Malmesbury Gardens

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Innovate UK project number	450050
Project lead, authors, and client	Swindon Council, Oxford Brookes University
Report date	April 2015
InnovateUK Evaluator	xxx (Contact via www.bpe-specialists.org.uk)

No of dwellings	**Location**	**Type**	**Constructed**
13 (2 plots sampled)	Swindon	Terraced houses	2011
Area	**Construction form**	**Space heating target**	**Certification level**
94 m^2 (typical)	Timber frame with solid external walls and Hempcrete	N/A	Code for Sustainable Homes (5)

Purpose of evaluation

Malmesbury Gardens was a social housing scheme intended to provide an innovative approach to affordable mixed-tenure housing design, procurement and finance. It consisted of 13 houses built to Code for Sustainable Homes Level 5 criteria. All homes achieved SAP rating A for both energy efficiency and environmental performance. Two houses had a co-heating test, infrared thermography, air permeability testing, in-situ U-value measurement test, review of commissioning processes, observation of the handover process, a BUS questionnaire survey, a walkthrough and interviews with the occupants. The construction was based on the application of Hempcrete. Hempcrete was cast into a timber frame to achieve high thermal mass levels in combination with optimized U-Values. The airtightness target of 2 m^3 (m^2.h) was not met.

Design energy assessment	**In-use energy assessment**	**Sub-system breakdown**
SAP A (99)	SAP B (88) recalculated	Yes (both plots)

The primary heating system was based on exhaust air heat pumps. The NIBE Fighter 410P heat pumps used the warm air inside the dwelling as its primary heat source, drawing the heat energy via the ventilation system. In addition, the heat pump is supplemented with solar pre-heat which supplies hot water to the unit, thereby reducing the amount of electricity consumption by the heat pump's compressor. The heat pumps serve underfloor heating systems. Most of the houses did not have the heating system adjusted correctly and were given instructions of how to use it more efficiently. Not all tenants had read the Home User Guide resulting in a lack of knowledge about the system's operation. The MVHR system in both plots were found to be unbalanced resulting in increased energy use, noise and draughts. The systems were recommissioned.

Occupant survey type	**Survey sample (two plots)**	**Structured interview**
BUS (domestic)	13 and 19 (Responses: 9 and 11)	N/A

The houses performed well compared to other surveyed UK houses. Variables that fell significantly below the BUS benchmarks were air quality during summer (which appeared to be drier than expected), control over cooling, and noise levels from outside and in between the rooms. Occupants in both houses found the electricity bills were high. They were not satisfied with the heat pump performance.

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About this document

This report template is to be used by BPE teams to draw together the findings of the entire BPE process and to record findings and conclusions, as specified in the 'Building Performance Evaluation, Domestic Buildings – Guidance for Project Execution'. The template is designed to assist in prompting the project lead to cover certain minimum specific aspects of the reporting process. Referring to the document 'Building Performance Evaluation, Domestic Buildings – Guidance for Project Execution will remind you of the elements that should be included in each section. The overall report structure should allow for detailed commentary on the research carried out; explanation of both the hard and soft monitoring undertaken, detailing and evaluation of the findings and rigorous explanation of the lessons learnt. Where further details are being recorded in other reports it is expected these will be referred to in this document. Where translating energy into carbon emissions, ensure common factors / units are used as elsewhere, such as in DomEARM, to enable common comparisons.

The compilation / authorship of this report is the responsibility of the project lead for BPE. It is not the responsibility of the Technology Strategy Board Evaluator or Monitoring Officer to assist with completing this document. The Technology Strategy Board recognises that the project lead may not have all the relevant information of the specific technical knowledge to complete all sections of the report. It is expected that parts of the report will need to be completed by other members of the project team, however, it is the responsibility of the project lead to manage this process and ensure that the report is robust, with all sections fully completed to a high standard. It is the project leads responsibility to ensure that the report is submitted in a timely manner. Submission of this final report is a mandatory element of the Building Performance Evaluation programme.

Use of illustrations. BPE teams are encouraged to include diagrams, photos and clear sketches where helpful in illustrating a certain point. This can either be in the main body of the report or as appendices. The aim of using various illustrations is to assist with the narrative of the project and give additional understanding to the relevant sections they relate to. Therefore please attribute a caption to all images and ensure that the captions are active and informative (e.g. 'the solar panel was orientated north-south instead of east-west as specified' rather than 'a solar PV panel'). A template for the insertion of images is available in the appendices of this document. You must ensure you have all the relevant permissions for using images and give the correct credit to the image owner if necessary. Please be aware of data protection issues that may arise from photographing the property. Efforts should be made to anonymise the building to some extent where possible.

Each section of this report allows for the addition of subheadings, however for consistency reasons do not modify this form without permission from the Technology Strategy Board.

File naming conventions: Please prefix your 10 digit applicant number [xxxxx-xxxxx] to the beginning of the filename when saving and submitting this report. Please remember to update the table of contents [right mouse click > update field] before submitting this report.

Contents

1 Introduction and overview

Technology Strategy Board guidance on section requirements:	This section of the report should be an introduction to the scope of the BPE project, the expected results and will include a summary of the key facts, figures and findings. Give an introduction to the project covering the project team and a broad overview of the energy strategy, design strategy rationale and soft and hard monitoring. Also summarise the building type, form, materials, surrounding environment and orientation, as well as related dwellings in the development (which may or may not be part of the BPE project). Other amenities, such as transport links, cycling facilities, etc. should also be outlined where relevant. Give information on any environmental requirements issues that are relevant to the site, but not to the research. Only the basic facts etc. should be included here - more detailed information should be given in the relevant sections in this document and added to the data storage system as appropriate.

The Low Carbon Building Group (LCBG) of Oxford Institute for Sustainable Development (OISD) at Oxford Brookes University in collaboration with NPS Group and Swindon Borough Council, has undertaken a detailed building performance evaluation (BPE) study of two social housing dwellings at Malmesbury Gardens in Swindon, during the *post-completion and early occupation stage (Phase 1)*, as well as the *in-use stage (Phase 2).* This report describes the findings from *Phase 2* of the study, although some findings from Phase 1 are also included in this report in order to provide a more clear understanding of the issues. Both phases of the BPE study have been funded by the Technology Strategy Board's Building Performance Evaluation programme. The key objectives of the BPE programme are to:

- Close the feedback loop between design aspiration and performance-in-use.
- Foster BPE to the extent that it becomes a routine feedback method for improvement of building performance.
- Generate a knowledge base of building performance for wider dissemination within the industry through the publication of research papers, and articles in appropriate journals.

The report is subdivided in the following study elements which form the In-use performance and post-occupancy evaluation audit:

- Infrared thermography (2 tests for each of the dwellings)
- Air permeability testing (2 tests for each of the dwellings)
- Review of the MVHR system
- Home User guide evaluation
- Arup BUS questionnaire survey
- Initial walkthrough and interviews with the occupants
- Monitoring of energy use and environmental conditions
- Occupant activity logging
- Monitoring of window opening

Malmesbury Gardens is a social housing scheme that was intended to provide an innovative approach to affordable mixed tenure housing design, procurement and finance, with large scale delivery potentials. It consists of 13 council houses built to Code for Sustainable Homes level 5 criteria aiming to a low energy performance along with space flexibility and design excellence. All homes have achieved SAP rating A for both energy efficiency and environmental impact.

The general design approach targeted a Code level 5 rating by a combination of an optimized and airtight building envelope supported by an innovative space and water heating solution and the use of renewables. The construction was based on the application of hempcrete cast into a timber frame in order to achieve high thermal mass levels in combination with optimized U-Values and a maximum airtightness of 2 $m^3/(h.m^2)$ under pressure of 50 Pa. Heating, hot water and mechanical ventilation is provided by an Exhaust Air Heat Pump (EAHP) while the systems are supported by a solar thermal and pre-heat hot water cylinder and photovoltaic panels on the roof.

The triangulation of both quantitative and qualitative data provided a great insight on the performance of the Code level 5 Malmesbury Garden houses and a significant number of lessons can be learned concerning the procurement, design and management of low carbon housing projects in generally. The most important findings and recommendations are summarised below.

- The 1st air-permeability testing showed that in both cases the measured air permeability value, 5.36 $m^3/(h.m^2)$ for House 5 and 15.77$m^3/(h.m^2)$ for House 11, was well above the design target of 2 $m^3/(h.m^2)$ suggesting noticeable heat losses due to air leakage paths. Those could be attributed to poor fitting of skirting boards and windows, lack of sealing in the systems cupboard and other construction issues. The second test, undertaken a year later revealed even lower air-tightness levels that may be attributed to the shrinking of the hempcrete. This is a consequence of using hempcrete that needs to be taken into account during construction.

- A series of thermographs showed small thermal anomalies on external walls and confirmed the high air permeability values indicating heat losses through fitting of openings.

- The MVHR system in both properties was found to be unbalanced resulting in increased energy use, noise and draughts that reduce occupant comfort. The systems need to be re-commissioned. Seasonal commissioning of mechanical ventilation systems and low-carbon technologies is recommended.

- In terms of benchmarking, Malmesbury Gardens houses perform well compared to other houses in the UK that have been evaluated through the BUS questionnaire methodology. The overall picture of the survey revealed a positive opinion towards the houses. Respondents generally feel that the facilities provided meet their needs well and rate favourably the appearance, layout, location and space of the houses. Other key aspects that work well are considered to be the garden, the layout and the size of the rooms.

- The main aspects that work poorly for the occupants are the lack of storage space and the poor water drainage of the downstairs shower room that leads to flooding. Furthermore, the limited control over the heating and mechanical ventilation system in combination with the high energy bills moderated the otherwise highly rated comfort levels.

- Expectations regarding the amount of storage space vary between occupants. Contradictory answers were received through the occupant survey with 18% of the respondents finding it more than enough and another 27% not finding it enough.

- Temperatures during winter are generally regarded as quite comfortable, whereas temperatures during summer are regarded as less comfortable.

- Lighting levels, overall, are one of the most appreciated elements of the building; most likely, in part, to be due to the south orientation and high window to floor ratios of the houses.

- Findings from interviews and walkthroughs revealed that some of the occupants are confused about the operation of the heating and ventilation systems. A visual User Guide, in addition to an extended handover that allows for a hands-on approach, is recommended in order to ensure good occupant understanding.

This study provides a robust template comprised of both qualitative and quantitative methods to be used for future POE, monitoring and feedback. Through the analysis of the research findings recommendations are drawn for councils, developers, house builders and equipment suppliers to alleviate problematic issues in future developments and ensure the establishment of robust low carbon housing development strategy; provided lessons are taken on board on an iterative basis and embedded into knowledge management systems.

2 About the building

Technology Strategy Board guidance on section requirements:	This section should cover the project up until before commissioning. Give more details on the building type, form, materials, surrounding environment and orientation, as well as related dwellings in the development (which may or may not be part of the BPE project). Other amenities, such as transport links, cycling facilities, etc. should also be outlined where relevant to the design specification. Also provide comments on the design intent, construction process and the product delivered (including references to drawings, specifications, commissioning records, log book and building user guide). If the original specification is available, describe how closely the final design meets it, what the discrepancies are and why these occurred. Indicate whether the explanation comes from the design team or from evaluator judgement. Identify any discrepancies between the design and SAP and whether the design accurately reflected in the SAP calculations and describe where these discrepancies lie. Does the SAP performance match the specified performance and was this informed through measured or calculated data. As far as possible provide an explanation of the rationale behind the design and any changes that occurred. In particular, it will be helpful to understand the basis for making key decisions on the choice of measures and technologies. These may have been chosen to suit the particular property or a physical situation, or they may have been chosen to test an innovative material or a new product. List and describe any aspects of the design that are likely to introduce performance issues – e.g. cold bridges? Describe any aspects of the design that were a challenge to construct robustly - e.g. introduction of air leakage paths. Finally this section should also outline the construction and construction management processes adopted, construction phase influences i.e. builder went out of business, form of contract issues i.e. novation of design team, programme issues etc. Describe the overall construction process, highlighting any supply chain issues, delays in construction, contract(or) issues Important: please describe steps taken to overcome any stated challenges and issues. Report perceptions, concerns and positive nuggets raised by the client, designers, and construction team. Complete this section with conclusions and recommendations.

2.1 Background to the scheme

The Malmesbury Gardens housing development was completed in March 2011 and is owned by the Swindon Borough Council. In addition to achieving code level 5 certification, all homes have achieved SAP rating A for both energy efficiency and environmental impact.

The general design approach targeted a Code level 5 rating by a combination of an optimized and airtight building envelope supported by an innovative space and water heating solution and the use of renewables. The construction was based on the application of hempcrete cast into a timber frame in order to achieve high thermal mass levels in combination with optimized U-Values and a maximum airtightness of 2 $m^3/(h.m^2)$ under pressure of 50 Pa. Heating, hot water and mechanical ventilation are provided by an Exhaust Air Heat Pump (EAHP) while the systems are supported by a solar thermal and pre-heat hot water cylinder and photovoltaic panels on the roof.

