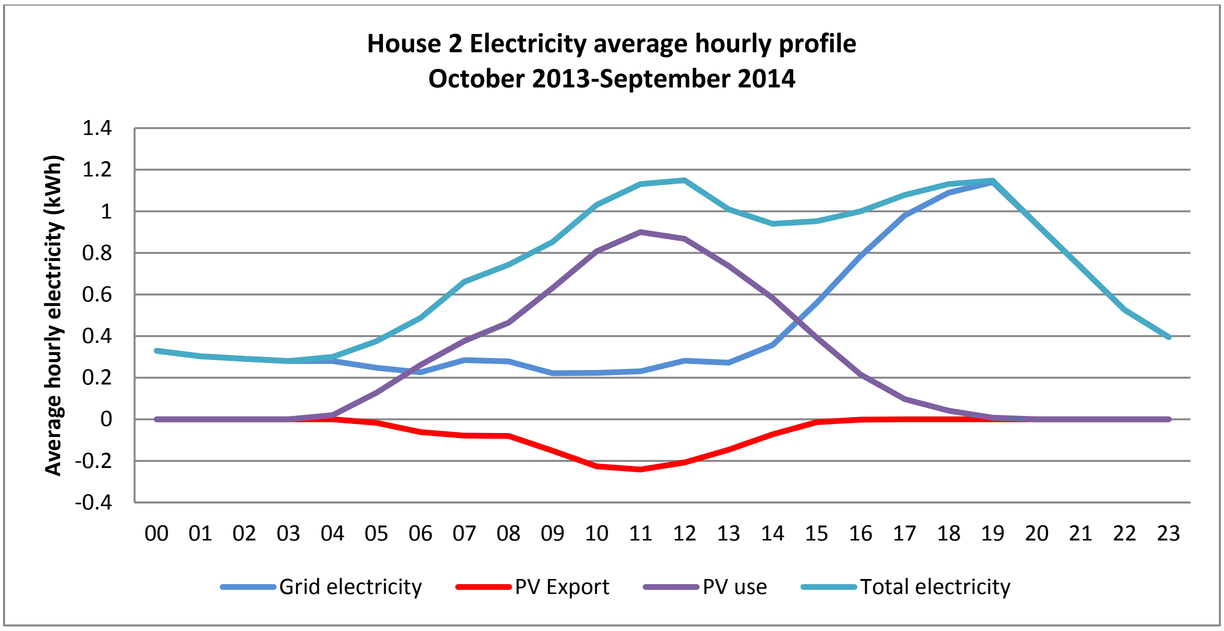
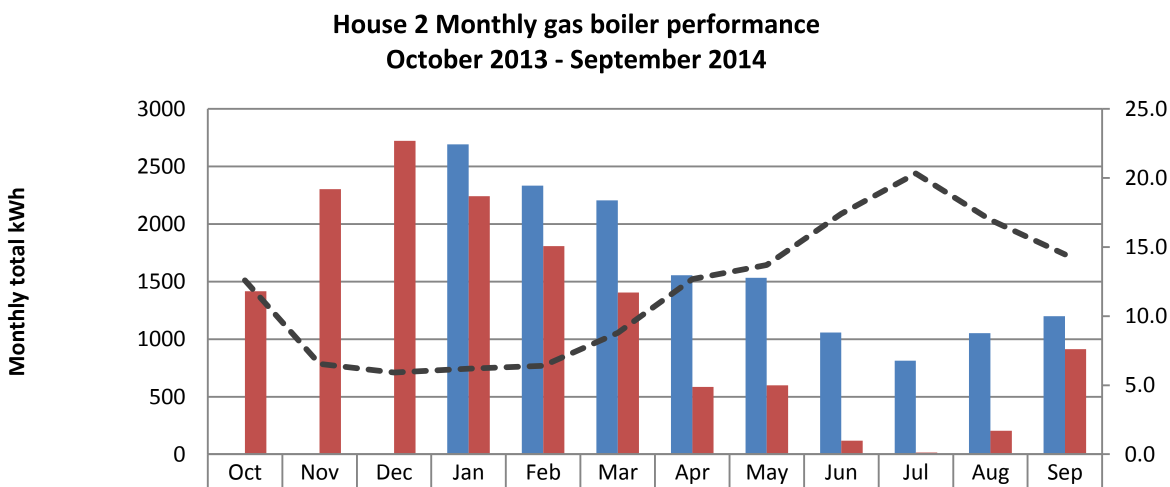


Figure 56 Average hourly electricity profile from October 2013 to September 2014.

Figure 57 shows the monthly gas boiler performance. During the monitoring period space heating energy ranges between 900 kWh in September to 2,722kWh in December.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Gas kWh				2,693	2,333	2,206	1,554	1,532	1,057	812	1,051	1,200
Heating Energy	1,416	2,304	2,723	2,243	1,807	1,405	584	599	117	15	203	914
Temperature degC	12.6	6.5	5.9	6.2038	6.4	8.8	12.694	13.698	17.415	20.327	16.964	14.5

Gas kWh — Heating Energy — Temperature degC

Figure 57 Monthly space heating and domestic hot water energy demand from October 2013 to September 2014.

8.3.2.2 Internal and external temperature

Figure 58 shows the average daily internal temperatures of the living room, the kitchen and of two bedrooms. The temperatures for each space during the winter months are close to the lower part of the comfort band of 20-25^{o}C. The highest temperatures were recorded in Bedroom 2 and the lowest temperatures were recorded in the kitchen. During July temperatures were high above the comfort band reaching 30^{o}C as the external temperature was around 25^{o}C. As mentioned above, the heating was on during the summer because of a system breakdown. In order to get rid of excess heat the occupants kept the windows open throughout the day. From October onwards temperatures fall around 20^{o}C and occupants continue to leave the bedroom and living room windows open for most of the day. This behaviour is not efficient and explains the high space heating energy demand during November and December.

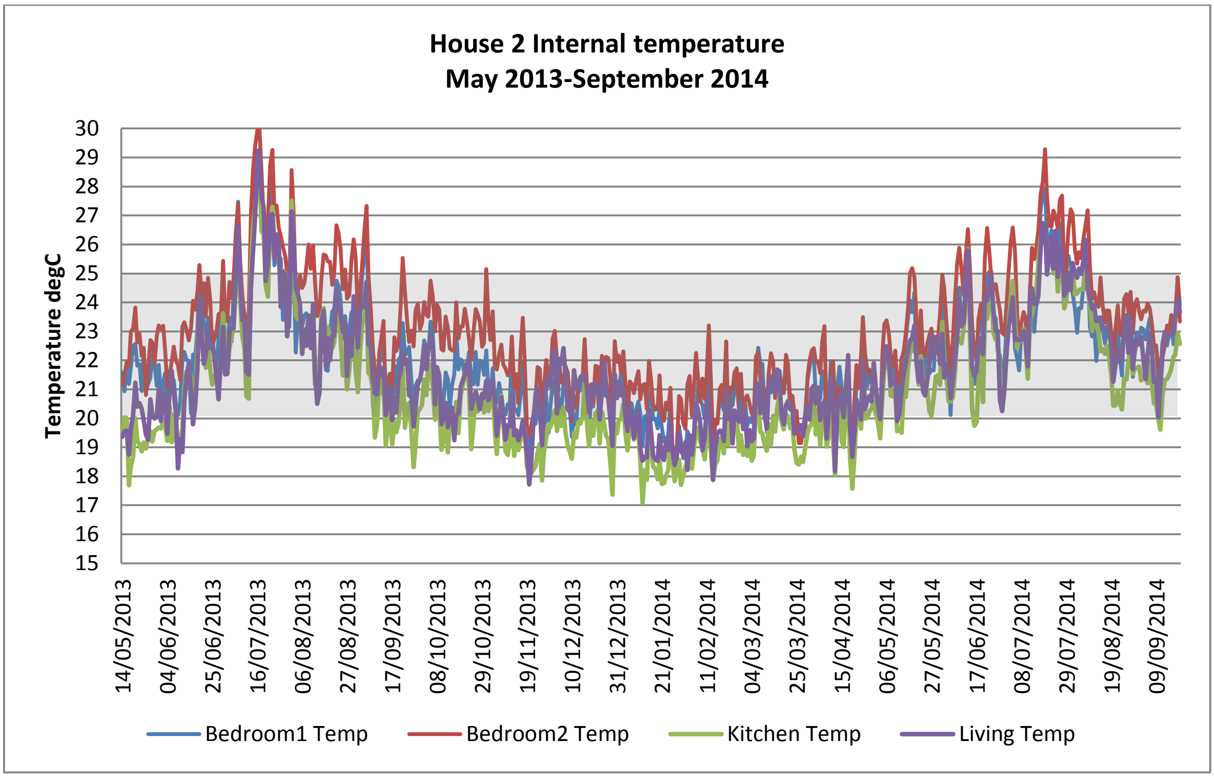


Figure 58 Daily average internal and external temperatures (May 2013-September 2014).

Figure 59 shows the monthly mean, maximum and minimum temperatures recorded in the living room during the monitoring period. Monthly mean temperatures range from 20^{o}C in May to 25^{o}C in July. Mean temperatures in July and August (2014) are close to the upper limit of the comfort band (25^{o}C) and maximum temperatures reach 32^{o}C suggesting that the house was overheating significantly during the summer months. However, these temperatures are related to the high external temperatures recorded during the July heat wave and the heating system breakdown. During the winter months (November-February) average monthly temperatures range between 20-21^{o}C but maximum temperatures exceed 26^{o}C. On-site inspection revealed that the occupants set the thermostat at 30^{o}C and leave the windows open thus increasing the space heating energy demand and gas consumption.

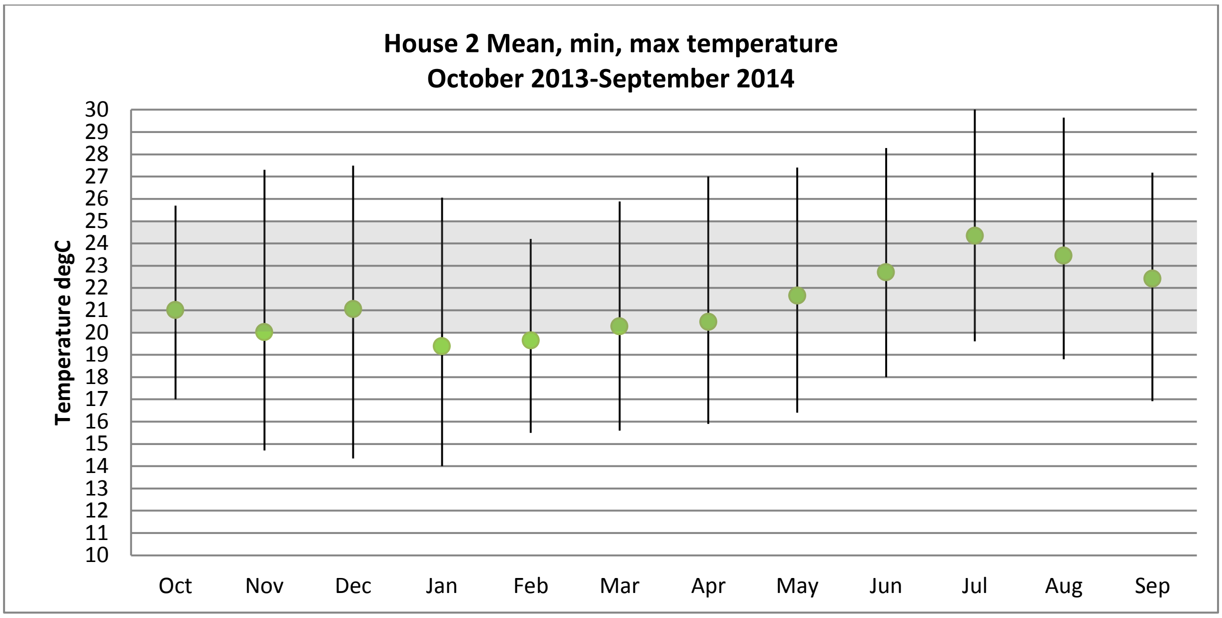


Figure 59 Living room temperatures: monthly mean, max, min (October 2013 – September 2014).

Temperatures in the living room and kitchen are between 20-22°C for 33% of the time, 22-24°C for 16-22% of the time and above 26°C for 4% of the time. Bedroom temperatures are higher, remaining between 20-22°C for 39% of the time, between 22-24°C for 27% of the time and above 26°C for 4% of the time (Figure 60).

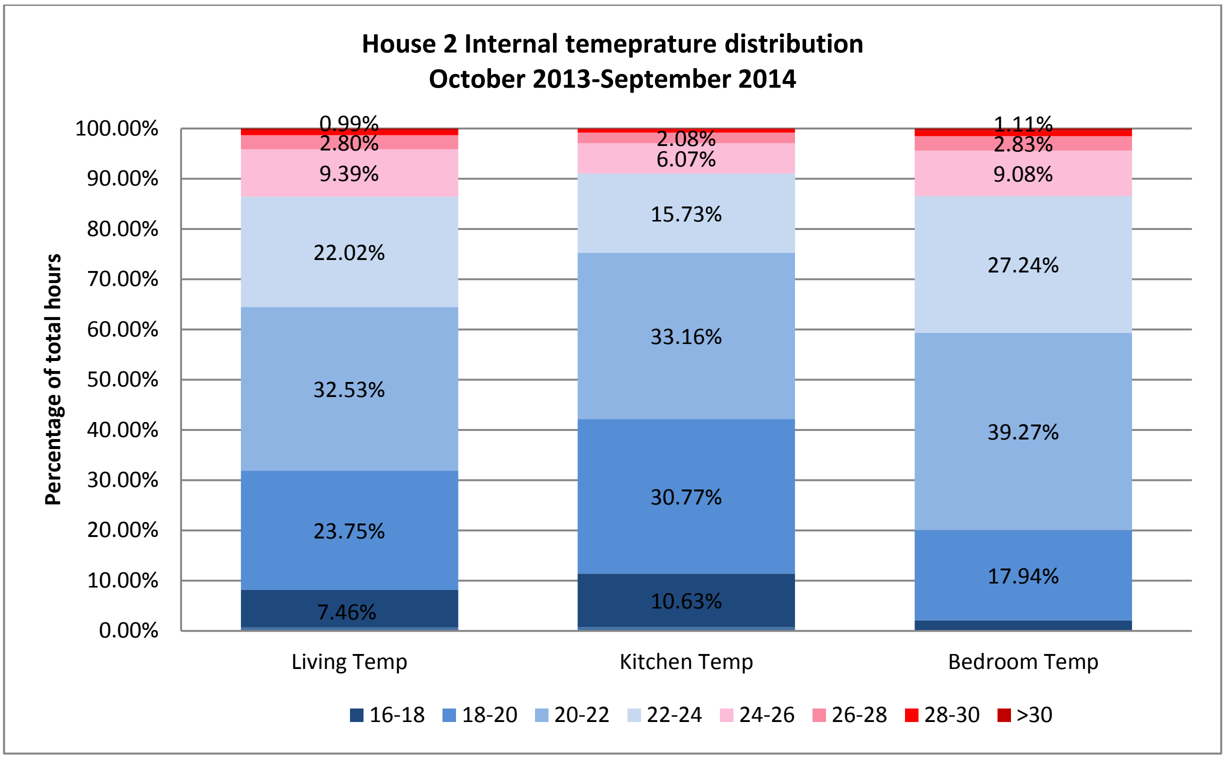


Figure 60 Internal temperature distribution from October 2013 to September 2014.

8.3.2.3 Internal and external relative humidity

Average daily relative humidity in the house remains within the CIBSE recommended range of 40-70% throughout the monitoring period (Figure 61). RH levels gradually rise reaching 70% in September. RH levels follow the same pattern in all spaces.

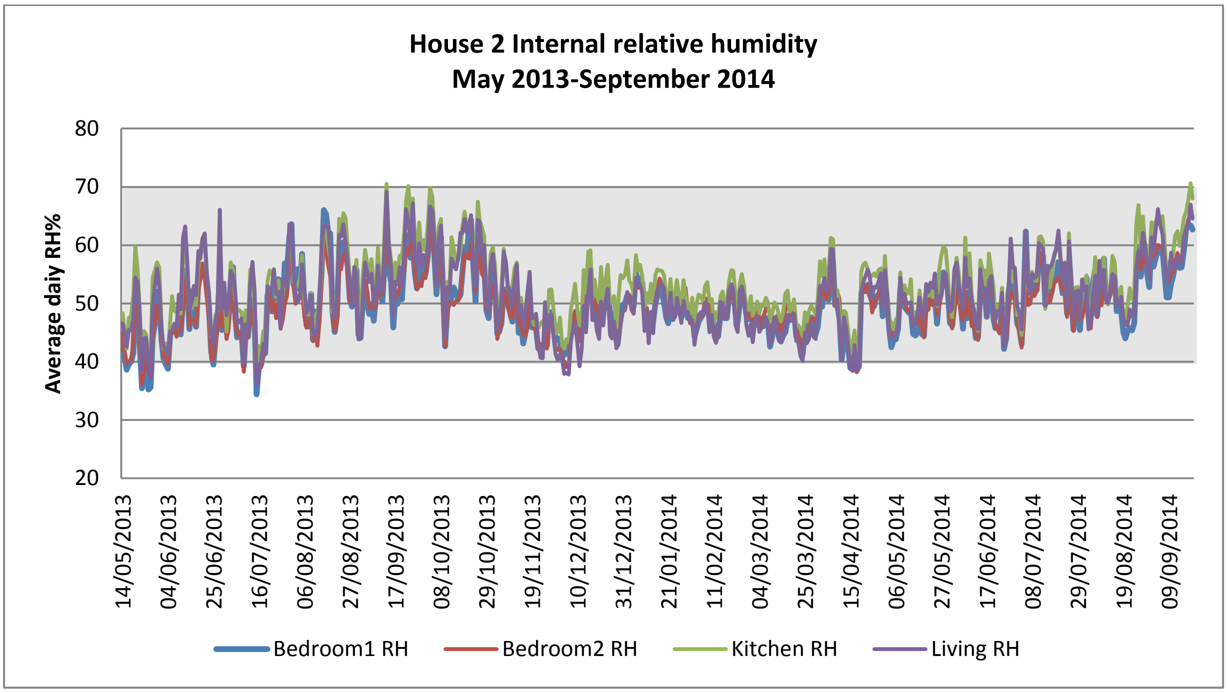


Figure 61 Internal and external relative humidity levels (May 2013-September 2014).

Figure 62 shows the monthly mean, maximum and minimum relative humidity levels recorded in the living room. Maximum RH levels recorded rarely exceed the CIBSE band upper level of 70%.

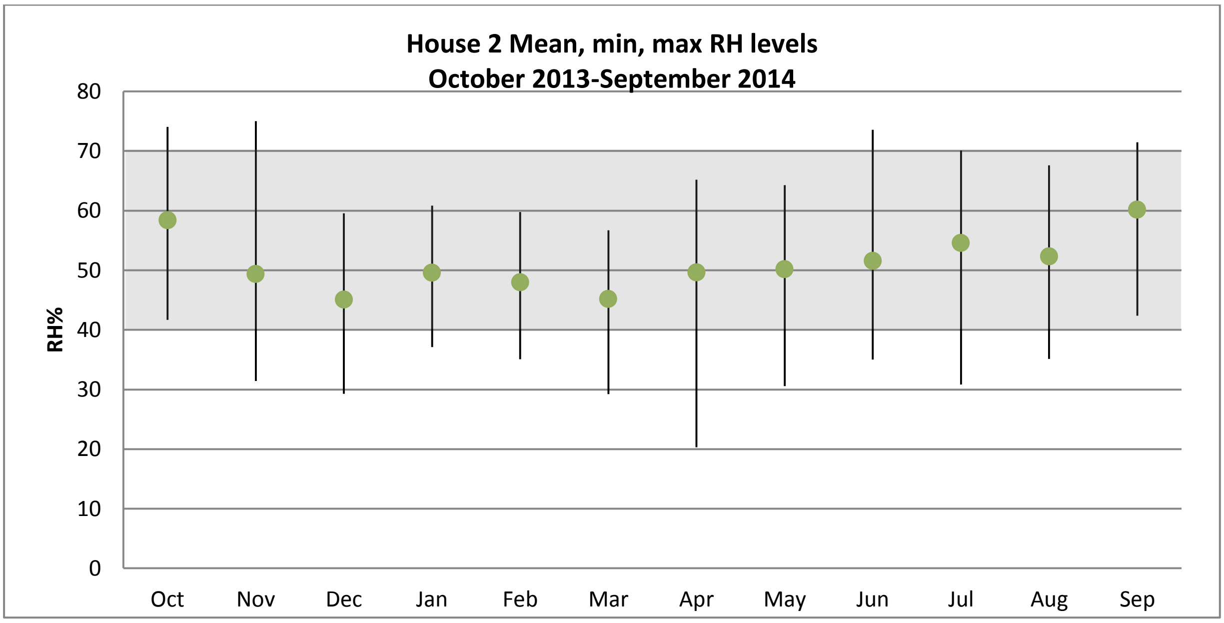


Figure 62 Living room relative humidity: monthly mean, max, min (October 2013-September 2014).

Winter temperatures range between 20-27°C while summer temperatures are higher, ranging between 22-29°C. Comfort conditions (in terms of both RH and temperature) are achieved during most of the time during winter and half of the time during summer (Figure 63). Relative humidity levels during summer range between 40-60%, while the winter values are lower due to reduced ventilation levels.

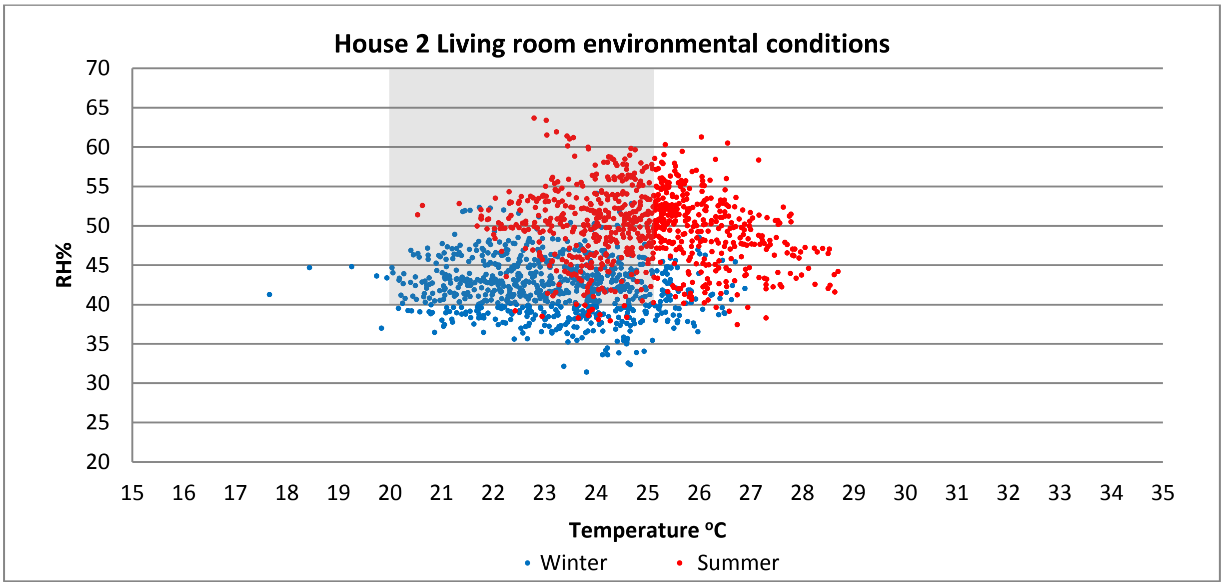


Figure 63 Living room environmental conditions during winter (January 2014) and summer (August 2014).

8.3.2.4 Internal CO_2 as a proxy of air quality

Figure 64 shows the monthly mean, maximum and minimum CO_2 concentration in the living room. Average monthly CO_2 levels in the space are within acceptable levels ranging between 400-650ppm. Maximum values can exceed the ASHRAE recommended limit of 1000ppm exceeding 1500ppm during the winter months.

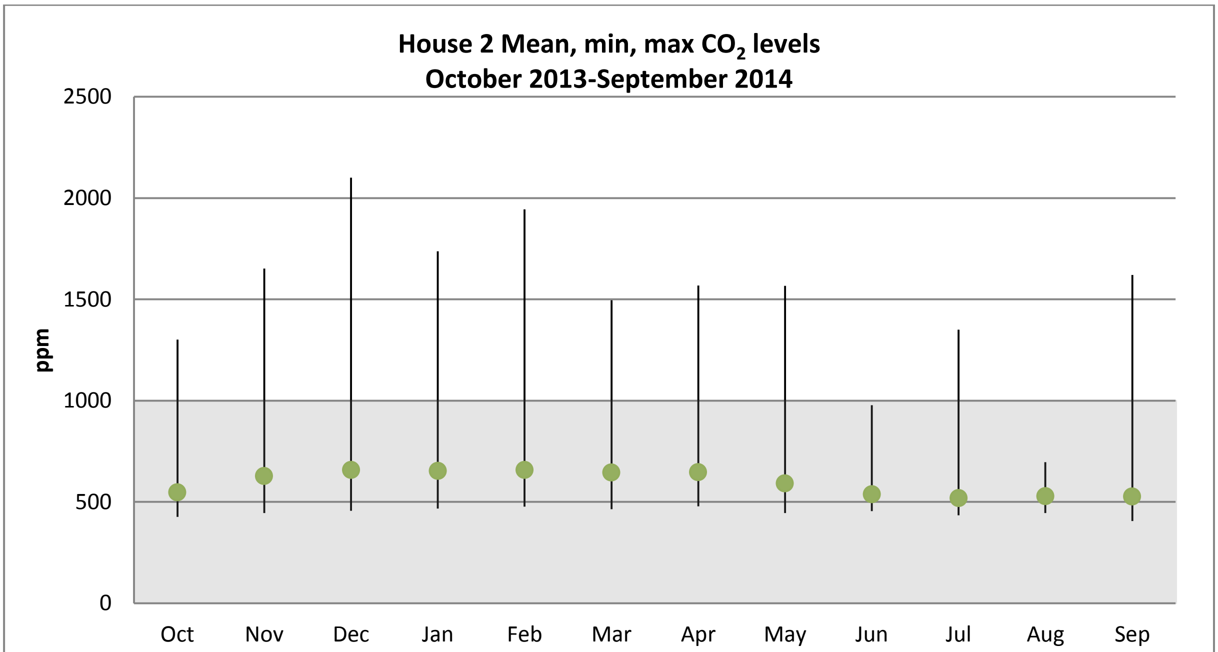


Figure 64 Living room CO_2 concentration levels: monthly mean, max, min (October 2013-September 2014).

CO_2 concentration in the living room remains between 500-1000ppm for 67% of the time. Bedroom CO_2 levels remain between 500-1000ppm for 62% of the time and above 1500ppm for 6% of the time (Figure 65).