To identify any deviation from the design intent and map the occupants' initial reactions, a Phase 1: Post-construction and early occupancy BPE study was conducted prior to the Phase 2: In-use and post-occupancy study. The Phase 1 study covered the design and construction stage as well as the post construction and early occupancy phase of the new homes. The parties involved in both studies consist of the research team, the owner (Swindon Borough Council), the design team and the contractors (Swindon Commercial Services).

Findings from the Phase 1 study indicated a lack of experience with hempcrete and the systems that were used. The whole house heat-loss test clearly revealed that the performance of the building envelope was worse than the anticipated values based on the initial specifications. Instead of the predicted total heat loss values, the actual loss was about 20% higher for both of the case study dwellings. Through the SAP calculation review, differences were found between the existing and recalculated ratings for the same dwellings. Lack of proper fitting and finishing of pipework, for example, has led to performance gaps such as lower airtightness, higher U-values and heat loss levels as well as improperly commissioned systems. The drawings review and walkthrough identified issues with the usability of the air source heat pumps and their controls. Additionally, it was discovered that hempcrete requires a significantly longer drying period than expected. Furthermore, occupant interviews revealed that tenants did not fully understand the purpose of the mechanical ventilation system.

During the Phase 2 study two homes, house numbers 5 and 11 (Figures 1, 2, 3), in the Malmesbury Gardens development were monitored.

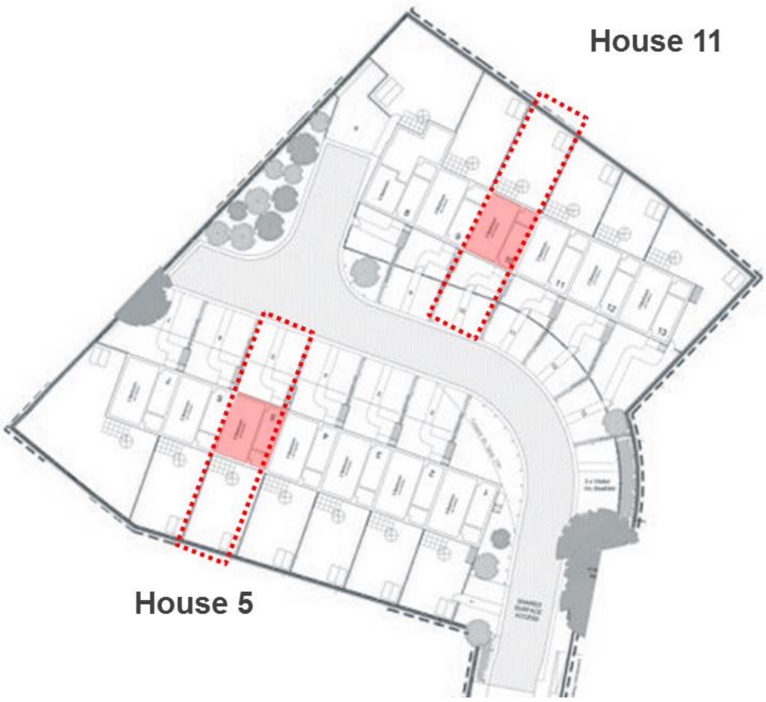


Figure 1 Malmesbury Gardens development, plan and elevations (two case study dwellings highlighted on plan).

Figure 2 House 5 front elevation (North)

Figure 3 House 11 front elevation (South)

The complex consists of 13 council houses built to Code for Sustainable Homes Level 5 criteria aiming at a low energy performance along with space flexibility. The types of units vary between 2 bedroomed, 3 bedroomed and 5 bedroomed mid- and end-terrace houses.

These homes are constructed of prefabricated timber frame wall panels with solid cast in situ hempcrete. The external walls are solid, made of 310mm hempcrete cast in situ with a 9mm Multipro XS LT permanent shutter to the inside and a temporary shutter to the outside. The whole wall is breathable, has a U value of 0.18 W/m²°C and a 60 minutes fire resistance. The roof is constructed of grey concrete interlocking roof tiles and is insulated through 250mm hemp fibre insulation bats (45kg/m³) within the depth of the timber beams. Double glazed timber framed windows and doors, with a U value of ≤1.6 W/m²°C and double air seals to all sides of the frame were used along with a level access threshold on the doors.

Acoustic quilt was used in all voids with internal walls and floors having a minimum design value of airborne sound insulation of 40dB. The envelope was designed to achieve an air permeability of 2 m³/h.m² @50Pa. The details of dwelling construction are presented in Table 1.

Table 1 Construction details

Main construction elements	Prefabricated timber frame wall panels (generally 89x38mm studs) with solid cast in situ hempcrete around the frame with 9mm permanent shutter to the internal face and temporary shutter to the external.
Substructure and ground	Piled foundation with reinforced concrete ground beams supporting prefabricated galvanised steel permanent shuttering with insulated slab over supporting screed with underfloor heating for ground floor. 250mm minimum void. Design U-value 0.12 W/m²K
Outer walls	Solid external walls -310mm hempcrete cast in situ around the timber frame with Multupro XS LT permanent shutter to the internal face and temporary shutter to the external. External finish -25mm rough caste through colour white lime render. Internal finish -3mm lime plaster. Whole wall breathable. Design U-value 0.18 W/m²K
Party wall	Timber framed cavity wall with sheathing. 89mm timber studs with 9mm OSB sheathing and UdiSteam vapour control layer, and 75 mm (min) cavity between sheathing with no cavity ties. 2 layers 12.5mm British Gypsum Fireline Board and scrim to internal face. 60 mm wire reinforced mineral wool batts (60kg/m3) both sides. Party walls taken up to underside of roof. No value for their U-value was stated.

2.2 Building services and energy systems

Aiming for sustainability and comfort, the building holds a series of passive building design features paired with highly efficient services design. The renewables solution includes Photovoltaics, Solar Thermal and Exhaust Air Heat Pumps (EAHP).

Space heating is achieved through exhaust air heat pumps (EAHP) with under floor heating, supported by solar thermal and pre-heat hot water cylinder (Table 2). The primary heating system to the dwelling is served by the exhaust air heat pump. The NIBE Fighter 410P heat pump uses the warm air inside the dwelling as its primary heat source, drawing the heat energy via the ventilation system. The solar thermal pre-heats all water before entering the EAHP, within which the hot water is stored at 50°C, boosted once a week to control Legionella. Heating output from the heat pump is served via an under floor heating system. The Photovoltaics provide energy to power the EAHP and immersions, maximising the tenant benefit of the renewables (Figure 4).

The EAHP unit has two access control levels: one for general use and the other for commissioning and setup, which is concealed behind the front panel.

The photovoltaic system provided is a 3kW peak grid connected solar array comprising of polycrystalline collectors.

Table 2 Building services and energy systems.

Main heating	NIBE Fighter heat pump air-to-water. Heat pump load or weather compensation.
Heating controls	Time and temperature zone control
Hot water	From primary heating system. Immersion present
Solar water heating	Nu-Heat solar panel. South oriented
Underfloor heating	Nu-Heat 14mm Fastflo
Hot water cylinder	Nu-heat 210 litre, immersion heating
Ventilation	Mechanical extract from kitchen and bathroom, fresh air supply in other rooms, connected to the EAHP.

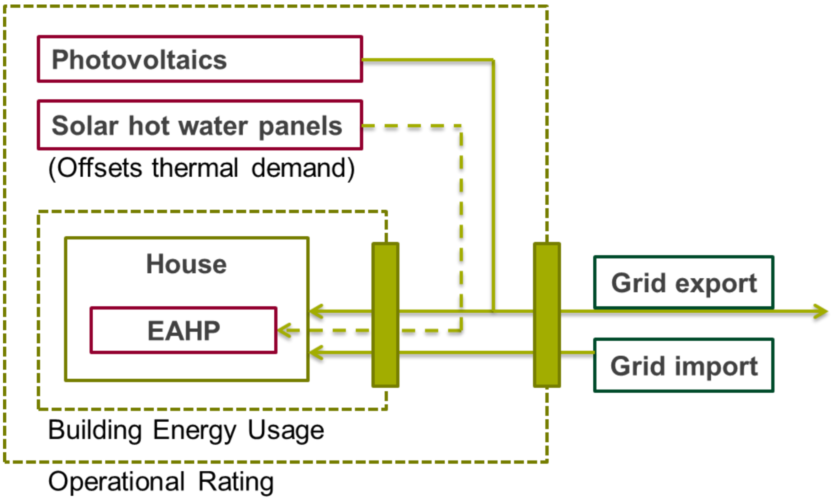


Figure 4 Schematic diagram of the buildings' energy systems.

3 Fabric testing (methodology approach)

Technology Strategy Board guidance on section requirements:	This section should provide a summary of the fabric testing undertaken as part of the mandatory elements of the BPE programme, *plus* any other discretionary elements that have been undertaken. Ensure that information on u-value measurements; thermography, air-tightness, any testing on party wall bypasses and any co-heating tests are covered. Give an overview of the testing process including conditions for the test any deviations in testing methodology and any measures taken to address deficiencies. Confirm whether any deviations highlighted have been rectified. As some tests (particularly the thermographic survey) are essentially qualitative it is important that the interpretation is informed by knowledge of the construction of the elements being looked at. Comment on the use of particular materials or approaches or their combination or installation methods lessons learned. Complete this section with conclusions and recommendations for future projects.

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 certain rate of air exchange 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 the air movement is uncontrolled and additional to the designed ventilation causing an unnecessary increase to the total heat loss.

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

Two surveys were undertaken, one at the beginning of the study (July 2013) and one towards the end of the study (July 2014). The surveys were undertaken whilst the properties were occupied.

The measured average air-permeability rate of both dwellings was tested using the method contained in the ATTMA standard TS1. 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.

In both cases the values were well above the design target of 2 $m^3/(h.m^2)$ suggesting noticeable heat losses due to air leakage paths (Table 3):

- House 5: Air-permeability rate did not meet UK Building Regulation Best practice ($5m^3/h.m^2$).
- House 11: Air-permeability rate did not meet UK Building Regulation Good practice ($10m^3/h.m^2$).

Table 3 Air permeability measurements

Air-permeability values	House 5	House 11

Design air permeability $m^3/(h.m^2)$	2	2
Average measured air permeability $m^3/(h.m^2)$ _July 2013	**5.36**	**15.77**
Average measured air permeability $m^3/(h.m^2)$ _July 2014	**6.35**	**16.48**
Energy Saving Trust Recommendation for CSH Level 5 (EST, 2008)	3.00	3.00
UK Building Regulation Best practice	5.00	5.00
UK Building Regulation Good practice	10.00	10.00

Smoke pencil tests carried out revealed significant levels of volume flow entering the NIBE and solar cupboards, as well as flows into electrical cabinets/cupboards (Figures 5 and 6). Other air leakage paths were revealed around: cracks in window frame joints, electrical outlets, skirting to floor junctions, services cupboards penetrations, under window cill boards, ceiling access hatches.

Figure 5 NIBE cupboard. Gaps in insulation and air leakage paths.

Figure 6 View into roof from NIBE cupboard

Comparison of the two tests reveals that the air-tightness levels of both houses have changed by 15% in House 5 and by 5% in House 11. This indicates the importance of taking shrinkage into account when conducting air permeability tests. An estimated percentage deterioration (perhaps up to 15%) over time might need to accompany reporting of the as-built value.

Finally, such high air-permeability levels compromise the contribution of mechanical ventilation. These findings indicate that the MVHR system provides a surplus of fresh air that has a negative effect on the heating load of the house.

3.2 Thermographic survey

A series of thermograms[1] were taken of the various elevations of the buildings. For the purposes of this survey, images were primarily taken of the external walls and internal surfaces that exhibited any thermal anomalies. The survey was undertaken on 28th February 2014. Findings in both surveys are similar and no deterioration of the envelope was observed.

The environmental conditions and building fabric properties were entered into the thermal imaging reporting software and the relevant corrections were made. This survey was undertaken in the late afternoon.

The thermograms of this report, as shown in the following sections, show a number of thermal anomalies, and additional information is provided in both the figure description, and in the thermograms themselves through spot and area temperatures (minimum and maximum). In general terms these anomalies were considered to be as a result of the build process. No major issues were discovered.

[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.