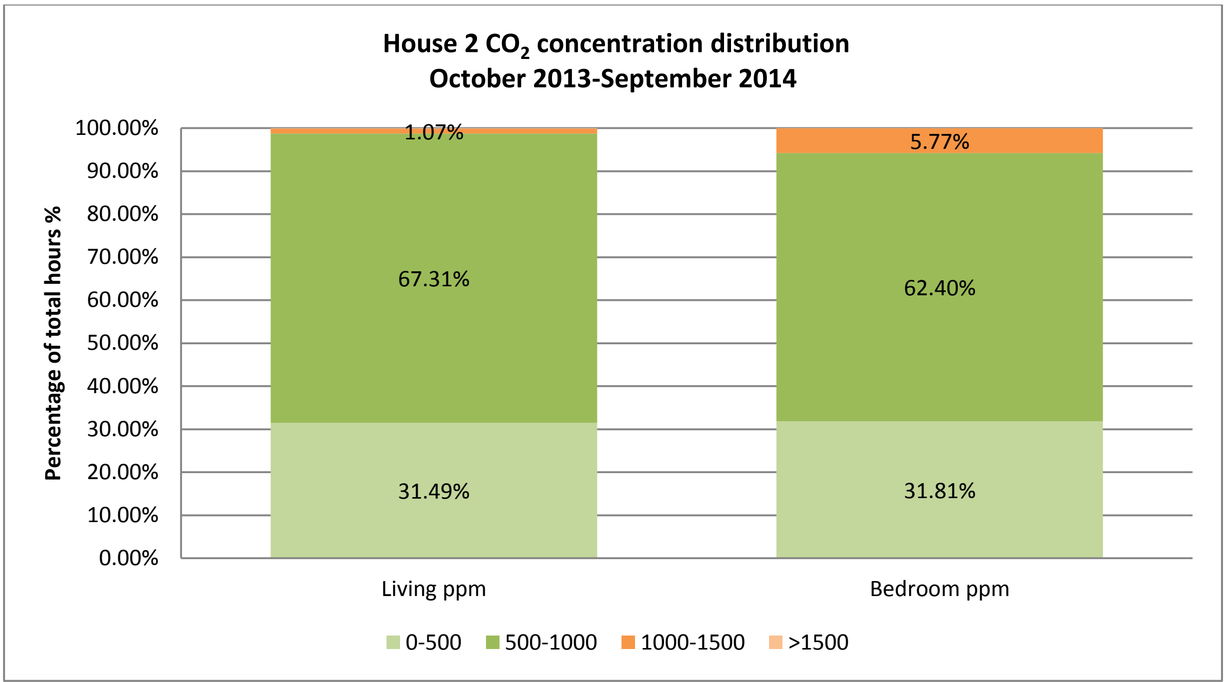


Figure 65 CO_2 concentration distribution from October 2013 to September 2014.

CO_2 levels during summer rarely exceed 500ppm, whereas during winter CO_2 levels range between 500-800ppm (Figures 66, 67). These findings indicate that the air quality in the houses is good during both seasons.

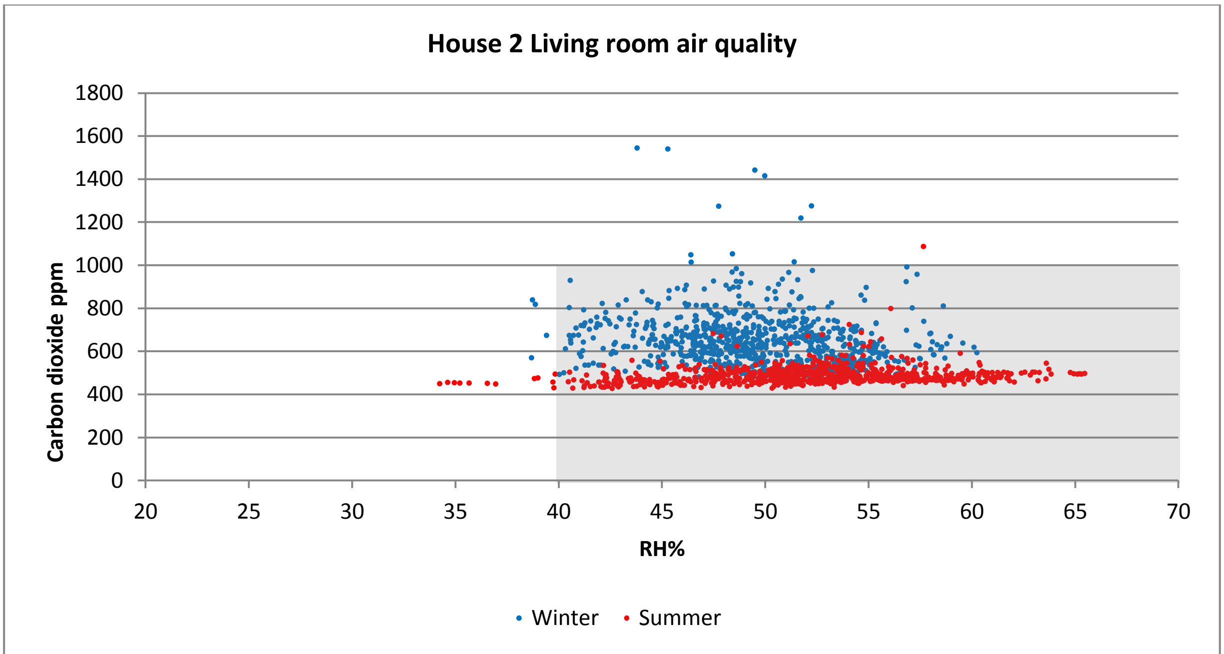


Figure 66 Living room air quality during winter (January 2014) and summer (August 2014).

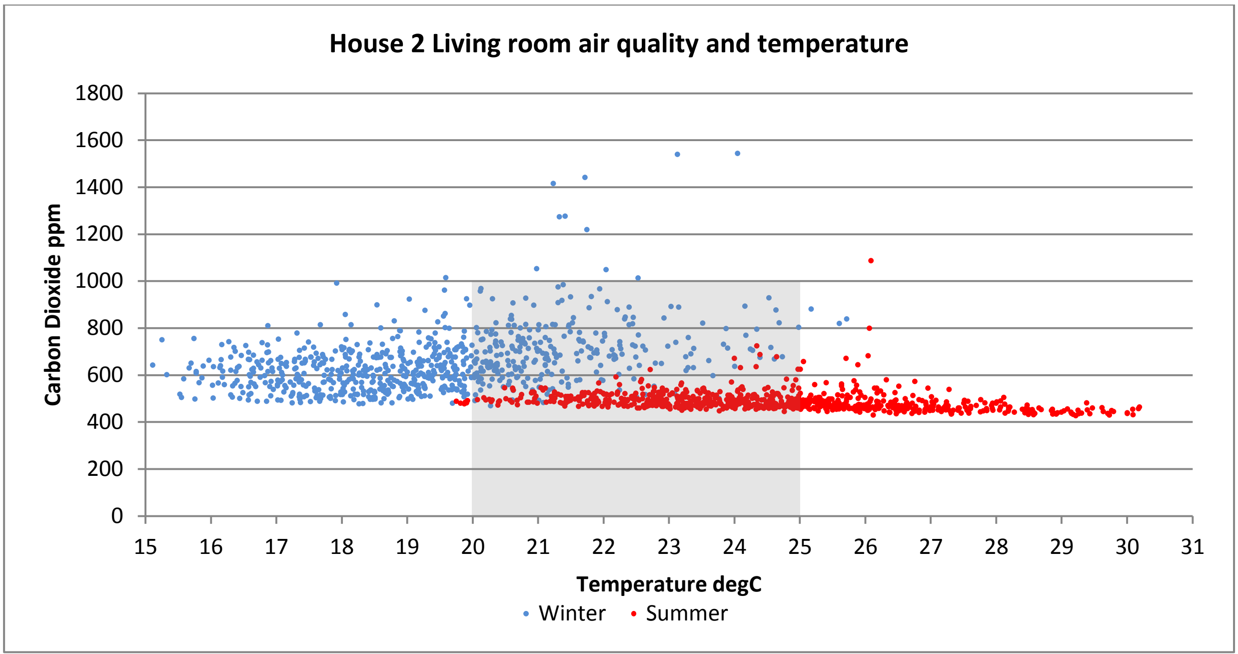


Figure 67 Living room air quality and temperature during winter (January 2014) and summer (August 2014).

8.4 Overheating analysis

There is no accepted definition of overheating yet. CIBSE (2006) suggests values for overheating criteria for a range of building types. The criterion values for dwellings are given in Table 20. For summer design conditions the Environmental Design, Guide A (CIBSE, 2006) suggests that indoor comfort temperatures for non-air-conditioned buildings should be 25°C for living areas and 23°C for bedrooms. CIBSE notes that people generally expect temperatures to be lower at night than during the day and find sleeping in warm conditions difficult. It is noted that sleep may be impaired above 24°C.

Table 20 Benchmark summer peak temperatures and overheating criteria. Data taken from CIBSE (2006) Environmental Design, Guide A

	Benchmark summer peak temperature	Overheating criterion
Living areas	28°C	1% of annual occupied hours over comfort temperature of 28°C
Bedrooms	26°C	1% of annual occupied hours over comfort temperature of 26°C

The temperature distribution in living rooms and bedrooms is shown in Figure 68 and 69. Following the Environmental Design, Guide A (CIBSE, 2006) overheating criteria, the living rooms show instances of overheating during summer with temperature remaining above 28^{o}C for more than 1% of occupied hours (House 1: 3%, House 2: 6%). In bedrooms summer temperatures remain above 26^{o}C for far more than 1% of occupied hours (House 1: 4%, House 2: 7%) indicating that the houses overheat. However, it should be noted that in House 2 the heating was on during the summer months as a result of poor commissioning and breakdown of the heating systems leading to unusually high temperatures inside the houses.

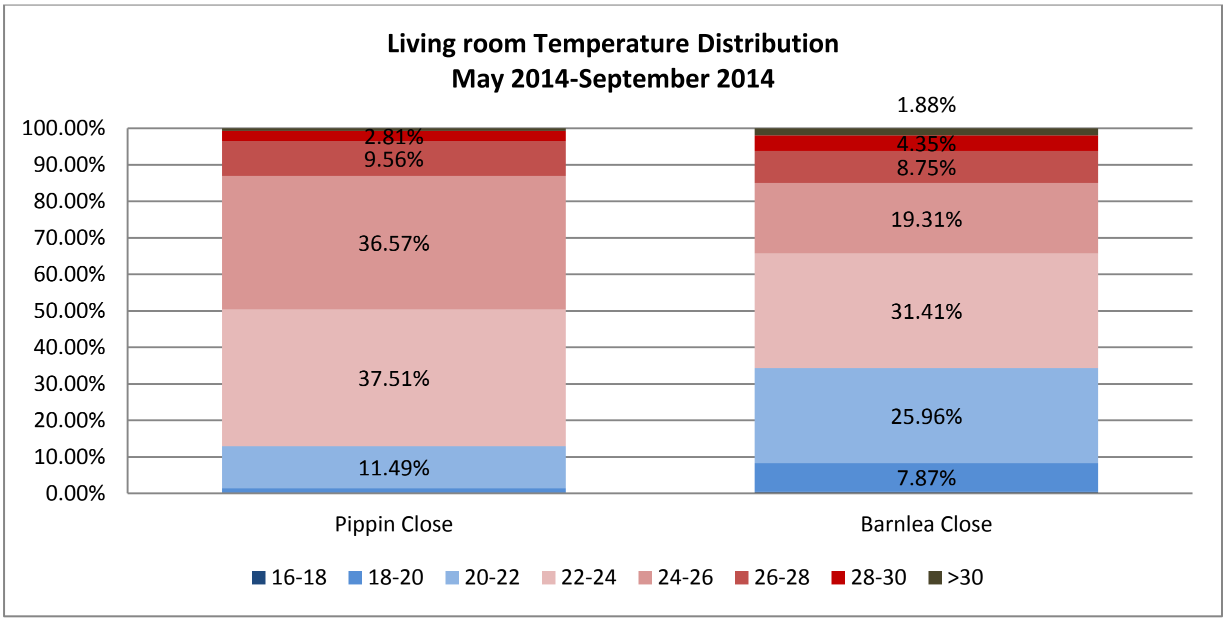


Figure 68 Living room temperature distribution during occupancy hours during the non-heating period

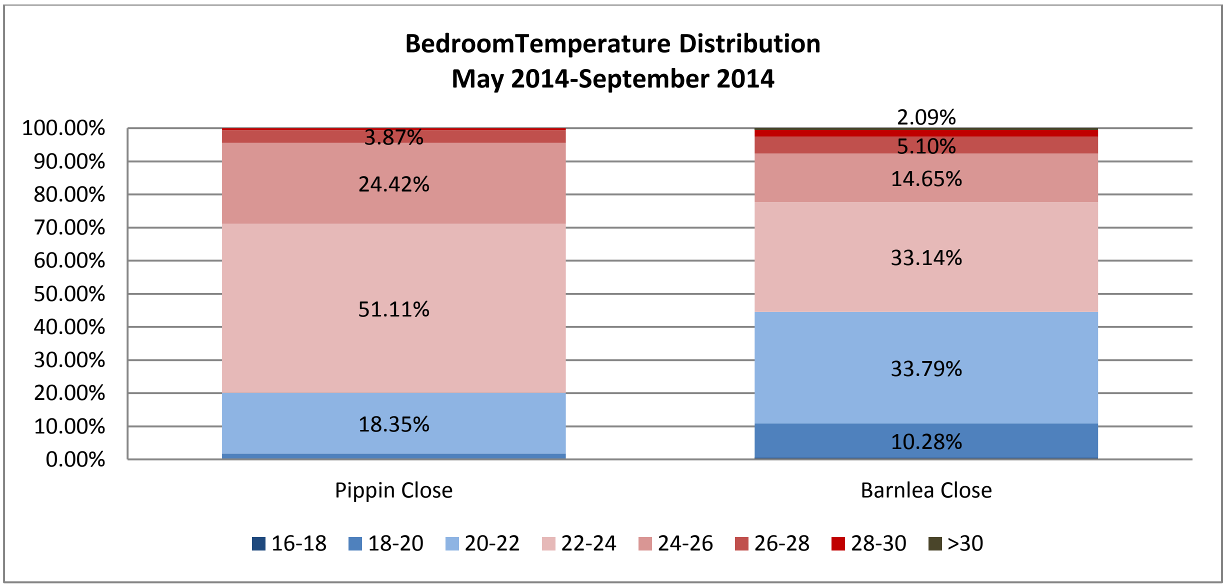


Figure 69 Bedroom temperature distribution during occupancy hours during the non-heating period

However, while the CIBSE recommendations are basically sound, the assumption that there is a single indoor temperature limit irrespective of outdoor conditions is being challenged. The CIBSE Overheating Task Force decided that a new approach to the definition of overheating was necessary, particularly for buildings without mechanical cooling. Based on the concept of thermal comfort, the BS EN 15251 criteria were developed (BSI, 2007). The CIBSE (2013) TM52 document suggests a series of criteria by which the risk of overheating can be assessed or identified. The first criterion suggests that the number of hours during which the internal temperatures are 1K higher or equal to the upper comfort limit during the period from May to September should not exceed 3% of occupied hours (CIBSE, 2013). Following this criterion, the percentage of overheating and hours of temperature exceedance of the adaptive comfort upper limit in living rooms and bedrooms across the case studies were plotted in Figures 70 and 71. The percentage of occupied hours when internal temperatures exceed the upper comfort limit by 1K is shown in Table 21. It is evident that according to the BS EN 15251, House 2 slightly overheats during summer.

However, these results indicate a big discrepancy between the two methods for assessing overheating which needs to be further researched.

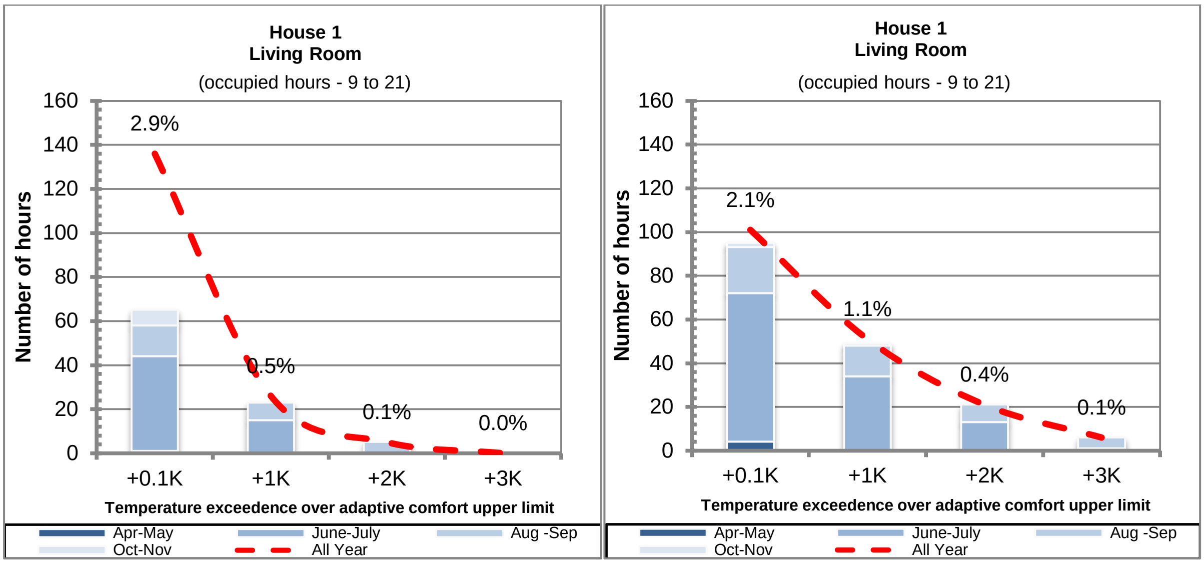


Figure 70 Living room overheating calculation during occupancy hours

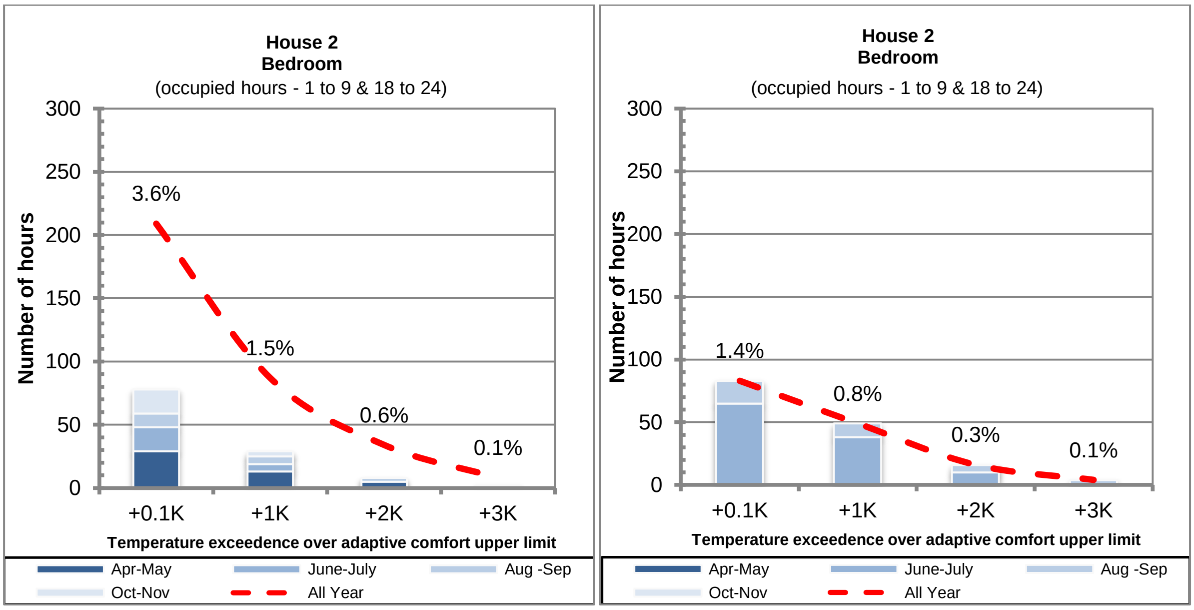


Figure 71 Bedroom overheating calculation during occupancy hours

Table 21 Percentage of time that temperature exceeds the adaptive comfort upper limit during occupancy hours in living rooms and bedrooms (May – September).

	Living Rooms	Bedrooms
	+1K above limit (%)	+1K above limit (%)
House 1	1	1
House 2	2	1.5

8.5 Window opening

Open-close state of the principal windows in the living room and bedrooms are monitored concurrently with environmental conditions to better understand the causes for unusual environmental conditions. The hourly percentage of window opening in living rooms and bedrooms for winter and summer is plotted against hourly average internal temperatures in Figures 72-75.

In House 1 occupants tend to open the living room window and backdoor when indoor temperatures rise, whereas in House 2 occupants leave the living room window open throughout the day. This behaviour explains, to some extent, the high energy use discussed in the previous section.

During summer, occupants in both houses open their windows for longer periods of time in order to get rid of excess internal gains. Bedroom windows are left open throughout the day whereas opening of living room windows tend to follow occupancy patterns possibly due to security reasons as living rooms are located on the ground floor. As a result of this pattern bedroom temperatures are 1-2°C lower than living room temperatures indicating the positive effect of night-time ventilation. In House 2 the living room window is left open during night-time as well.

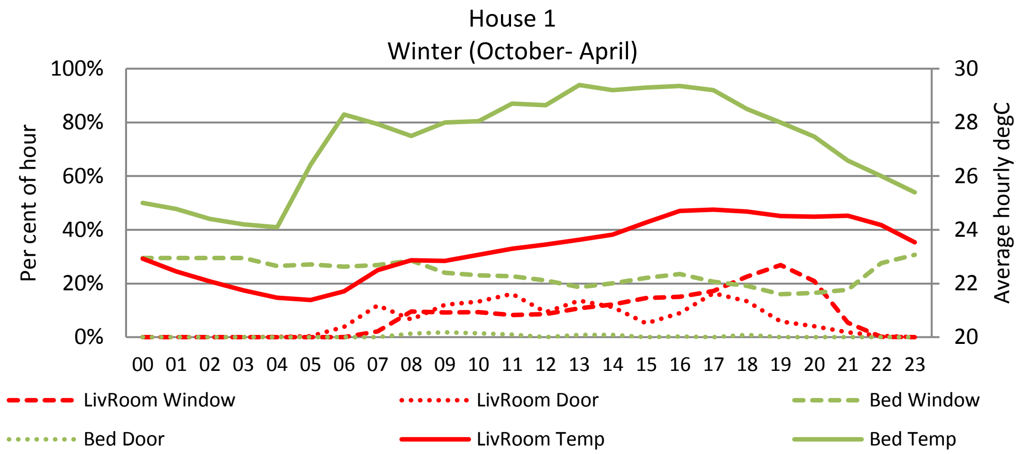


Figure 72 House 1 (winter). Hourly average temperatures and hourly percentage of window opening across the day in all four seasons.

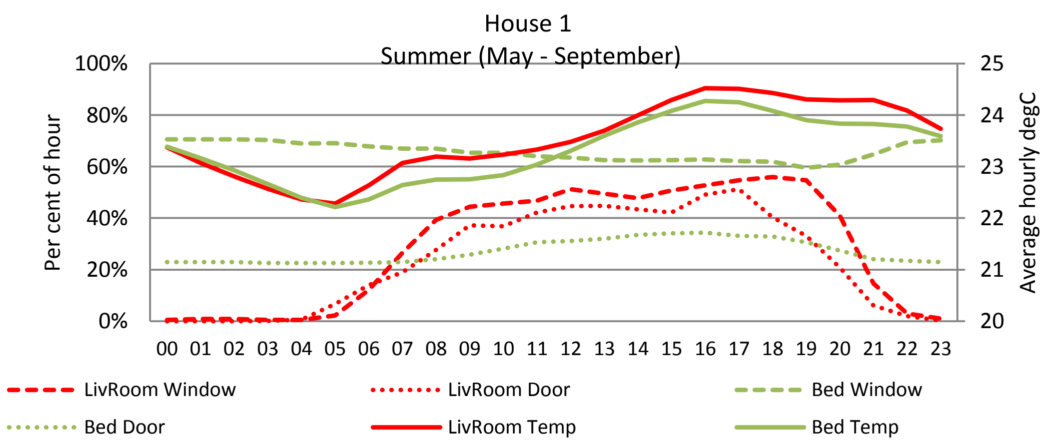


Figure 73 House 1 (summer). Hourly average temperatures and hourly percentage of window opening across the day in all four seasons.

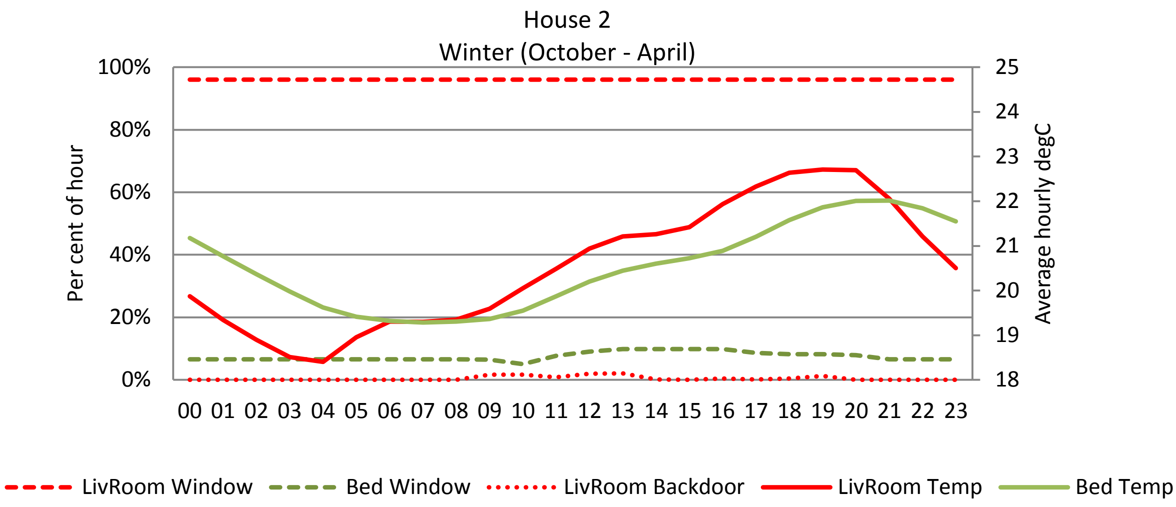


Figure 74 House 2 (winter). Hourly average temperatures and hourly percentage of window opening across the day in all four seasons.