3.2.1 House 5

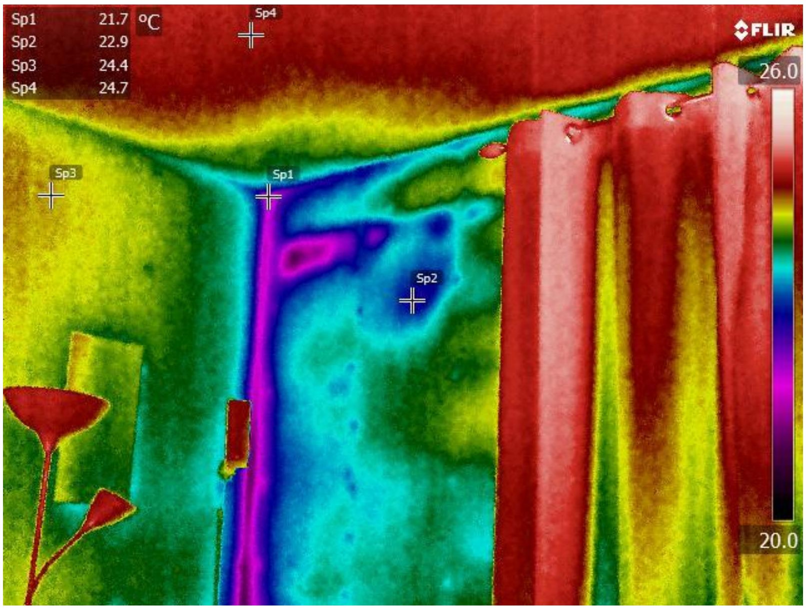


Figure 7 Living room ceiling thermogram. Image shows heat loss through the exposed wall. Cold spot identified on wall.

Figure 8 Living room ceiling digital photograph.

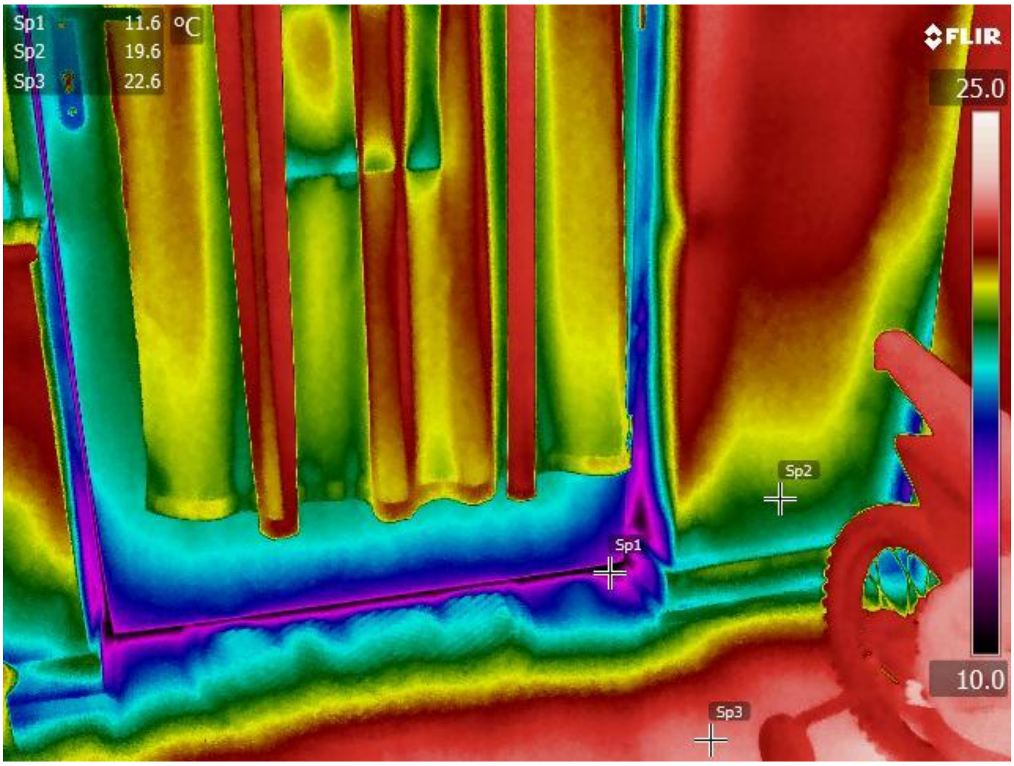


Figure 9 Main entrance door (threshold) thermogram (taken from indoors). Image shows air leakage around the bottom section of the frame and thermal bridging across threshold.

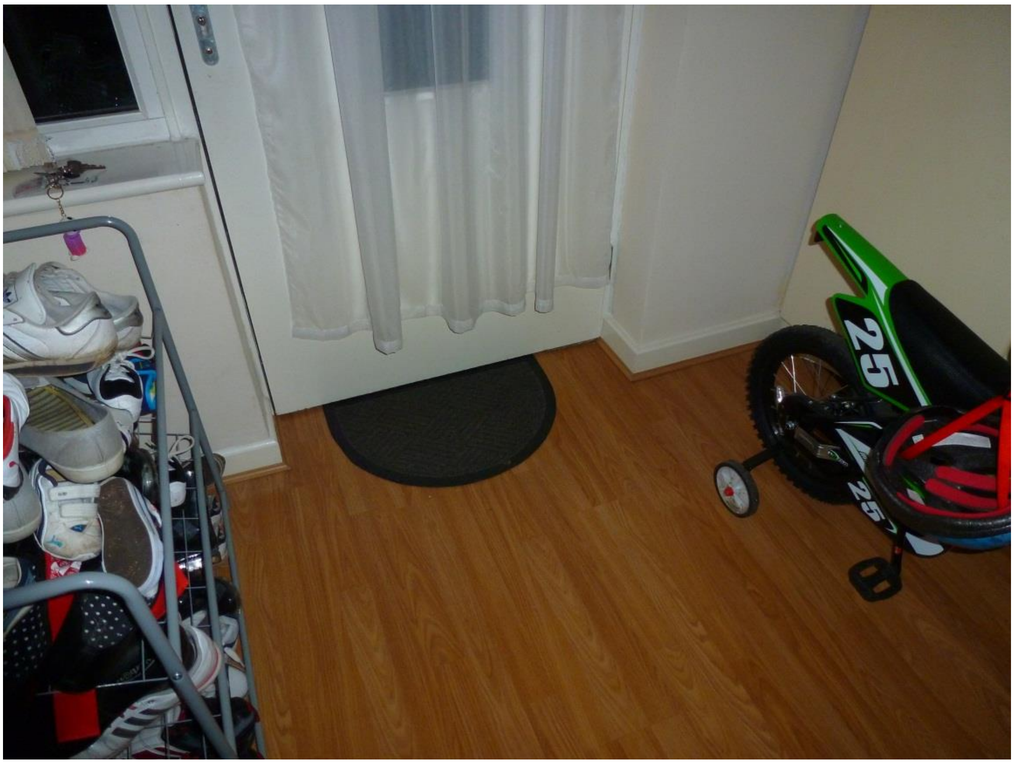


Figure 10 Main entrance door (threshold) digital photograph (taken from indoors).

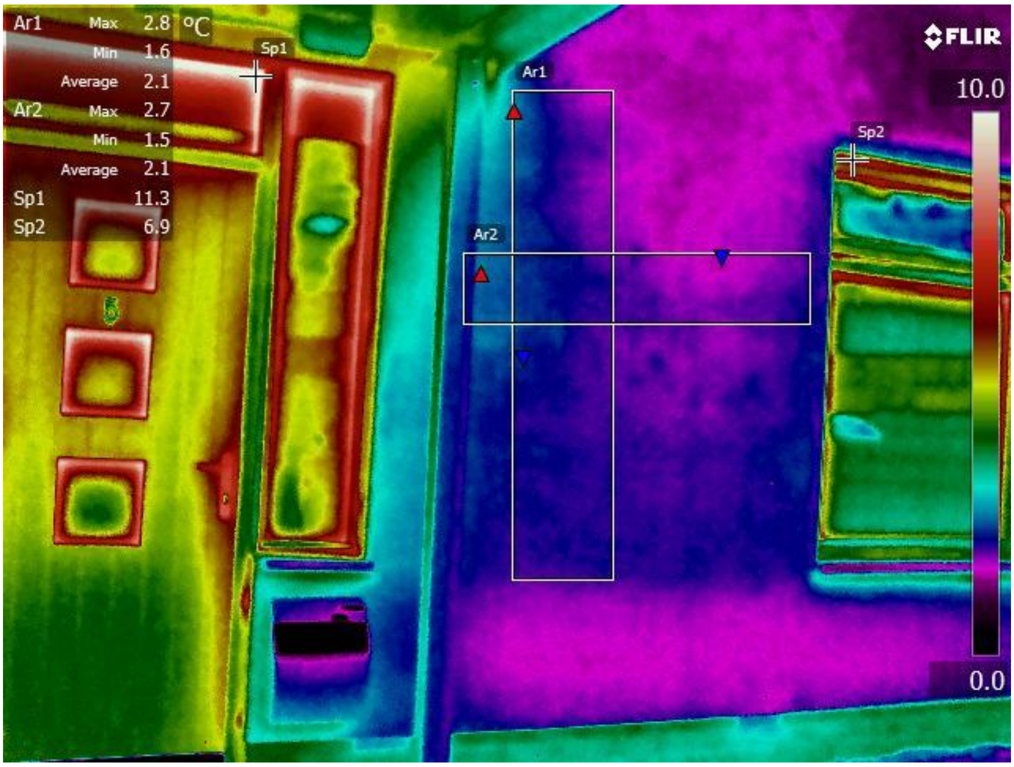


Figure 11 **North elevation main entrance thermogram (taken from outside). Image shows air leakage through the top of the door frame and through the window sill. Elevated temperatures in the upper part are likely to be due to poor fitting; a finding common to all doors and windows in both houses.**

Figure 12 North elevation main entrance digital photograph (taken from outside).

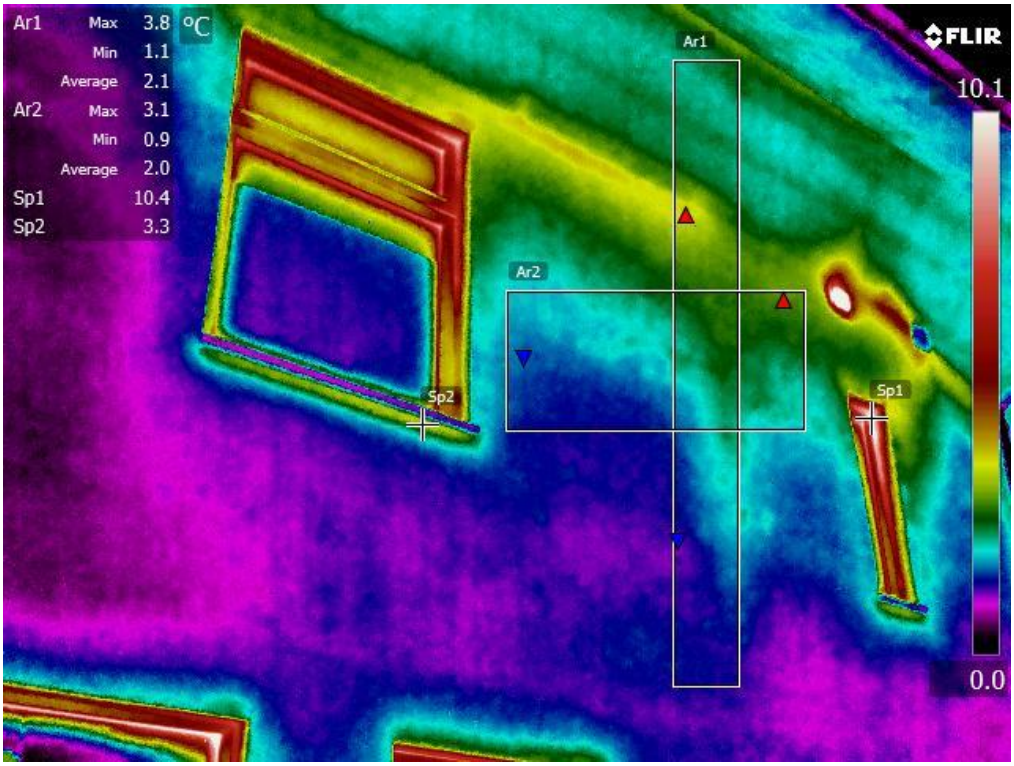


Figure 13 South upper elevation thermogram. Image shows heat loss through the upper part of the wall. The heating unit is located behind the wall at the right side of the narrow window.

Figure 14 South elevation digital photograph.