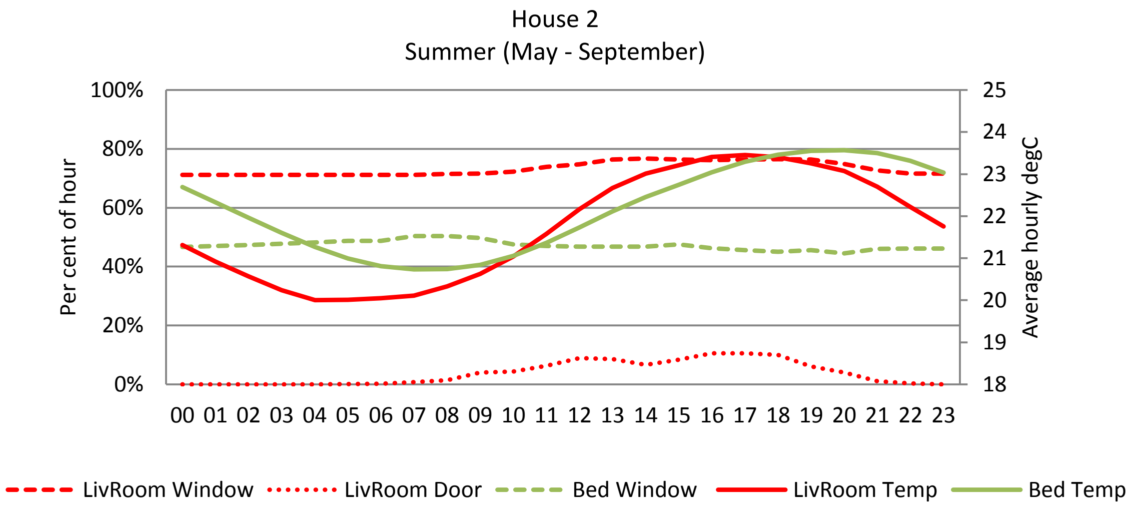


Figure 75 House 2 (summer). Hourly average temperatures and hourly percentage of window opening across the day in all four seasons.

8.6 Conclusions and key findings

Energy use

- Electricity consumption (kWh/m2) in House 1 is higher than that of House 2. Average daily electricity consumption in House 1 is constantly higher than that of House 2. Findings clearly indicate that occupant behaviour and lifestyle can have a big impact on the energy performance of houses.
- House 1: PV systems capacity is 1.65kWp. PV generation (use and export) is 907kWh. As-designed SAP indicates that the PV panels would generate 937kWh/year. Gas consumption during that period is 15,867kWh.
- House 2: PV system capacity is 1.88kWp. Total electricity generated by the PV panels is 1,238kWh. As-designed SAP estimate for annual PV generation in the house is 1351kWh.

Environmental monitoring

- Temperatures in both houses are within the comfort band of 20-25^{o}C for most of the monitoring period. Relative humidity levels in both houses are quite low; falling below the CIBSE recommended value of 40% during the winter months when the heating is on.
- House 1: Monthly mean temperatures are close to the upper part of the comfort band. Mean temperatures in July and August are to the upper limit of the comfort band (25^{o}C) and maximum temperatures reach 31^{o}C suggesting that the house overheats during summer. Maximum winter temperatures show that the house is being overheated and clearly indicate that gas consumption could be reduced by adjusting the thermostats settings.
- House 2: Monthly mean temperatures range from 20^{o}C in May to 25^{o}C in July. Mean temperatures in July and August are close to the upper limit of the comfort band (25^{o}C) and maximum temperatures reach 32^{o}C suggesting that the house was overheating during summer. During the winter months (November-February) average monthly temperatures range between 20-21^{o}C but maximum temperatures exceed 26^{o}C. On-site inspection revealed that the occupants set the thermostat at 30^{o}C and leave the windows open thus increasing the space heating energy demand and gas consumption.
- Overheating is observed in House 2, however occupants expressed satisfaction with summer temperatures.
- In House 1 occupants tend to open the living room window and backdoor when indoor temperatures rise, whereas in House 2 occupants leave the living room window open throughout the day. This behaviour explains, to some extent, the high energy use in the homes.
- During summer, occupants in both houses open their windows for longer periods of time in order to get rid of excess internal gains. Bedroom temperatures are 1-2^{o}C lower than living room temperatures due to the bedroom windows being left open throughout the night, indicating the positive effect of night-time ventilation.
- Measured indoor CO_2 levels suggest that satisfactory air quality in the houses is provided, as also evidenced through occupant feedback. This is likely to be due to regular opening of windows (on a daily basis) by occupants in order to ventilate the houses, but also wasting heat when the space heating is also on.

9 Other technical issues

9.1 Review of control interfaces

Control interfaces are the meeting point between users and building technology or fabric. So it is vital to first identify the key control interfaces between people and their homes, and secondly, to rigorously evaluate the 'interactive adaptation' at these points offered by the control interfaces. The six-point criteria developed by Buildings Controls Industry Association (BCIA) was used by the BPE research team to visually rate (on a 5-point scale from poor-excellent) the performance and usability of control interfaces of heating, ventilation and lighting systems as well as touch-points of the building fabric (window controls). These criteria include **clarity of purpose**, **intuitive switching**, **usefulness of labelling and annotation**, **ease of use**, **indication of system response**, **degree of fine control** as well as **accessibility**. Such investigations into the relationship between the design and usability of controls give an indication of their effect on occupant control and housing performance.

9.1.1 Space heating and hot water controls

9.1.1.1 Space heating and hot water masterstat

- The space heating and hot water masterstat does not offer intuitive programming of heating schedules for the house; the complexity of the control suggests that occupants need further instructions.
- The buttons are small and the labelling is too small to read.
- The programmer offers the option to set up space heating and hot water to switch on and off during seven days of the week.
- The control offers independent control of hot water and separate central heating zones and up to three settings per day.
- There is an advance and boost facility and automatic summertime adjustment incorporated in the control.
- An override button allows occupants to manually switch on heating and/or hot water when extra heating and/or hot water is necessary. However, this has caused the heating to run constantly in one of the houses (House 2) where the occupants have set no schedule for heating. Although settings of heating have been defined by technicians that initially commissioned the control, occupants would have to read the control manual in order to change the settings.

Criteria	Poor				Excellent
Clarity of purpose					
Intuitive switching					
Usefulness of labelling					
Ease of use					
Indication of response					
Degree of fine control					
Accessibility					

9.1.1.2 Space heating room thermostat

One room thermostat supplied by Sunvic Controls Ltd. has been installed in each property. The room thermostat in House 2 is located in the Ground floor entrance hall, while in House 1 the thermostat has been fixed on the wall next to ground floor bathroom. The commissioning review that took place in March 2013 in House 1 as part of the BPE study has revealed that the thermostat is located very close to the ground floor bathroom's radiator. This location would cause the heating to switch off once high temperatures occur in the surrounding area and therefore insufficient heating is provided in the rest of the property. The control is satisfactorily intuitive to use, although no significant annotation indicates the purpose of the device. A good level of fine control is provided.

Criteria	Poor				Excellent
Clarity of purpose					
Intuitive switching					
Usefulness of labelling					
Ease of use					
Indication of response					
Degree of fine control					
Accessibility					

9.1.1.3 Gas Boiler

A condensing combi gas boiler by Protteron provides space heating and hot water in each house. The boilers have Sedbuck rating A with 90.4% Sedbuck efficiency. The gas boilers are located in the kitchen of both properties and are easily accessible for commissioning and maintenance. There is no clear indication of system response, e.g. light indicating when boiler is switched on/off or light to indicate any error in boiler's operation.

Criteria	Poor				Excellent
Clarity of purpose					
Intuitive switching					
Usefulness of labelling					
Ease of use					
Indication of response					
Degree of fine control					
Accessibility					

9.1.1.4 Radiator valves

Thermostatic radiator valves supplied by Drayton are fitted on each radiator. Occupants are familiar with this type of heating control. The thermostatic radiator valves provide intuitive switching, ease of use and good degree of fine control (scale 1 to 6). Accessibility is rated as neutral since the radiator valves are located on low level close to floor and are occasionally obstructed by furniture.

Criteria	Poor				Excellent
Clarity of purpose					
Intuitive switching					
Usefulness of labelling					
Ease of use					
Indication of response					
Degree of fine control					

Accessibility					

9.1.2 MVHR controls

9.1.2.1 MVHR control unit panel

The MVHR unit is located in the loft of each house. Although adequate space is provided for operation and maintenance of the MVHR panel and switches in the loft, the space is hardly accessible; a portable ladder is essential to access the space. The MVHR system purpose is not clear and there is no indication of system response or whether any fault is occurring. There is no indication of when filters need to be changed and users and developer have not been informed about the importance of changing filters and maintaining the unit regularly.

Criteria	Poor				Excellent
Clarity of purpose					
Intuitive switching					
Usefulness of labelling					
Ease of use					
Indication of system response					
Degree of fine control					
Accessibility					

9.1.2.2 MVHR diffusers

There is one MVHR diffuser located in each room. Occupants cannot distinguish a supply from an extract diffuser. Most of diffusers were found to be closed in the two case-study houses. Their location, especially in bedrooms creates an unpleasant feeling, and occupants complained that there are cold draughts. As a result, MVHR supplies were found closed in the two properties. In House 1 the MVHR unit was also switched off completely, while in House 2 the system was still working.

Criteria	Poor				Excellent
Clarity of purpose					
Intuitive switching					
Usefulness of labelling					
Ease of use					
Indication of system response					
Degree of fine control					
Accessibility					

9.1.2.3 MVHR boost switch

It is possible to provide extra ventilation in the two houses through a fan boost switch located in the kitchen of each property. The control has good labelling and intuitive switching; however occupants did not know how and when this switch should be used and to which system it is connected.

Criteria	Poor				Excellent

Clarity of purpose					
Intuitive switching					
Usefulness of labelling					
Ease of use					
Indication of system response					
Degree of fine control					
Accessibility					

9.1.3 Passive controls

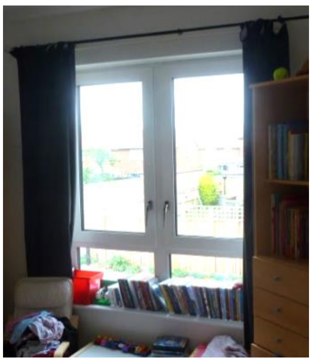
9.1.3.1 Main doors

The main door has a three point multi-way locking system with a split spindle. Overall the door is easy to open.

Criteria	Poor				Excellent
Clarity of purpose					
Intuitive switching					
Usefulness of labelling	N/A				
Ease of use					
Indication of response	N/A				
Degree of fine control					
Accessibility					

9.1.3.2 Windows

Windows are easy to open and operate. There is a restrictor which allows limited aperture of windows. The window can also be opened to a 90 degree angle for cleaning purposes. When the window is closed again, the width restrictor would automatically engage.



Criteria	Poor				Excellent
Clarity of purpose					
Intuitive switching					
Usefulness of labelling	N/A				
Ease of use					
Indication of response					
Degree of fine control					
Accessibility					

9.2 Conclusions and key findings

- The usability of space heating and hot water controls is not intuitive and needs instructions for proper use. Clarity of purpose and labelling could be improved. The degree of fine control is good but the system override is unclear. The purpose and function of the space heating and hot water programmer and the space heating thermostats should be communicated to the occupants in order to improve energy efficiency.

- Occupants would need more training on how to use MVHR system (especially to check MVHR filters in case they need changing before the scheduled date of maintenance by the developer) and controls that would include information about the benefits of the correct operation of the ventilation system. The system in both case study houses was found to be unbalanced because supply vents had been closed by occupants due to cold draughts or the central MVHR unit was completely shut.

- Generally intuitive switching of lights and fuses has been observed in both properties. However in some instances more comprehensive labelling may be useful to avoid confusion of which switch corresponds to which light, appliance or circuit.

- Windows and doors serve a clear purpose and are easy to operate. In addition, the locking mechanism and restrictors provide safety for kids and the household overall.

- Water controls and services have a good level of intuitive switching. On the kitchen taps, a degree of fine control can be further improved by providing mixer taps throughout the properties.