3.2.2 House 11

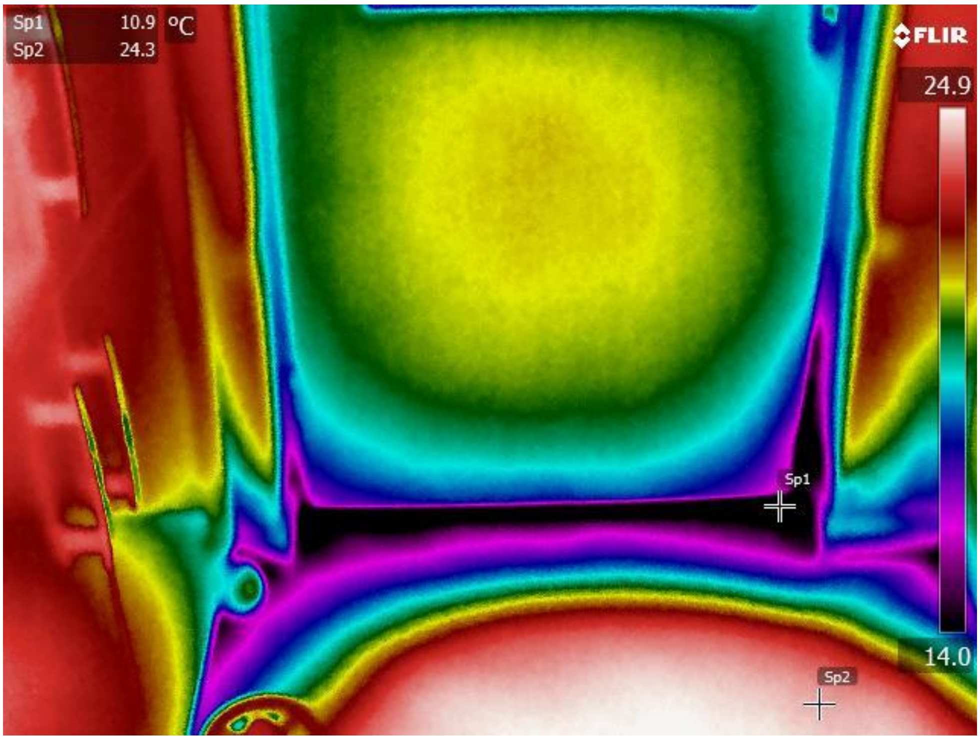


Figure 15 Rear kitchen door threshold thermogram (taken from inside). Image shows air leakage around the bottom of the door frame and thermal bridging across threshold.

Figure 16 Rear kitchen door threshold digital photograph (taken from inside).

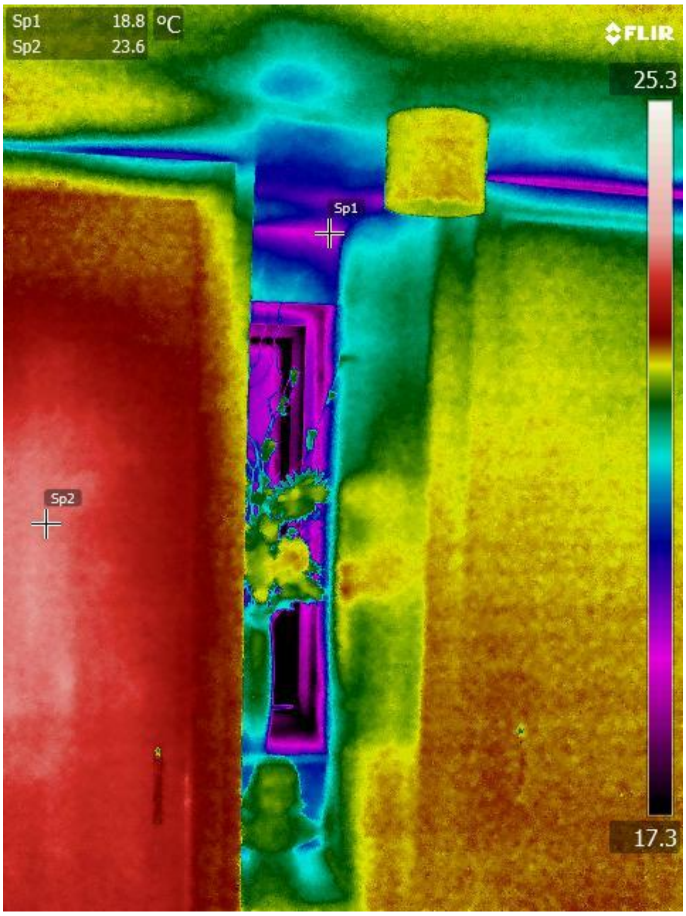


Figure 17 First floor landing thermogram. Image shows the heating unit cupboard heating up its surroundings and possible air leakage through the small window next to it (cold areas around window and on ceiling).

Figure 18 First floor landing digital photograph.

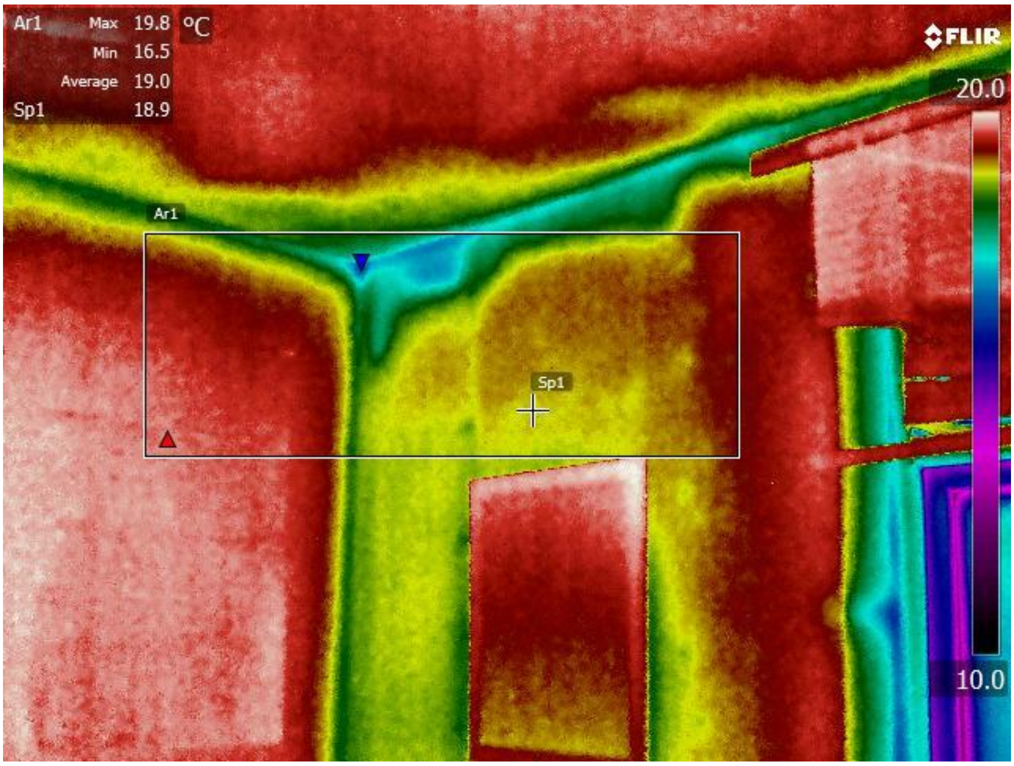


Figure 19 North bedroom ceiling thermograph. Cold spot and heat loss through exposed wall.

Figure 20 North bedroom ceiling digital photograph.

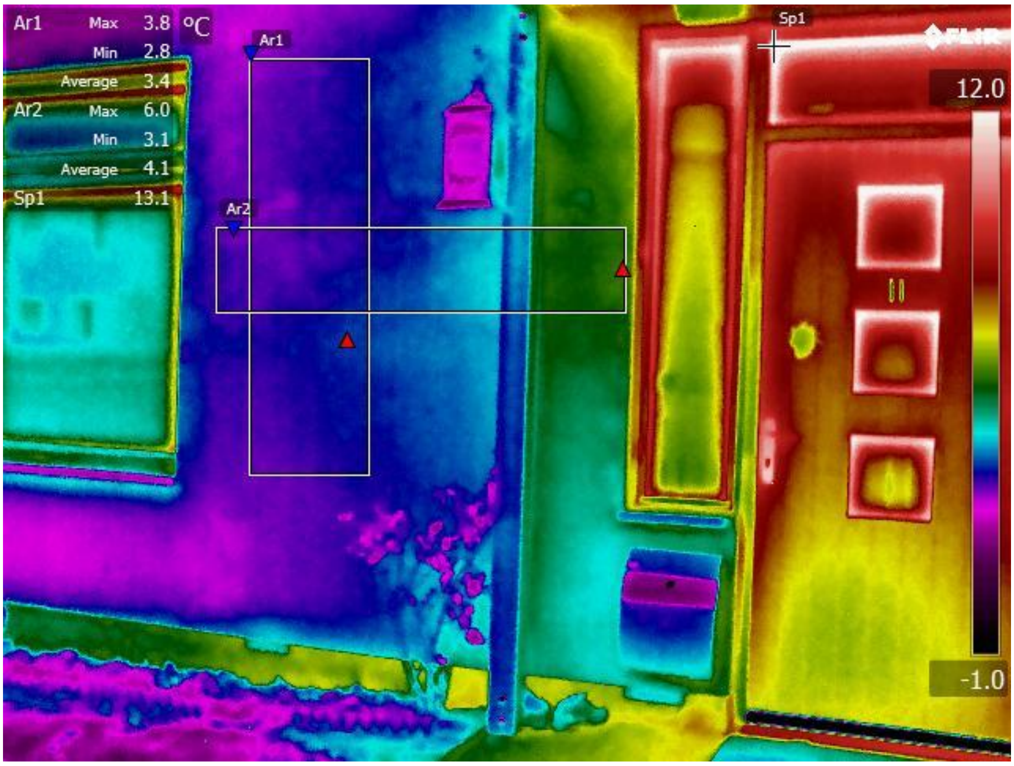


Figure 21 South elevation main entrance thermogram. Image shows air leakage through the top of the door frame.

Figure 22 South elevation main entrance digital photograph.

3.3 Key findings and recommendations

3.3.1 Key findings from the air tightness test

The air tightness tests showed that the houses do not meet the design air permeability target. In both cases, the values were well above the design target of 2 $m^3/(h.m^2)$ suggesting noticeable heat losses due to air leakage paths:

- In House 5 air-permeability was measured at 5.27 $m^3/(h.m^2)$ (depressurisation) and did not meet UK Building Regulation Best practice (5 $m^3/h.m^2$).
- In House 11 air-permeability was measured at 15.74 $m^3/(h.m^2)$ (depressurisation) and did not meet UK Building Regulation Good practice (10 $m^3/h.m^2$).

Significant levels of volume flow entering the NIBE and solar cupboards were observed, as well as flows into electrical cabinets/cupboards.

These findings indicate poor construction and finishes, particularly surrounding the electrical and mechanical services. Little attention appears to have been given to following the design standards and construction guidelines for achieving an air tight envelope. This highlights the need for greater co-ordination between building contractors and mechanical and electrical services contractors to ensure proper care is taken during the construction phase. Additionally, the findings indicate that the air-tightness test undertaken after construction, while the building was evaluated for Code level 5, was not done properly. Swindon Council was informed of the test findings in July 2013 but no action has been taken.

3.3.2 Key findings from the thermographic survey

The thermographic survey revealed no great issues. However, minor anomalies were detected:

- Heat loss through the exposed walls was found in both houses and in some cases, cold spots were identified on the external walls.
- Images show air leakage around the bottom section of the frame and thermal bridging across threshold of the front and back doors in both houses.
- Images also show how the heating unit cupboard heats up its surroundings, and indicates the significant air movement through and around the adjacent window.
- Images taken from outside show heat loss through the window sills and air leakage due to poor fitting (common to all doors and windows in both houses).

The findings are mostly related to the poor fitting of doors and windows. Swindon Council has been informed of the findings but no action has been taken as yet.

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

Technology Strategy Board guidance on section requirements:	This section should highlight the BPE team's initial studies into possible causes and effects, which may require further study. The section should reveal the main findings learnt from the walkthrough with the design and delivery team covering the early stage BPE process and the design intentions. Comment on lessons learned, key findings, conclusions and recommendations on what would be done differently next time. A critical feature of this section is reviewing the original aspirations for the project as stated by the design team and comparing with the delivered building. This often goes beyond what is stated in supporting documentation and is a crucial initial discussion which then frames the discussion about what changed during the process and why. The purpose of the walkthrough is to compare design intent with reality and why there is a gap between the two. Explore the degree to which the design intent has been followed through in terms of delivery and subsequent adoption by the occupant(s). Focus on what constraints or problems they had to accept or address in delivering the project. Cover construction team issues and how these were cascaded through the project for example: training for design team on utilising specific technologies and new materials, sequencing of trades. Describe and evaluate the documentation generated to confirm and record the commissioning and hand-over from specialist contractor to house builder. Include in the appendix if necessary. How did this process influence the design and delivery team walkthrough? Can anything be improved? Capture and assess how decisions were made and captured when the team are together e.g. the materials being used and whether they are required or desired – is there the possibility of changing materials and if so it this known by the procurement and constructions teams. Are there any issues relating to the dwelling's operation? This would include: programmers; timing systems and controls; lights; ventilation systems; temperature settings; motorised or manual openings / vents. Do the developer / manufacturer produced user manuals help or hinder the correct use of the dwelling? Have there been any issues relating to maintenance, reliability and reporting of breakdowns of systems within the dwelling? Do breakdowns affect building use and operation? Have issues been logged in a record book or similar? Add further explanatory information if necessary. Explain any other items not covered above that may be relevant to a building performance study. This walkthrough should be compared and contrasted with the occupant walkthrough (see later section) with comments on whether the design intent was desired, delivered and valued by the occupant and where and how differences between intent and expectation have arisen. If action was taken to remedy misunderstandings, improve support or feed occupant preferences into future design cycles this should be explained.

	Graphs, images and test results could be included in this section where it supports a developing view of how well or otherwise the design intent has been delivered during the pre and post completion phases. This section should provide a summary of the initial aftercare process, post completion building operation, and initial maintenance and management – particularly in relation to energy efficiency, reliability, metering strategy, building operation and the approach to maintenance i.e. proactive or reactive. Guidance on walkthroughs is available in the document *TSB BPE Domestic - Guidance on handover and walkthroughs.doc*, which can be downloaded from the Building Performance Evaluation site on `_connect'.

4.1 BUS survey

The Building Use Studies (BUS)[2] questionnaire method was used to map the reactions of the occupants in Code Level 5 Homes in Malmesbury Gardens, Swindon. The questionnaires were distributed on 4th June 2013. Some of the occupants filled them in and returned them the same day, whereas others were provided with pre-paid envelopes and were asked to return the questionnaires through the post. A total of 11 responses out of 19 questionnaires delivered were obtained.

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 were needed. The survey also collects comments made by the respondents under each of the categories. A summary of these comments is shown in tables.

The questionnaire variables are compared with their respective scales midpoint and BUS benchmarks to provide a slider showing the mean score across the 11 responses using green/amber/red lights depending on where it sits within the upper and lower limits of the scale midpoint and benchmark. The benchmark used is the UK 2011 domestic benchmark which forms of multiple domestic sites (i.e. multiple dwellings) in the UK. The benchmark includes dwellings of various typologies and age.

4.1.1 Background information

All the houses in the development are of the same typology (terraced) and have the same design and layout. However, the houses provide the flexibility to use the attic space as an additional floor and expand the house from a two bed property to a three bed property. Therefore, some of the houses are being used as two bed properties (2-storey) and others as three bed properties (3-storey). All of the houses are occupied by families with young children. The number of occupants in the houses varies greatly depending on the number of children in each family (2-7 children). Most of the families have two children. According to the collected demographic data (Figure 23) the majority of the people who responded to the questionnaires were women (7 out of 11) Most of the participants have lived in their house for more than one year. The majority of the participants (9 out of 11) are over 30 years of age.

[2] http://www.busmethodology.org.uk/

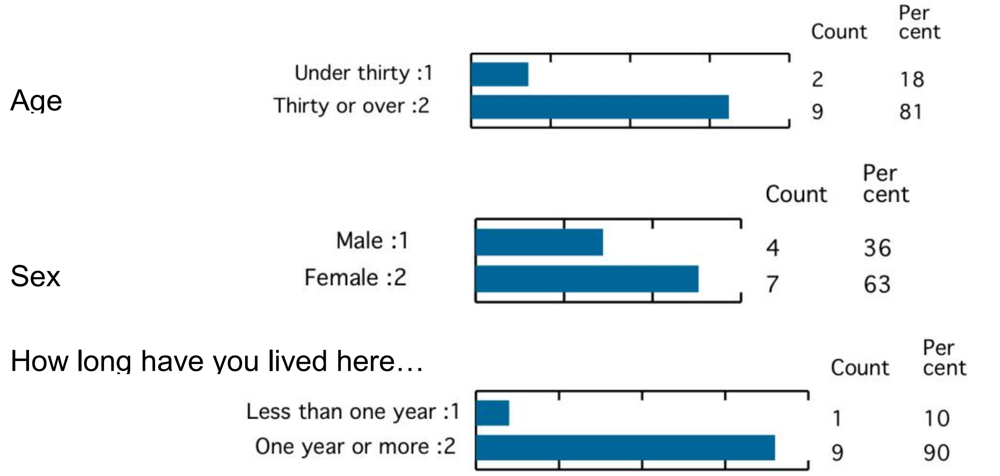


Figure 23 Demographic data

Eight of the participants reported that they are normally at home 'most of the time' whilst three are normally at home 'mostly in the evenings and during the weekends' (Figure 24).

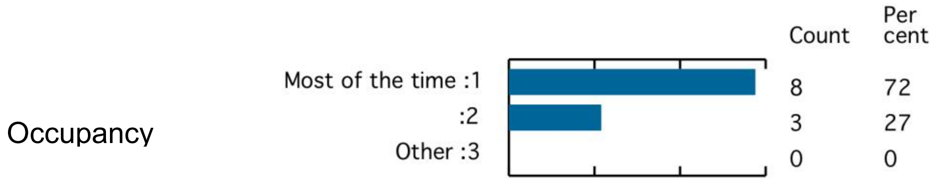


Figure 24 Occupancy pattern

4.1.2 The building overall

Overall, the survey reveals a positive opinion towards the houses, with most elements scoring higher than the scale midpoint but within the benchmark confidence limits, thus being classified as 'typical' (amber). It should be noted that confidence limits on the benchmarks are wide such as 'Design', hence the typical rating against benchmarks. The quality of light is one of the most appreciated elements. Lighting overall scores higher than the benchmark and towards higher end of the scale. Respondents generally feel that the facilities provided meet their needs well, with the houses scoring much higher than the benchmark. Temperatures during winter are generally regarded as quite comfortable, whereas temperatures during summer are regarded as less comfortable, scoring closer to the scale midpoint. Air quality is regarded as quite satisfactory during summer but less so during winter. Respondents generally believe that the house has not had any effect on their health (Figure 25).

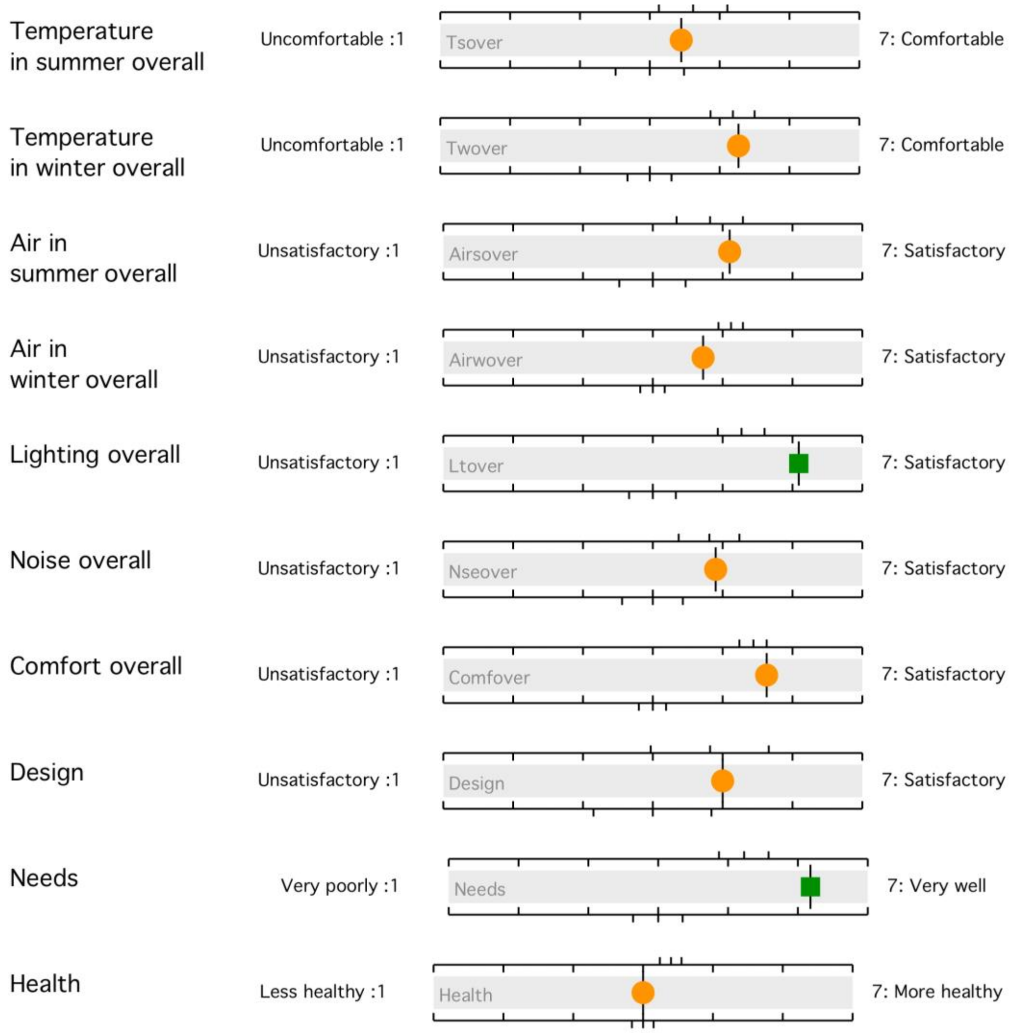


Figure 25 Overall findings

4.1.3 External appearance

Respondents rate the dwelling's appearance favourably with 4 out of 11 finding the appearance 'good' (Figure 26). The houses score higher than the scale midpoint and close to the benchmark mean.

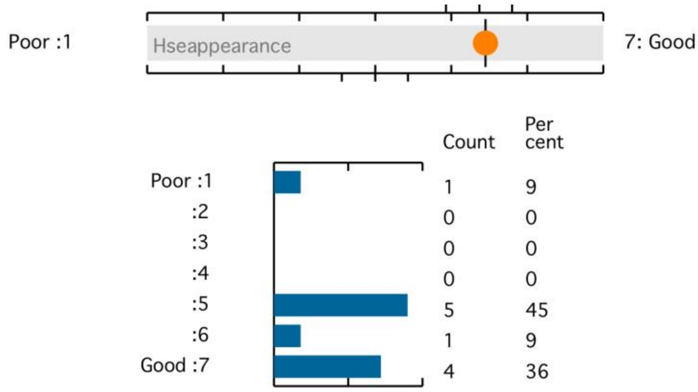


Figure 26 External appearance, slider and histogram.

Appearance
• *Paint peels off.* • *Plants are not tended by wardens. Kids break trees, fences.* • *Walls need tending to at front.* • *Warden does not tend area. Children make mess.*

4.1.4 Layout

The layout was rated as quite good with 5 of the respondents being fully satisfied. The layout of the houses scores much higher than the scale midpoint and towards the upper end of the benchmark confidence limits (Figure 27).

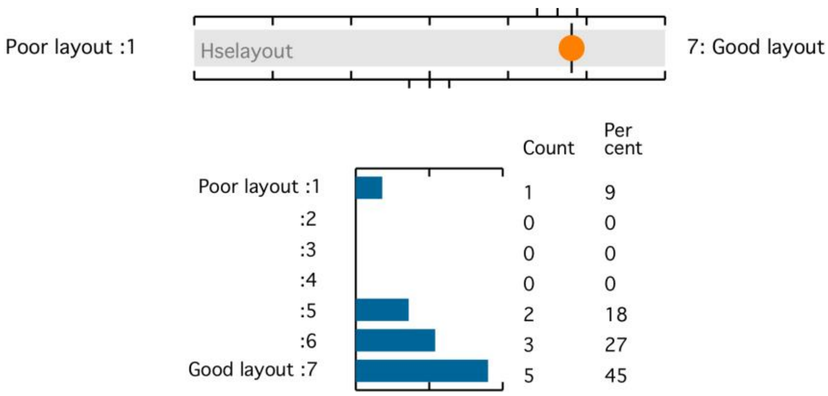


Figure 27 Layout, slider and histogram

Layout
• *They could have made the living room and dining/kitchen bigger.* • *Everything is fine apart from the joined kitchen and living room.* • *I am very happy with the layout.*

4.1.5 Location

The location of the houses was rated favourably with 5 of the participants being fully satisfied. The location scores higher than the scale midpoint but below the benchmark lower limit (Figure 28). Occupants comment that the houses are located in a quiet area, close to shops, buses and other local amenities.