10 Key messages for the client, owner and occupier

Table 22 summarises the key findings across the BPE study elements

Table 22 Key findings across study elements

	Key findings
Design and construction audit	• Little deviation from the design was observed. Changes in use of spaces were identified in House 1. • Discrepancy between 'as built' and 'as designed' SAP was observed as a result of differences in areas, system sizing and different expected and measured air-permeability levels.
Fabric performance	• The air tightness tests showed that the measured air-permeability rates were around 6 $m^3/h.m^2$ exceeding the design target of 3 $m^3/h.m^2$ and suggesting heat losses due to air leakage paths while also questioning the need for always-on MVHR systems. • Several air leakage paths were identified, common in both houses, indicating that the detailing and workmanship during construction was not up to standard to achieve the design air-permeability targets. In addition to increasing heating demand, higher heat loss through the fabric also leads to higher electricity use of the MVHR system. • The external walls are well insulated. This was confirmed by both the in situ measurements of the wall U-values that showed values lower than those intended at the design stage (0.21 W/m^2K) and the thermographic survey that did not show any thermal anomalies on the external walls. No significant fabric deterioration was observed. • Thermal bridges across thresholds and ceiling beams as well as cold spots on ceilings identified in the houses are a result of detailing. Areas of reduced temperature on top floor ceilings are likely to be due to poorly fitted insulation within the wall / roof construction.
Design and delivery team walkthrough	• Main intention of both parties was to create high performing social housing that would meet CSH Level 4 standards. Both parties are satisfied with the design product in terms of space, appearance, size and flexibility, and would be happy to use the same design strategy in future projects. These findings are in accordance with occupant feedback. • In order to achieve the design intentions a fabric first approach was followed and PV panels and MVHR system were implemented. • Lack of familiarity with the MVHR system in particular has resulted in a series of commissioning and operation issues that have undermined the reliability of the system. • It would have been beneficial if sustainability consultants were involved from the beginning of the design process in order to avoid complexity and ensure good space provisions for systems and technologies. • The developer's aim of reducing long term maintenance cost whilst achieving code compliance was pivotal in the selection of the heating system (gas boilers with radiators) and the decision to incorporate photovoltaic panels. MVHR systems were also used to achieve code compliance and were considered a low maintenance system. • The team pointed out the importance of enhancing familiarisation and education of occupants on low carbon technologies and controls.
Evaluation of handover process and user guidance	• Due to the large amount of information provided during the one-day handover not all information was retained by the occupants. Additionally, due to the structure of the handover not enough time was provided for the explanation of the operation of systems and controls. This has undermined occupant understanding of systems and has resulted in

	confusion regarding the MVHR system. • The smart meters installed for gas, water and electric were found to be disconnected limiting the occupants understanding and control of their energy consumption. • The contents of the home user guide are considered satisfactory, but its overall quality could be further improved to make the document more inviting and easy to read.
Occupant feedback	• Overall the BUS survey and interviews have revealed a positive opinion towards the houses. Occupants are very satisfied with the houses, the amount of space, the layout and appearance. • Occupants are not well familiar with the purpose and operation of the MVHR system and PV panels. Little information was retained from the handover and occupants are reluctant to read through the Home User Guide. The induction process and guidance has not helped the occupants gain full understanding of the technologies implemented. • Occupants are generally satisfied with the room temperatures, quality of heat and system responsiveness and find the heating controls easy to use. Familiarity with systems and controls has resulted in the occupants feeling that they have good control over heating. • Occupants in the case study houses keep their thermostats high and open the windows while the heating is on. These patterns lead to increased heating loads. • Interviews have revealed that occupants in both case study houses are unfamiliar with the purpose and use of the MVHR system and ventilate the houses by opening the windows on a daily basis. This combined with the fact that the measured air permeability of the houses is higher than $3m^3/m^2h$ may imply that MVHR system is essentially redundant. • Participants in the BUS survey generally feel that utilities costs are higher to those in their previous accommodations. However, occupants in the case study houses find their bills manageable as they are used to paying high bills because of the size of their families, needs and daily activities.
Review of systems installation and commissioning	• The MVHR units are located in the loft space and are not easily accessible by the occupants and maintenance technicians. • The MVHR ductwork is not properly insulated even though it is located in an unheated space. • The vents were not locked in a fixed position, allowing the occupants to shut them off completely, interfering with the balance of the system. • The MVHR tests revealed great discrepancy between the supply and extract rates. • Poor commissioning of the MVHR system in combination with poor occupant understanding has resulted in system imbalance which in turn resulted in noise and draughts coming from the system. Occupants in both houses have actively tried to stop the ‘annoying’ cold draughts by shutting the supply terminals thus further unbalancing the system. These findings strongly indicate the relationship between proper installation and commissioning and occupant comfort and control. Extra care needs to be given to innovative systems especially because occupants are used to operating their homes without them and can easily by-pass them.

Energy and environmental monitoring	• Actual grid electricity use in both case study houses is lower than the UK average housing but much higher than the CSH level 4 and Part L compliant benchmarks. Electricity use per m^2 in House 1 is higher than that in House 2, whereas gas use is lower. This discrepancy between benchmarks and actual energy use is related to occupant heating patterns and appliance's schedule. • House 1: Monthly mean temperatures are close to the upper part of the comfort band. Maximum winter temperatures show that the house is being overheated and clearly indicate that gas consumption could be reduced by adjusting the thermostats settings. • House 2: During the winter months (November-February) average monthly temperatures range between 20-21oC but maximum temperatures exceed 26oC. On-site inspection revealed that the occupants set the thermostat at 30oC and leave the windows open thus increasing the space heating energy demand and gas consumption. This pattern explains the high heating loads. • Overheating is observed in House 2, however occupants expressed satisfaction with summer temperatures. • In House 1 occupants tend to open the living room window and backdoor when indoor temperatures rise, whereas in House 2 occupants leave the living room window open throughout the day. This behaviour explains, to some extent, the high energy use in the homes. • During summer, occupants in both houses open their windows for longer periods of time in order to get rid of excess internal gains. Bedroom temperatures are 1-2oC lower than living room temperatures due to the bedroom windows being left open throughout the night, indicating the positive effect of night-time ventilation.
Review of control interfaces	• The space heating and hot water masterstat is not intuitive. The room thermostat, on the other hand is easy to use. The degree of fine control is good but the system override is unclear. • Occupants would need more training on how to use MVHR system and controls that would include information about the benefits of the correct operation of the ventilation system. • Windows and doors are easy to operate. • Water controls and services have a good level of intuitive switching.

10.1 Recommendations for the owner/developer

- Careful commissioning of all systems and controls after construction is essential. Build in seasonal commissioning (to avoid breakdowns, leaks etc) of 'unfamiliar' energy systems and specify that only calibrated equipment be used for commissioning and re-commissioning of systems.
- Opt for rapid diagnostics to quickly identify mistakes and omissions during the construction phase. This also acts as a quality control regime.
- Installation and commissioning procedures need to be robust, including appropriate certification by qualified technicians and documentation of commissioning reports.
- Provide training to maintenance personnel on low/zero carbon technologies to increase their understanding of the systems, maintenance requirements, and reduce any contradictory advice given to occupants.
- The induction and handover process should be reviewed to provide more detailed and hands-on experience to new tenants. In addition to demonstrations of the operation of the energy system (heating, ventilation etc) by the design team member, also let occupants try out the energy systems themselves to ensure they understand how to operate them. Follow this up through subsequent visits to ensure that the information presented has been absorbed by the occupants.

- Review the Home User Guide to include advice on summer and winter operation of homes, including change the settings of the heating system seasonally, in a simple and user-friendly manner. Provide the occupants with a more compact and easy to ready home user guide according to systems of each property. Consider the use of videos clips to make the Home User Guide easier to follow.
- Consider re-training of existing occupants on the systems within the homes to include hands-on experience of heating settings, boost button, and filter change, in order to help enhance familiarity of the symbols and processes.
- It is recommended to check the smart metering arrangements and ensure that there are no conflicts of interest with the gas, electricity and water companies.
- Collate all lessons learnt on the project from issues raised (heat pump breakdowns, leaks, renewables installation) and use them as feedback to future projects.
- Take measures to improve the performance of the MVHR system by training the occupants, re-balancing the system and addressing breakdowns.
- Since the design intent of achieving low energy homes with low running costs has not been met and is likely be due to the imbalanced and constantly on MVHR systems combined with higher air permeability rates, TVHA needs to review the strategies for air-tightness and ventilation. MVHR should be introduced only if necessary as there are alternate solutions available such as natural ventilation, passive stack ventilation or even demand controlled ventilation.
- Improve customer care and help service for rapid trouble-shooting. Make occupants and housing maintenance team aware of the maintenance requirements of ventilation systems.
- Take measures to improve the performance of the MVHR by re-balancing the system and addressing breakdowns quickly.
- Promote the use of systems and controls that are easy to operate and intuitive. Good occupant control improves energy performance as well as the perception of comfort.

10.2 Recommendations for design team

- Carefully review air tightness specifications and inspection of construction quality and detailing for future project, to ensure that design airtightness is achieved in reality. Use robust construction details to avoid thermal bridging at the joints, junctions and corners. Take extra care in detailing and finishes during construction to avoid air leakage paths and construction flaws.
- Develop a holistic services (especially for heating and ventilation systems) and controls strategy at the design stage to ensure integration with the building fabric, siting of systems and integration of ductwork and usability of controls.
- It is important to update SAP worksheets (as-built SAP) to record changes in construction or design details that could affect the energy performance of the dwelling. Update SAP according to measured air permeability results.
- Perform accurate and reliable air permeability tests in all properties right after construction and take measures to address deficiencies.
- Consider using a front door of higher specifications and insulation levels as the door tends to become the weakest link in the dwelling.
- Review noise specification standards for partition walls between houses, as well as within the homes themselves (floors and walls).
- Before specifying suppliers, the design and construction team should ensure that there is a sufficient post-installation support and maintenance guarantee.

- Take measures to improve the performance of the MVHR system by ensuring that designed air-permeability levels are achieved in reality, re-balancing the system, training the occupants, and addressing breakdowns quickly.
- MVHR units should be located within the insulated envelope and in a more easily accessible space to allow enough space for maintenance and filter change.
- Reconsider the need for MVHR systems in buildings that are not expected to be air-tight.
- Design the Home User Guide to be concise and visual and provide accurate and useful information to occupants on how and when to change the settings of the heating and ventilation system seasonally.
- Take advantage of south orientation to allow for solar gains during winter and increase daylight.

10.3 Recommendations for building users

- Understand the operation and maintenance of heating and ventilation systems, and low/zero carbon technologies installed in the house by trying them during training and induction sessions.
- Read the home user guide and provide feedback to the owners/developers if it does not provide the information required.
- Seek guidance on the summer and winter operation of low energy homes.
- Understand the ventilation strategy and the purpose of the MVHR system. Shutting the MVHR grilles results in system imbalance which can affect indoor air quality.
- Maximise use PV-generated electricity by shifting use of appliances to the day-time as this saves on electricity costs.

11 Wider Lessons

The BPE study of Thames Valley Housing development has provided us with important lessons for the industry, clients, developers, building users and the supply chain. The BPE study has revealed several issues relating to commissioning, handover, design and construction. Wider lessons learnt from the BPE study are presented in the following sections.

BPE study and fine-tuning building performance

- It is important to highlight that without the BPE study, the various faults with the systems and services that were discovered would go unnoticed and transform into bigger issues at a later stage requiring expensive and possibly disruptive remedial works.
- The developer used the BPE findings especially on the under-performance of ventilation systems to bring back the sub-contractors to undertake remedial works. This shows the benefits of BPE studies for the developers and designers as a diagnostic tool to verify and improve building performance. Without this level and depth of evaluation of building performance, the gap between designed and actual energy use could widen and Government national CO_2 targets could be compromised.

Other lessons learnt from the BPE study for the industry are as follows:

Design stage

- An open and transparent discussion between industry, Government and academe is urgently required to understand the balance between ventilation and airtightness levels for zero energy/carbon homes. It is evident from this study (and other domestic BPE studies that the authors are involved in) that the industry is failing to deliver air-tightness levels <3 $m^3/h.m^2$ in mainstream low energy housing, thereby questioning the need for adding expensive always-on mechanical ventilation systems.
- Arrangements for sub-metering energy use (hot water, space heating, lighting, appliances and cooking) in houses should be carefully considered as they are less expensive and easy to install at the construction stage, but difficult and expensive to retrofit later on. Good sub-metering data can provide deep insights to residents and developers, as to how and why energy is used and wasted.
- There is a need to integrate the (heating and ventilating) systems and controls strategy early in the design process in order to provide a more clear and simplified approach that occupants can understand and operate more easily. Usability and adaptability of systems, services and controls need to be considered at the design and specification stages to avoid any potential misuse by occupants.
- The installation of mechanical ventilation and heating systems are seen to be taking over the already limited storage space in housing. Designers need to carefully provide space for heat exchangers and pumps in a manner that storage spaces are not compromised leading to resident dis-satisfaction with the design and low carbon technologies.

Construction and commissioning stage

- Robust detailing of joints, junctions and thresholds should be carefully followed during design and construction stages. Weaknesses in thermal performance of building fabric can be picked up using a combination of thermal imaging and air-tightness testing especially for early detection of problems. In the long term changes in design practices and construction skills are required to prevent these issues. There is also a growing recognition in the industry to develop shared resource of robust construction details for different types of building systems. Also design and construction teams can consider appointing an air-tightness champion on site to intervene when needed.

- Accurate 'as-built' SAP models (already required under Building Regulations) should become mandatory and enforced rigorously for all projects of all scales. This could ensure that SAP worksheets and drawings are updated to record changes made on-site that could affect the energy use.
- Maintenance regime of heating and ventilation system should be clarified at the installation and commissioning stage so that the perception of 'fit and forget' does not exist. If necessary, maintenance (service) contracts should be set up for unfamiliar low carbon systems such as heat pumps, MVHR.
- Good levels of documentation of housing performance should be enforced which is currently piecemeal. Commissioning records of services and systems should be used to check the performance of heating and ventilation systems through seasonal commissioning.

Handover and training

- Occupants need to be trained through graduated and extended handover that involves occupants trying out systems and controls in the presence of trained housing officers, supplemented by visual home user guides (developed by the Architects) offering clear guidance on the daily and seasonal operation of systems and controls. Individual background and abilities have to be taken into careful consideration when introducing occupants to new systems and unfamiliar technologies.
- In addition providing occupants with feedback on the relationship between daily activities, habits and energy bills and showing them ways to actively reduce fuel bills could be attractive especially for social housing tenants.

In-use

- The BPE study has revealed that actual energy use in the case study houses exceeds their design predictions by a factor of nearly two. This disparity is a result of higher demand temperatures set by occupants, unexpected opening of windows during winters due to under-performance of mechanical ventilation combined with habitual behaviour; over-use of the heating system to compensate for higher than expected air permeability and un-balanced MVHR systems; lack of understanding of operation of heating and ventilation systems; and poorly-designed control interfaces. For houses to perform as intended it is important to tackle these interdependencies between the physical and occupant related parameters of housing performance from the design stage to construction, handover and operation.
- For instance, control interfaces need to be intuitive, labelled and properly designed, and installed in an accessible location that encourages occupants to interact with their environment in an adaptive and positive manner.
- Ultimately it is vital that all stakeholders (developers, designers, constructors) use BPE studies to develop foresight for improving future building design, specifications and performance.