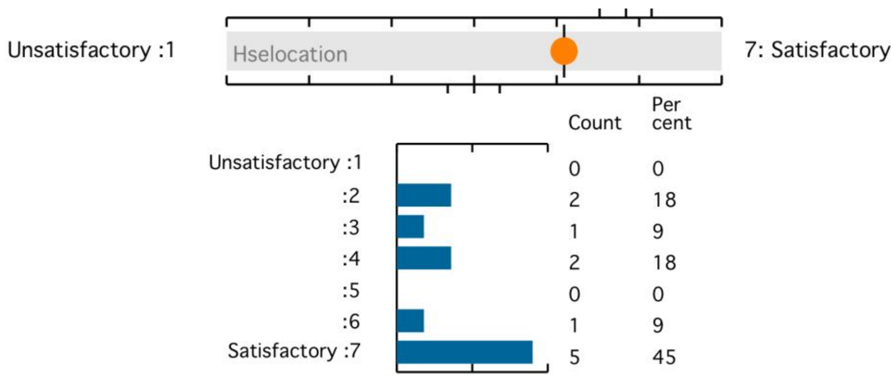


Figure 28 Location, slider and histogram

Location
• *I like the location.*   • *Nice, quiet area, close to shops, schools, doctors and buses.*

4.1.6 Space

Space is one of the most appreciated aspects of the development with the majority of the respondents (8 out of 11) being fully satisfied with it (Figure 29). The score is significantly higher than both the scale midpoint and the benchmark.

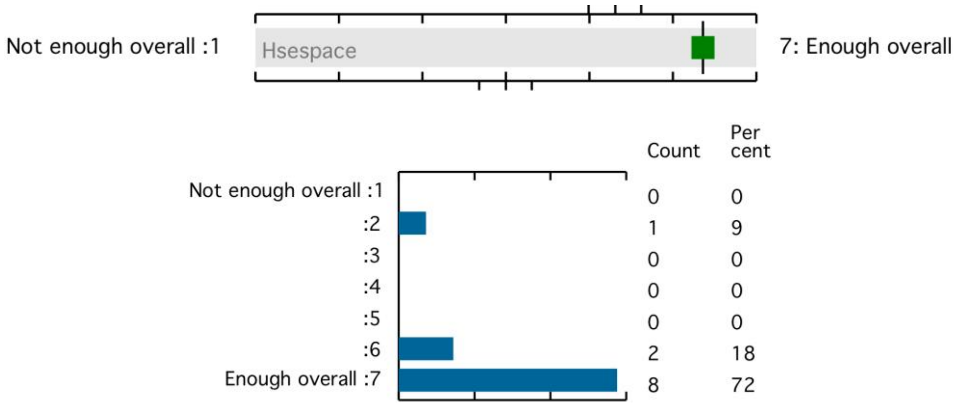


Figure 29 Space standards, slider and histogram

Space
• *Good size house.*   • *Living room could be bigger.*   • *Space is very good.*   • *I like drive spaces and rooms.*

4.1.7 Storage

The mean storage score is close to the scale midpoint and close to the benchmark mean. Contradictory answers were received regarding the amount of storage space with 4 of the respondents finding it more than enough and another 4 not finding it enough (Figure 30). This might be due to the fact that some houses are used as two bedroom properties, whereas others are used as three bedroom properties, having converted the attic space into bedrooms. Occupant interviews from the case study houses (two bedroom properties) reveal that in one of the houses the attic space is used for storage and occupants are satisfied with the amount of storage space, whereas in the other house occupants feel there is lack of dedicated storage space and they are not making use of the attic space. Additionally, the contradictory responses might be a result of the number of occupants living in the house. This number varies between 3-10 occupants, depending on the number of children of each family.

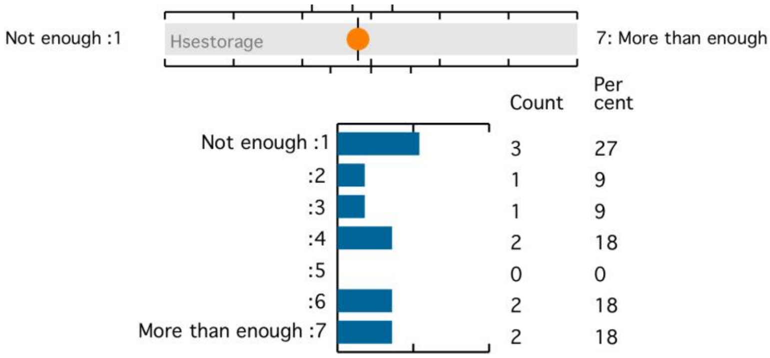


Figure 30 Storage, slider and histogram

Storage
• *There is no storage inside the house, only the shed in the garden.* • *There is not enough storage space (x2).* • *Storage could be more for such a big house.* • *There is only one small storage room with the washing machine.*

4.1.8 Comfort, design and needs

4.1.8.1 Comfort

The degree of comfort that users experience within a building is an important parameter of building performance. Participants were asked about their perceived comfort within the building in relation to the air temperature, air quality, noise, lighting, ventilation and level of personal control. The respondents were generally positive about overall comfort with 2 out of 11 being fully satisfied. In terms of comfort the score is much higher than the scale midpoint and right on the benchmark upper confidence limit (Figure 31).

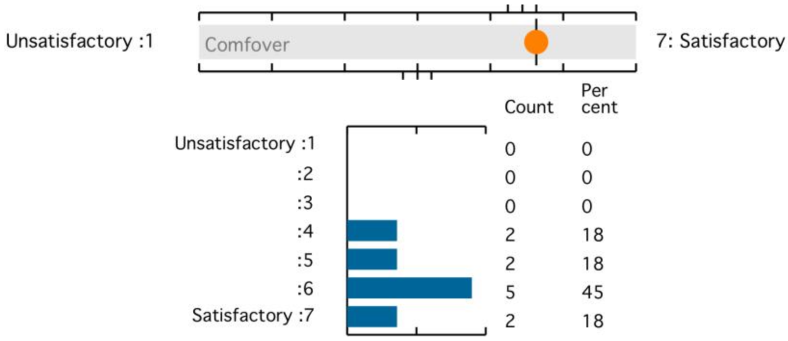


Figure 31 Comfort overall, slider and histogram

4.1.8.2 Design

The design of the houses is rated positively, with the score sitting higher than the scale midpoint and close to the benchmark mean (Figure 32).

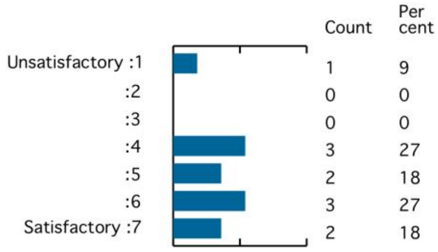


Figure 32 Design, slider and histograms

4.1.8.3 Needs

The respondents feel that their needs are met well, with the houses scoring higher than the benchmark. Six out of eleven occupants said their needs were met very well (Figure 33).

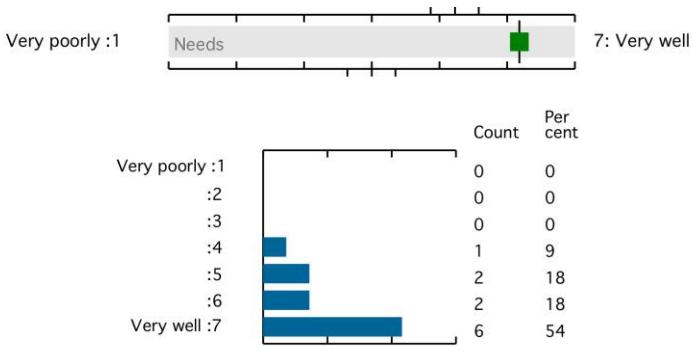


Figure 33 Needs, slider and histogram

4.1.9 Air temperature and quality

In general, the overall summer and winter conditions are perceived as comfortable, but less so in summer than winter (Figures 34 and 35). During both periods the scores sit within the benchmarks. However, whilst 3 of the respondents are fully comfortable in winter, none are in the summer.

People seem to be satisfied with the level of heat provided by the under-floor heating but find that their heating bills are high and there are some reports of this impeding the occupant's use of heating system in the winter.

4.1.9.1 Temperature in winter: overall

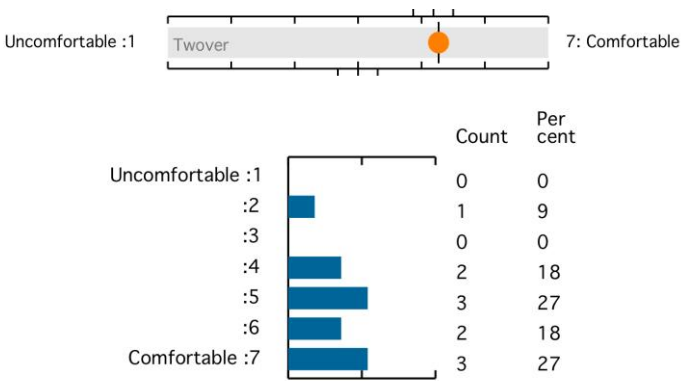


Figure 34 Temperature in winter overall, slider and histogram

4.1.9.2 Temperature in summer: overall

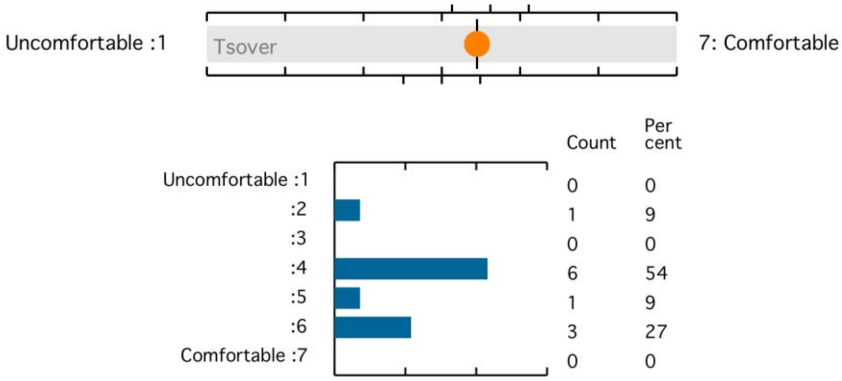


Figure 35 Temperature in summer overall, slider and histogram

4.1.9.3 Temperature: detail variables in winter/summer

Summer temperatures are perceived as slightly hot, with a mean score below the scale midpoint and close to the benchmark upper confidence limit. Winter temperatures are perceived as slightly cold, with scores higher than the scale midpoint and towards the middle of the benchmark. During both seasons temperatures are considered slightly stable, scoring close to the scale midpoint (Figure 36). Occupants report that the heating system is good but expensive. Other comments received point out that it is hard to control the heating system.

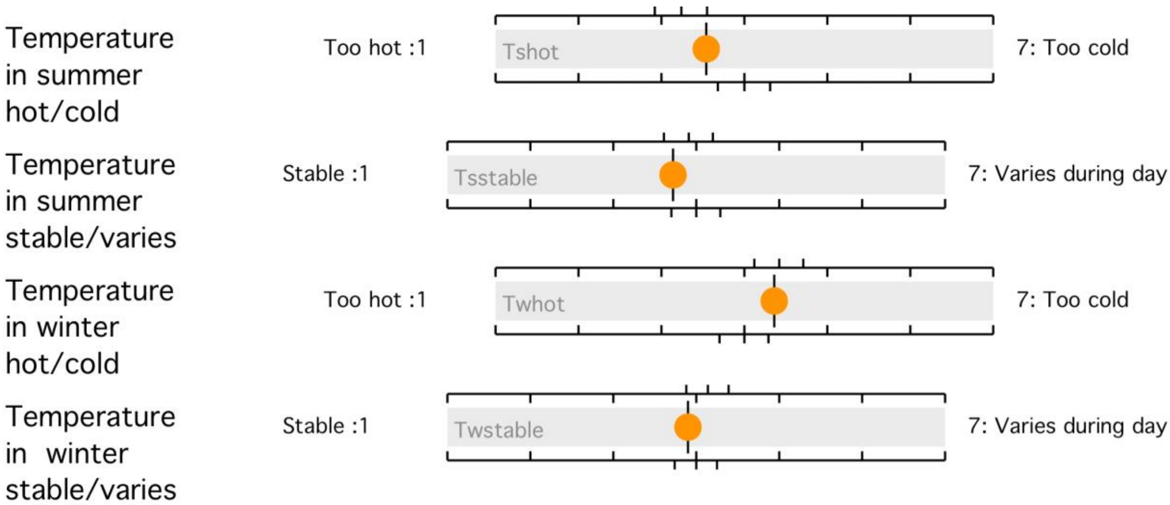


Figure 36 Temperature detail variables in winter/summer

Heating
• *Heating is erratic and no one knows how to control it either cold or hot and no in-between. I called the electric company and Council but received no answers.* • *It gets very cold when heating is not working.* • *It is perfectly warm downstairs and on the 1st floor but really cold on the 2nd floor* • *Under floor heating good but expensive.* • *Under floor heating is very expensive to run. Due to cost in the winter we cannot afford to have it on.*

- *When working properly & not costing fortune in electric, very good system.*

4.1.9.4 Air quality in winter: overall

Air quality in winter is perceived as slightly satisfactory, with only 1 of the respondents being fully satisfied (Figure 37) but scores towards the middle of the benchmark. This result appears to indicate that the MVHR system is not performing very well in providing the houses with fresh air.

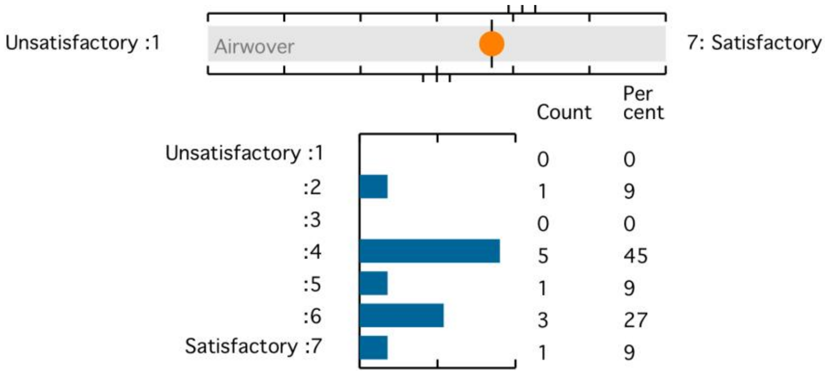


Figure 37 Air quality in winter overall, slider and histogram

4.1.9.5 Air quality in summer: overall

Air quality in summer was rated favourably, scoring towards the benchmark upper confidence limit. 4 out 11 occupants rated it close to the scale midpoint (Figure 38).

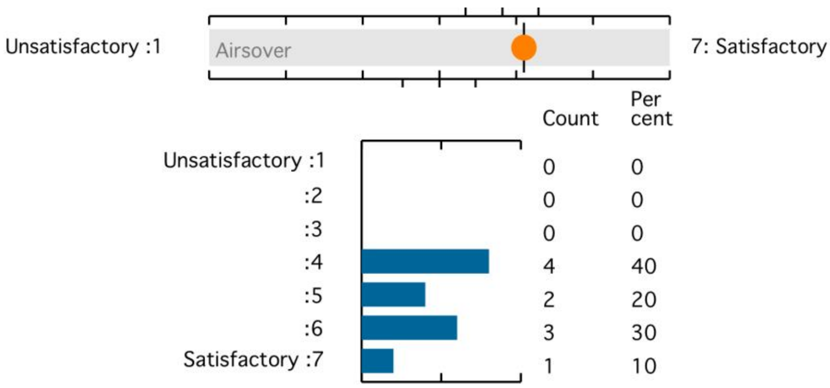


Figure 38 Air quality in summer overall, slider and histogram

4.1.9.6 Air quality detail variables in winter/summer

In general, air quality detail variables are rated favourably (Figure 39). However, air in summer is perceived as dry, scoring statistically below the benchmark confidence limits and below scale midpoint. The parameter indicating air freshness/stuffiness was rated favourably in both seasons, but more so during summer when it scores above the benchmark.The parameter indicating 'air still/draughty' is also rated favourably in both seasons, scoring closer to the scale midpoint and above the benchmark in winter. A better performance is to be expected from houses with MVHR systems. Problems may be linked to the low air tightness levels of the houses, the lack of knowledge from the side of the users (boost button, filter change) and to the system not being balanced properly.

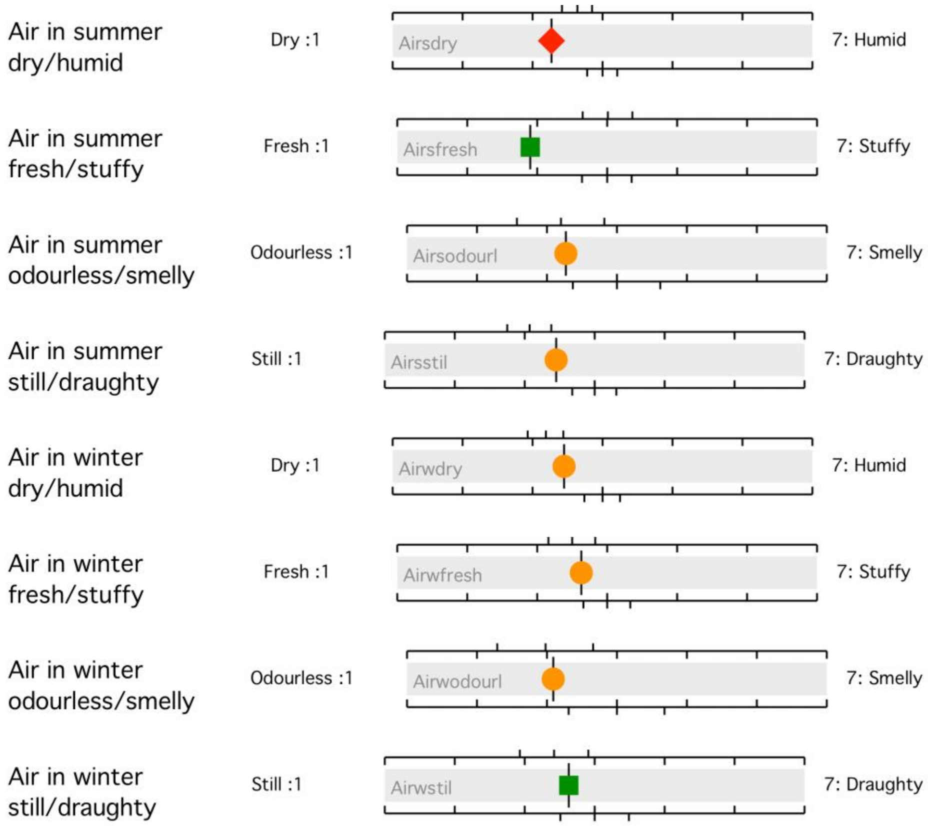


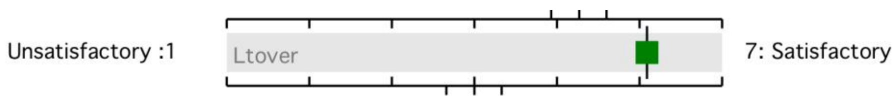
Figure 39 Air quality detail variables in summer and winter

4.1.10 Lighting

Lighting levels overall are one of the most appreciated elements of the building, with 5 of the respondents being fully satisfied. This parameter scores much higher than the benchmark (Figure 40). These results are potentially due to the south orientation and high window to floor ratios of the houses.

However, artificial lighting is considered high, scoring below the benchmark and towards the 'too much' end of the scale (Figures 41, 42). Natural lighting scores close to the benchmark mean, with the majority of the respondents (7 out of 11) being fully satisfied with it (Figures 41, 42)

4.1.10.1 Lighting overall



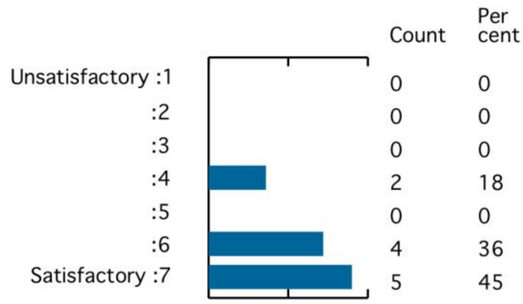


Figure 40 Lighting overall, slider and histogram

4.1.10.2 Artificial/natural lighting

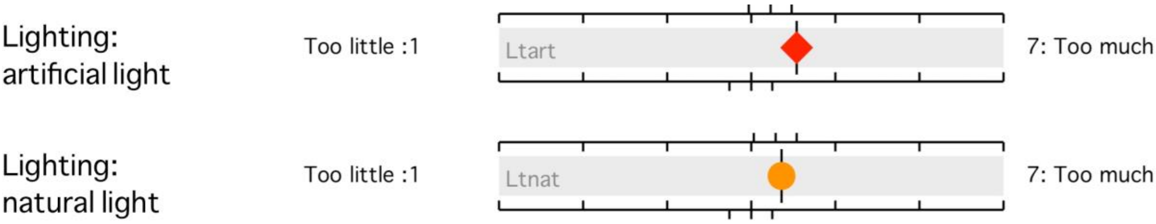


Figure 41 Artificial/natural lighting

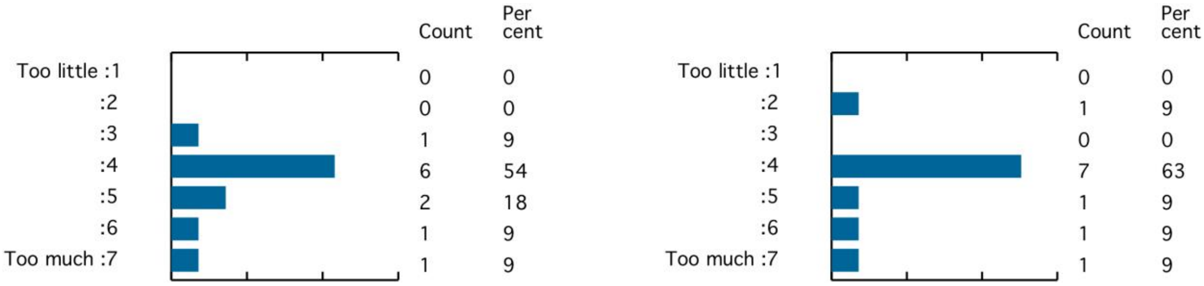


Figure 42 Artificial lighting (left), Natural lighting (right) histograms.

Lighting
• *Lighting is ok.* • *Daylight is good.* • *Would be nice if the lights had a dimming ability.*

4.1.11 Noise

4.1.11.1 Noise overall

Noise overall is rated favourably, scoring higher than the scale midpoint and close to the benchmark mean (Figure 43).

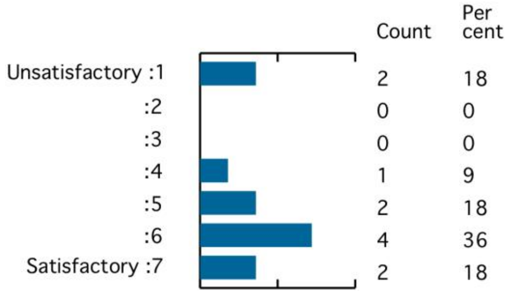


Figure 43 Noise overall, slider and histogram

4.1.11.2 Noise from outside

Noise from outside is not a problem for the majority of the respondents (7 out of 11). The score for this parameter sits close to the scale midpoint and falls towards the 'too little' side of the scale (Figure 44).

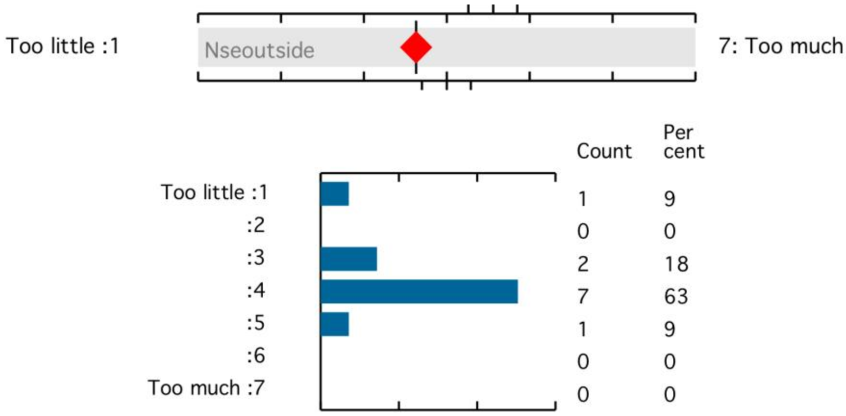


Figure 44 Noise from outside, slider and histogram

4.1.11.3 Noise from neighbours

Noise from neighbours scores close to the scale midpoint. 7 of the respondents do not have a problem with noise from neighbours, with only 1 respondent believing it is 'too much' (suggesting it is a localised issue) (Figure 45).

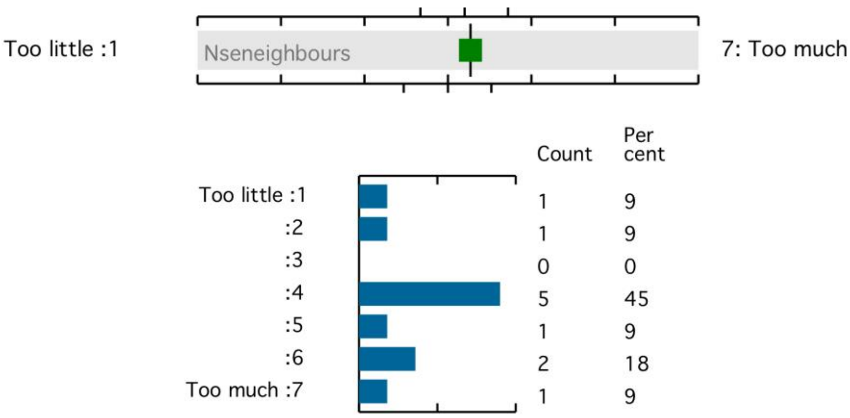


Figure 45 Noise from neighbours, slider and histogram

4.1.11.4 Noise from other people

Noise from other people in the house is not a problem for the majority (7 out of 11) of the respondents. The score sits in the scale midpoint and is higher than the benchmark (Figure 46).