12 Appendices

12.1 Air-tightness

Dwelling Airtightness Testing Report

P Dooley
2014.08.11 15:24:47 +01'00'
Quality Approved Digital Signature

BSRIA Compliance
Building Regulation Compliance Testing

Head Office:
Old Bracknell Lane West
Bracknell
Berkshire
RG12 7AH
T: 0800 5871000
F: 01344 465691
E: Compliance@bsria.co.uk
W: www.bsria.co.uk

Part E - Sound Insulation | Part F - Ventilation Verification | Part L - Airtightness

Report N°: DAT-OXF01-NA001-PIP01-PL1-T3

Date:	11/08/2014	**Airtightness Engineer:**	C Knights
Accreditation Body:	ATTMA	**Registration Number:**	0005

Client:	Oxford Brookes University	**Plot N°:**	1
Region:	N/A	**Developers Type:**	N/A
Address:	Department Of Architecture School of the Built Environment Headington Campus, Gipsy Ln Oxford, Oxfordshire OX3 0BP	**Development Name:**	Pippin Close
		Development Address:	2 Pippin Close Feltham Middlesex TW13 5AG
Telephone:			
Facsimile:			

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	1892
Measured Air Permeability (m³/(h.m²)):	5.99	**Design Air Permeability (m³/(h.m²)):**	

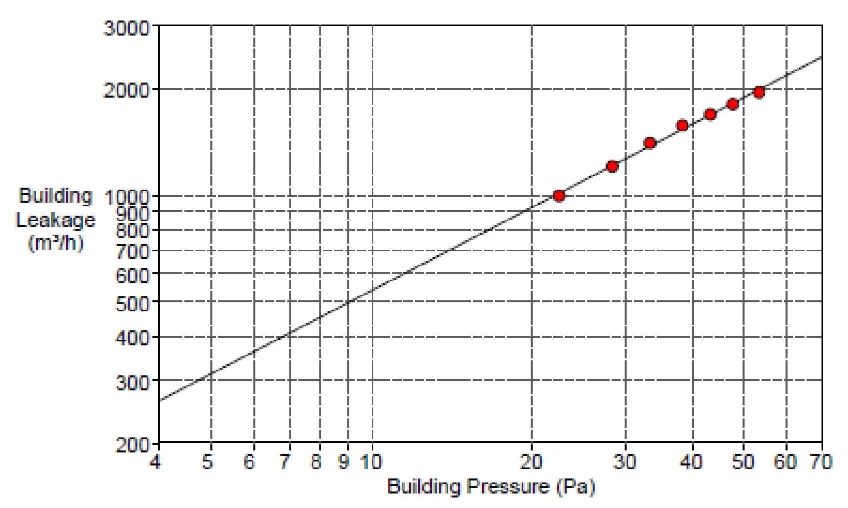
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	89.4	**Air Leakage Coefficient (C_L):**	89.4
Exponent (n):	0.78	**Correlation Coefficient (r²):**	0.9976

Test Information

		TS1 Leakage Area (m²):	0.094
Type of Test:	Depressurisation	**Test Method:**	B
Test Standard:	TS1	**Regulation Complied With:**	N/A



Dwelling Airtightness Testing Report

G Brown
2014.09.15 08:33:37 +01'00'
Quality Approved Digital Signature

BSRIA Compliance
Building Regulation Compliance Testing

Head Office:
Old Bracknell Lane West
Bracknell
Berkshire
RG12 7AH
T: 0800 5871000
F: 01344 465691
E: Compliance@bsria.co.uk
W: www.bsria.co.uk

Part E - Sound Insulation | Part F - Ventilation Verification | Part L - Airtightness

Report N°: DAT-OXF01-NA001-PIP01-PL1-T4

Date:	11/08/2014	Airtightness Engineer:	C Knights
Accreditation Body:	ATTMA	Registration Number:	0005

Client:	Oxford Brookes University	Plot N°:	1
Region:	N/A	Developers Type:	N/A
Address:	Department Of Architecture School of the Built Environment Headington Campus, Gipsy Ln Oxford, Oxfordshire OX3 0BP	Development Name:	Pippin Close
		Development Address:	2 Pippin Close Feltham Middlesex TW13 5AG
Telephone:			
Facsimile:			

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	1903
Measured Air Permeability (m³/(h.m²)):	6.02	Design Air Permeability (m³/(h.m²)):	

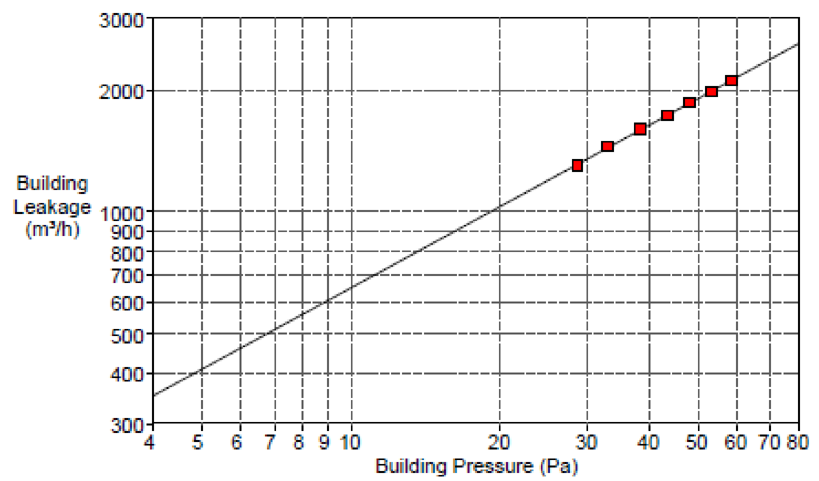
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	139.9	Air Leakage Coefficient (C_L):	139.6
Exponent (n):	0.67	Correlation Coefficient (r²):	0.9993

Test Information

		TS1 Leakage Area (m²):	0.095
Type of Test:	Pressurisation	Test Method:	B
Test Standard:	TS1	Regulation Complied With:	N/A



Dwelling Airtightness Testing Report

G Brown
2014.07.17 12:13:47
+01'00'
Quality Approved Digital Signature

BSRIA Compliance
Building Regulation Compliance Testing

Head Office:
Old Bracknell Lane West
Bracknell
Berkshire
RG12 7AH
T: 0800 5871000
F: 01344 465691
E: Compliance@bsria.co.uk
W: www.bsria.co.uk

Part E - Sound Insulation | Part F - Ventilation Verification | Part L - Airtightness

Report N°: DAT-OXF01-NA001-BAR01-080714-PL1-T3

Date:	08/07/2014	**Airtightness Engineer:**	C Knights
Accreditation Body:	ATTMA	**Registration Number:**	0005

Client: Oxford Brookes University
Region: N/A
Address: Department Of Architecture
School of the Built Environment
Headington Campus, Gipsy Ln
Oxford, Oxfordshire
OX3 0BP
Telephone:
Facsimile:

Plot N°: 1
Developers Type: N/A
Development Name: Barnlea Close
Development Address: 16a Barnlea Close
Twickenham
Middlesex
TW13 5LQ

Test Results at 50 Pascals

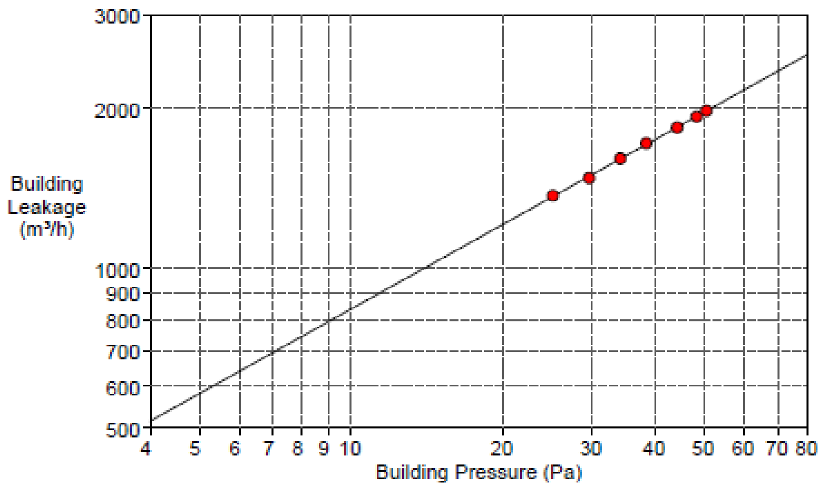
		Q_{50}: Airflow (m³/h):	1968
Measured Air Permeability (m³/(h.m²)):	6.22	**Design Air Permeability (m³/(h.m²)):**	
Did the dwelling achieve the required air permeability as specified in the SAP calculations?			

Building Leakage Curve

Air Flow Coefficient (C_{env}):	247.1	**Air Leakage Coefficient (C_L):**	247.0
Exponent (n):	0.53	**Correlation Coefficient (r²):**	0.9995

Test Information

		TS1 Leakage Area (m²):	0.098
Type of Test:	Depressurisation	**Test Method:**	B
Test Standard:	TS1	**Regulation Complied With:**	N/A



Dwelling Airtightness Testing Report

G Brown
2014.07.17 12:13:42 +01'00'
Quality Approved Digital Signature

BSRIA Compliance
Building Regulation Compliance Testing

Head Office:
Old Bracknell Lane West
Bracknell
Berkshire
RG12 7AH
T: 0800 5871000
F: 01344 465691
E: Compliance@bsria.co.uk
W: www.bsria.co.uk

Part E - Sound Insulation | **Part F - Ventilation Verification** | **Part L - Airtightness**

Report N°: DAT-OXF01-NA001-BAR01-080714-PL1-T4

Date:	08/07/2014	**Airtightness Engineer:**	C Knights
Accreditation Body:	ATTMA	**Registration Number:**	0005

Client:	Oxford Brookes University	**Plot N°:**	1
Region:	N/A	**Developers Type:**	N/A
Address:	Department Of Architecture School of the Built Environment Headington Campus, Gipsy Ln Oxford, Oxfordshire OX3 0BP	**Development Name:**	Barnlea Close
		Development Address:	16a Barnlea Close Twickenham Middlesex TW13 5LQ
Telephone:			
Facsimile:			

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	1936
Measured Air Permeability (m³/(h.m²)):	6.12	**Design Air Permeability (m³/(h.m²)):**	

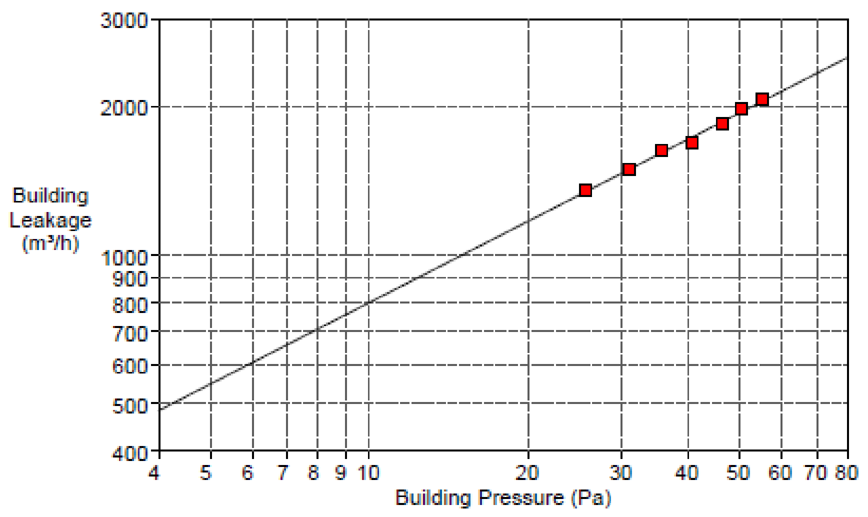
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	227.2	**Air Leakage Coefficient (C_L):**	226.0
Exponent (n):	0.55	**Correlation Coefficient (r²):**	0.9957

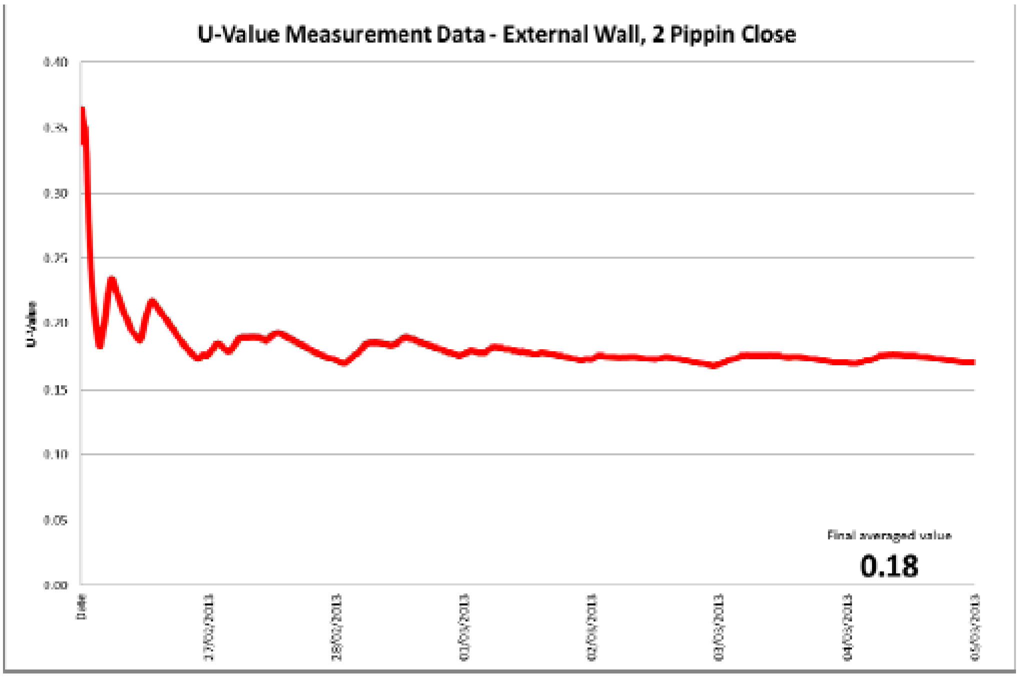
Test Information

		TS1 Leakage Area (m²):	0.097
Type of Test:	Pressurisation	**Test Method:**	B
Test Standard:	TS1	**Regulation Complied With:**	N/A

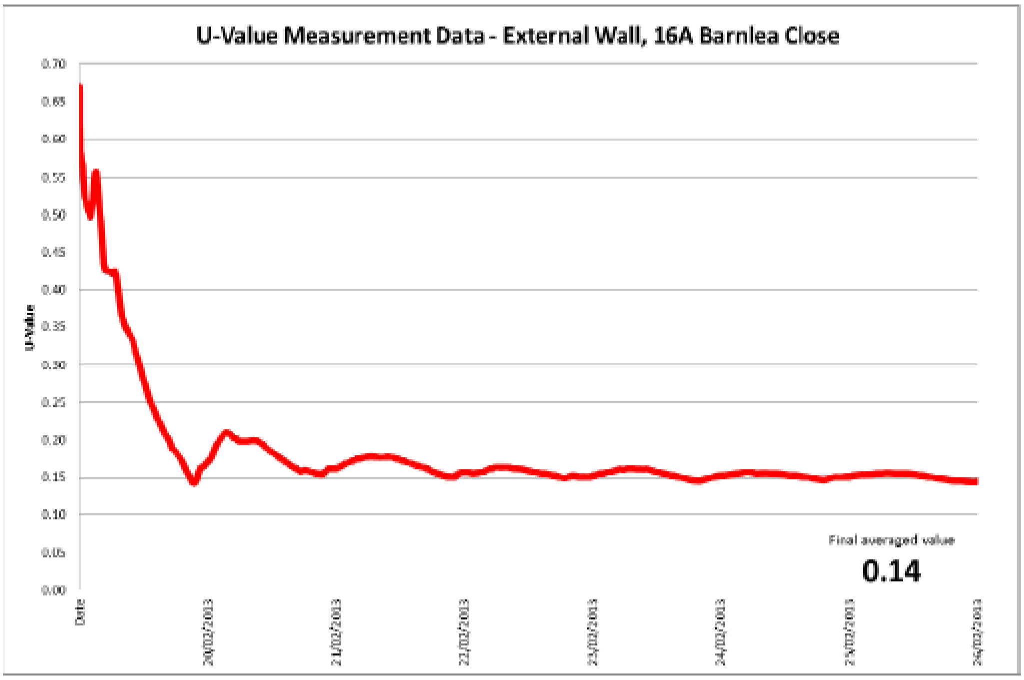


12.2 U-value test

House 1



House 2



12.3 MVHR tests

House 1

Sound Insulation: Part E & Section 5
Airtightness: Part L & Section 6
Ventilation: Part F

BSRIA Compliance

Ventilation Measurement Test Sheet

Date of Test: 16 January 2014

Report Number: PPV - OXF01 - NA001 - PIP01 - 160114 - PLI - T1

Client & Dwelling Information

Client: OXFORD BROOKES ENTERPRISES
Region: N/A
Address: OXFORD BROOKES ENTERPRISES
HEADINGTON CAMPUS
GIPSY LANE
OXFORDSHIRE
OX3 0BP

Plot Number: 1
Development: PIPPIN CLOSE
Address: 2 PIPPIN CLOSE
TWICKENHAM
MIDDLESEX
TW13 5AG

Measurement Equipment Information

Device	Manufacturer	Model	Equipment Identifier
Flow Hood	Observator	DIFF	DIFF4-1
Power Logger	Metrix	PX110	PPP1-1

Measurement Data - Extract

Room	Mode	Filters: Clean*		Filters: 50% Blockage*	
		Low Rate (l/s)	High Rate (l/s)	Low Rate (l/s)	High Rate (l/s)
Kitchen	Extract	4.50	4.50	4.30	4.50
Bathroom	Extract	4.60	4.50	4.40	4.50
WC	Extract	1.60	1.70	1.60	1.60
END OF DATA	-				
	Total	10.70	10.70	10.30	10.60

Measurement Data - Supply

Room	Mode	Filters: Clean*		Filters: 50% Blockage*	
		Low Rate (l/s)	High Rate (l/s)	Low Rate (l/s)	High Rate (l/s)
Lounge	Supply	2.4	2.4	2.3	2.4
Diner	Supply	2.0	1.9	1.8	1.6
Bed 1 - 1st rear	Supply	1.9	1.9	1.8	1.8
Bed 2 - 1st front	Supply	1.6	1.7	1.5	1.5
Bed 3 - 2nd rear	Supply	2.4	2.3	2.3	2.1
Bed 4 - 2nd front	Supply	2.1	2.1	2.0	2.2
	Total	12.4	12.3	11.6	11.6

Measurement Data - Energy Consumption

Measurement (1 minute intervals)	Filters: Clean		Filters: 50% Blockage	
	Low Rate Energy (w)	High Rate Energy (w)	Low Rate Energy (w)	High Rate Energy (w)
1	11.8	11.9	11.9	12.1
2	11.6	11.8	11.8	12.0
3	11.5	11.6	11.6	11.9
4	11.5	11.8	11.8	11.9
5	11.6	11.5	11.7	11.8
6	11.8	11.9	11.8	11.6
7	11.6	11.9	11.7	11.7
8	11.9	11.9	11.6	11.9
9	12.3	11.5	11.7	11.9
10	12.0	11.9	11.6	11.5
11	12.0	12.0	11.8	11.6
12	12.1	12.1	11.7	11.4
13	12.2	12.2	11.7	11.2
14	12.0	12.0	11.7	11.6
15	11.8	12.0	11.8	11.5
Average	11.8	11.9	11.7	11.7

*It should be noted that the filters had not been changed recently and were found to be dirty. Therefore the the requirement to test clean and partially blocked filters could not be achieved. The test results were as found. Whilst illuminating, the boost switch did not appear to be operational.

Name: Chris Knights
Position : Compliance Engineer

BSRIA Compliance
Old Bracknell Lane West
Bracknell
Berkshire, RG12 7AH

T: 0800 5871000
F: 01344 465691
E: compliance@bsria.co.uk
W: www.bsria.co.uk/services

House 2

Sound Insulation: Part E & Section 5
Airtightness: Part L & Section 6
Ventilation: Part F

BSRIA Compliance

Ventilation Measurement Test Sheet

Date of Test: 12 September 2013

Report Number: PPV - OXF01 - NA001 - BAR01 - 120913 - PL1 - T1

Client & Dwelling Information

Client: OXFORD BROOKES ENTERPRISES
Region: N/A
Address: OXFORD BROOKES ENTERPRISES
HEADINGTON CAMPUS
GIPSY LANE
OXFORDSHIRE
OX3 0BP

Plot Number: 1
Development: BARNLEA CLOSE
Address: 16A BARNLEA CLOSE
TWICKENHAM
MIDDLESEX
TW13 5LQ

Measurement Equipment Information

Device	Manufacturer	Model	Equipment Identifier
Flow Hood	Observator	DIFF	PPV1-1
Power Logger	Acksen	AL-2VA	201926

Measurement Data - Extract

Room	Mode	Filters: Clean		Filters: 50% Blockage	
		Low Rate (l/s)	High Rate (l/s)	Low Rate (l/s)	High Rate (l/s)
Kitchen	Extract	12.10	12.20	-	-
Bathroom	Extract	0.40	0.80	-	-
WC	Extract	13.10	13.50	-	-
END OF DATA	-	-	-	-	-
	Total	25.60	26.50	-	-

Measurement Data - Supply

Room	Mode	Filters: Clean		Filters: 50% Blockage	
		Low Rate (l/s)	High Rate (l/s)	Low Rate (l/s)	High Rate (l/s)
Lounge	Supply	3.8	5.4	-	-
Bed 1 - 1st rear LHS	Supply	6.1	9.5	-	-
Bed 2 - 1st rear RHS	Supply	5.9	8.6	-	-
Bed 3 - 1st front LHS	Supply	10.6	15.2	-	-
Bed 4 - 1st front RHS	Supply	3.5	7.8		
Bed 5 - Ground	Supply	0.0	0.0		
Diner	Supply	6.0	8.2		
	Total	35.9	54.7	-	-

Measurement Data - Energy Consumption

Measurement (1 minute intervals)	Filters: Clean		Filters: 50% Blockage	
	Low Rate Energy (w)	High Rate Energy (w)	Low Rate Energy (w)	High Rate Energy (w)
1	80.1	99.9	-	-
2	80.6	100.1	-	-
3	80.4	100.1	-	-
4	80.5	100.1	-	-
5	80.3	100.7	-	-
6	81.1	100.5	-	-
7	81.2	100.8	-	-
8	81.5	100.7	-	-
9	80.9	100.2	-	-
10	80.7	100.1	-	-
11	80.5	100.6	-	-
12	80.4	100.9	-	-
13	81.1	101.2	-	-
14	80.7	101.3	-	-
15	80.7	100.7	-	-
Average	80.7	100.5	-	-

Name: Chris Knights
Position: Compliance Engineer

BSRIA Compliance
Old Bracknell Lane West
Bracknell
Berkshire, RG12 7AH

T: 0800 5871000
F: 01344 465691
E: compliance@bsria.co.uk
W: www.bsria.co.uk/services

Sound Insulation: Part E & Section 5
Airtightness: Part L & Section 6
Ventilation: Part F

BSRIA Compliance

Ventilation Measurement Test Sheet

Date of Test: 16 January 2014

Report Number: PPV - OXF01 - NA001 - BAR01 - 160114 - PL1 - T2

Client & Dwelling Information

Client: OXFORD BROOKES ENTERPRISES
Region: N/A
Address: OXFORD BROOKES ENTERPRISES
HEADINGTON CAMPUS
GIPSY LANE
OXFORDSHIRE
OX3 0BP

Plot Number: 1
Development: BARNLEA CLOSE
Address: 16A BARNLEA CLOSE
TWICKENHAM
MIDDLESEX
TW13 5LQ

Measurement Equipment Information

Device	Manufacturer	Model	Equipment Identifier
Flow Hood	Observator	DIFF	DIFF4-1
Power Logger	Metrix	PX110	PPP1-1

Measurement Data - Extract

Room	Mode	~~Filters Clean*~~		~~Filters: 50% Blockage*~~	
		Low Rate (l/s)	High Rate (l/s)	Low Rate (l/s)	High Rate (l/s)
Kitchen	Extract	4.60	4.50	4.40	4.50
Bathroom	Extract	3.20	3.30	3.20	3.10
WC	Extract	3.70	3.70	3.50	3.40
END OF DATA	-				
	Total	11.50	11.50	11.10	11.00

Measurement Data - Supply

Room	Mode	Filters: Clean*		Filters: 50% Blockage*	
		Low Rate (l/s)	High Rate (l/s)	Low Rate (l/s)	High Rate (l/s)
Lounge	Supply	1.6	1.5	1.7	1.7
Bed 1 - 1st rear LHS	Supply	2.4	2.4	2.2	2.3
Bed 2 - 1st rear RHS	Supply	3.5	3.4	3.4	3.3
Bed 3 - 1st front LHS	Supply	3.0	2.9	3.0	3.0
Bed 4 - 1st front RHS	Supply	2.0	2.1	1.8	1.8
Bed 5 - Ground	Supply	1.1	1.1	1.0	1.1
Diner	Supply	3.8	3.7	3.5	3.6
	Total	17.4	17.1	16.6	16.8

Measurement Data - Energy Consumption

Measurement (1 minute intervals)	Filters: Clean		Filters: 50% Blockage	
	Low Rate Energy (w)	High Rate Energy (w)	Low Rate Energy (w)	High Rate Energy (w)
1	11.9	11.8	11.6	12.0
2	11.9	12.1	11.5	11.8
3	12.2	12.0	11.6	11.7
4	12.3	12.0	11.7	11.8
5	12.0	12.0	11.9	11.8
6	12.0	11.8	11.9	11.6
7	12.1	12.2	11.9	11.9
8	11.8	12.1	11.8	11.9
9	11.5	11.8	12.0	11.7
10	11.6	11.8	11.8	11.8
11	11.5	11.7	11.6	11.8
12	11.9	11.8	11.9	11.9
13	12.0	11.9	11.9	11.7
14	12.0	11.8	12.0	11.8
15	12.0	11.8	11.9	11.9
Average	11.9	11.9	11.8	11.8

*It should be noted that the filters had not been changed recently and were found to be very dirty. Therefore the the requirement to test clean and partially blocked filters could not be achieved. The test results were as found. Whilst illuminating, the boost switch did not appear to be operational.

Name: Chris Knights
Position: Compliance Engineer

BSRIA Compliance
Old Bracknell Lane West
Bracknell
Berkshire, RG12 7AH
T: 0800 5871000
F: 01344 465691
E: compliance@bsria.co.uk
W: www.bsria.co.uk/services