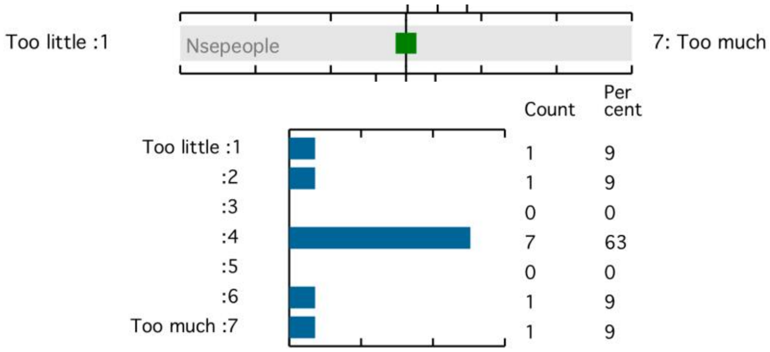


Figure 46 Noise from other people, slider and histograms

Noise
• *We can often hear the next door neighbours, doors slamming kids screaming, visitors* • *Noise is fine.* • *Noise transfer between floors.*

4.1.12 Personal control

Control over heating is rated positively, scoring slightly higher than the scale midpoint, yet individual results are contradictory; 2 respondents feel that they have full control, 4 are neutral and another 2 feel they have no control over heating (Figures 47, 48). This is related to each occupant's level of understanding of the heating systems and their controls as well as their participation in the induction process. Control over cooling is rated negatively, scoring below the scale midpoint and below the benchmark. 4 respondents feel that they have little and 2 feel they have no control over cooling. Lighting controls are generally rated positively, scoring higher than the scale midpoint but below the benchmark lower confidence limit. Control over ventilation scores close to the scale midpoint; 5 of the occupants feel that their control over ventilation is adequate, and 2 feel they have very good control over ventilation. Control over noise is lower than mid-point, with the majority of the respondents feeling they do not have sufficient control over it.

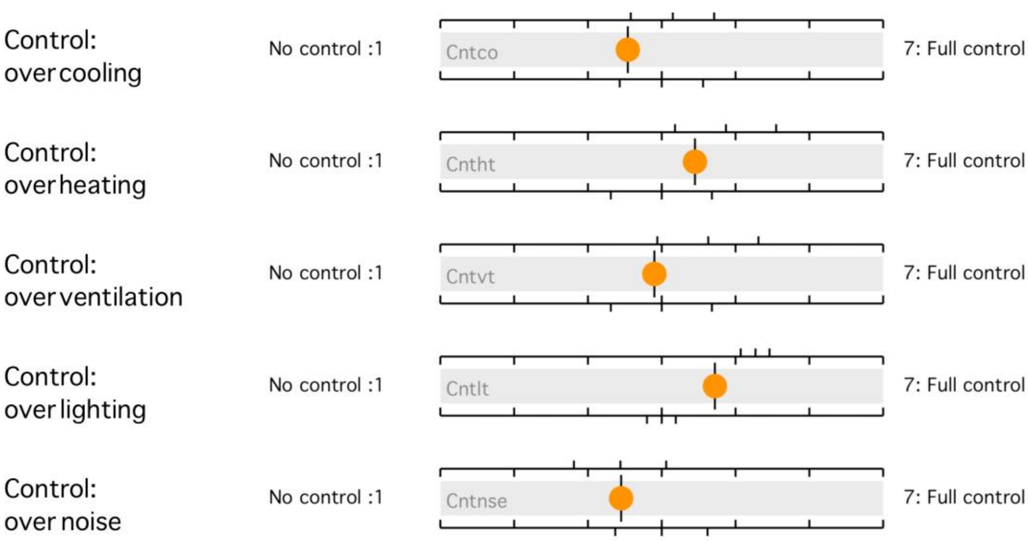


Figure 47 Personal control

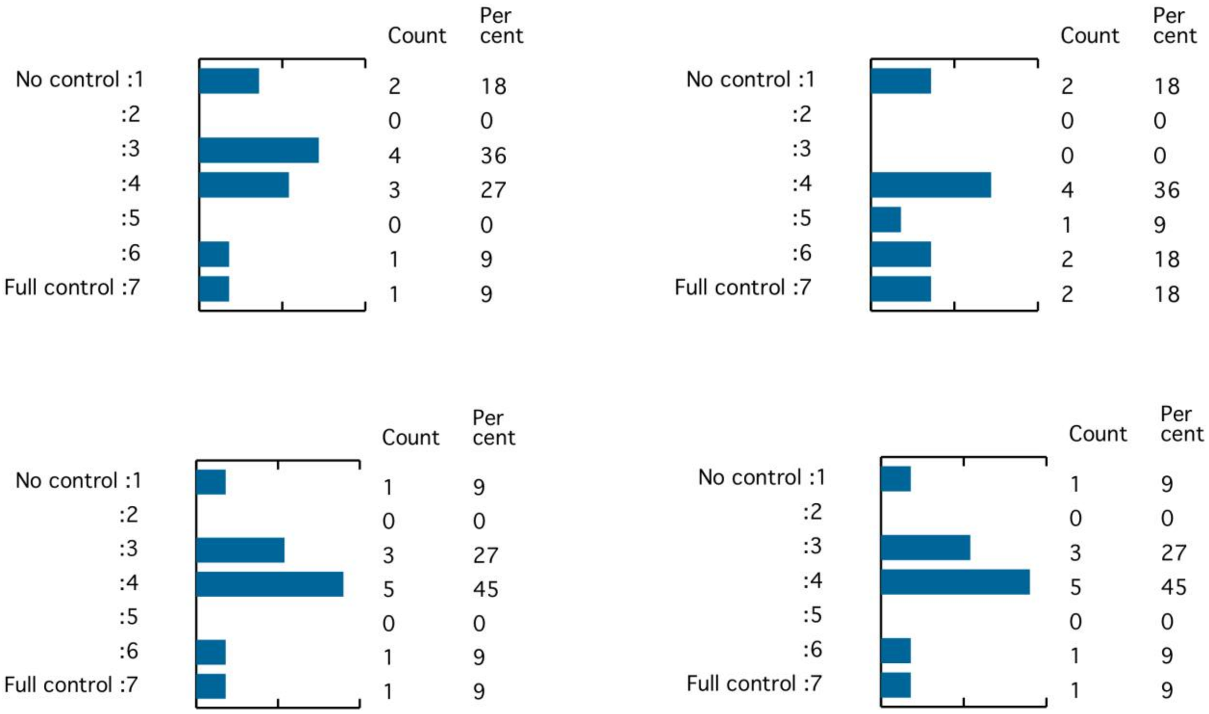


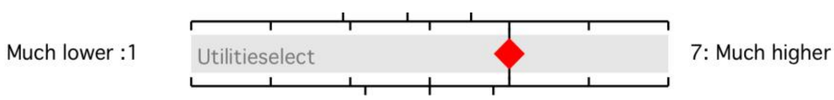
Figure 48 Control over cooling (top left), heating (top right), ventilation (bottom left), lighting (bottom right).

Control
• *I am unable to control the heating properly.* • *Difficult to control the heating properly and use less energy when no one knows how to.*

4.1.13 Utilities costs

In relation to the cost of electricity bills, many comments were received pointing out that bills are high even though the houses are supposed to be low carbon. It should be noted that the main source for the heating system in these properties is electricity.

Respondents generally feel that electricity costs are higher than those in their previous accommodations, with the score sitting close to the 'much higher' end of the scale. 3 of the respondents feel that their electricity bills are much higher than what they were previously (Figure 49). Comments received point out that the electricity bills are high and that occupant's expectations of the low carbon houses were very different.



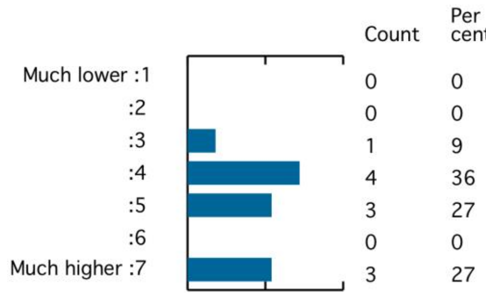


Figure 49 Electricity costs, slider and histogram

4.1.13.1 Heating

Heating costs received very similar ratings to electricity costs as the heating system runs on electricity (EAHP). Respondents generally feel that heating costs are higher in the new houses than those in their previous accommodations, with 3 of them feeling that they are 'much higher'. The score for this parameter is outside the benchmark limits (Figure 50).

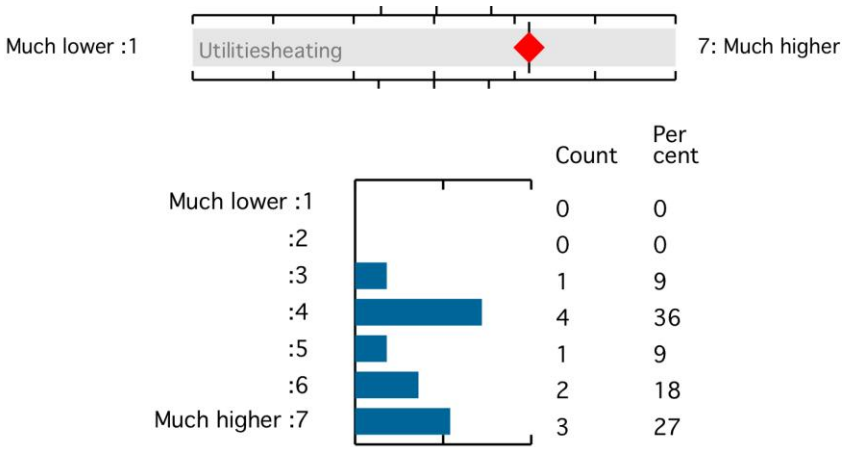


Figure 50 Heating costs, slider and histogram

4.1.13.2 Water

Respondents generally feel that water costs are similar to the ones in their previous accommodations, with the score sitting in the scale midpoint (Figure 51).

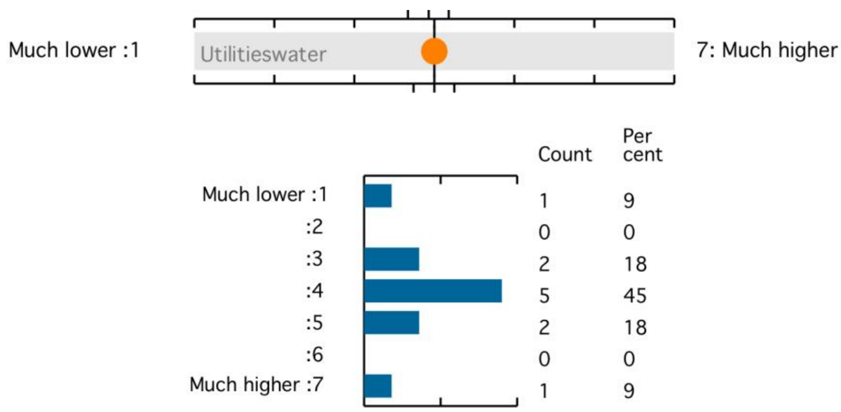


Figure 51 Water costs, slider and histogram

Utilities costs

- *Electricity bills are very high.*
- *Electricity is higher than in my last property which was not low carbon.*
- *When moving here I was told electricity would be cheap but it is not.*
- *It was supposed to be an eco-house saving us money but electricity bills are as high as in houses that do not have solar panels.*
- *The water meter has made us more aware of our water consumption and helped us to reduce it.*
- *Heating is very expensive; it is not affordable even with the help of solar panels. Water is good, no problems.*

4.1.14 Lifestyle

7 of the respondents state that living in the house has changed their lifestyle (Figure 52). A few people comment that having a garden has allowed them to invite more visitors over as there is more space.

Figure 52 Effect of houses on lifestyle

Lifestyle
• *It is far to go anywhere central in Swindon (town, outlet, train).*
• *It is close to school.*
• *It takes me less time from here to travel to school and to work.*
• *Everyone gets to have their own bedroom in the house.*
• *We enjoy the garden. We can have family and friends over and get together more as there is plenty of space.*
• *Nice to have a garden. We have more visitors over because of space.*

4.1.15 Perceived health

The majority of the respondents (9 out of 11) feel the house has not had any effect on their health (Figure 53).

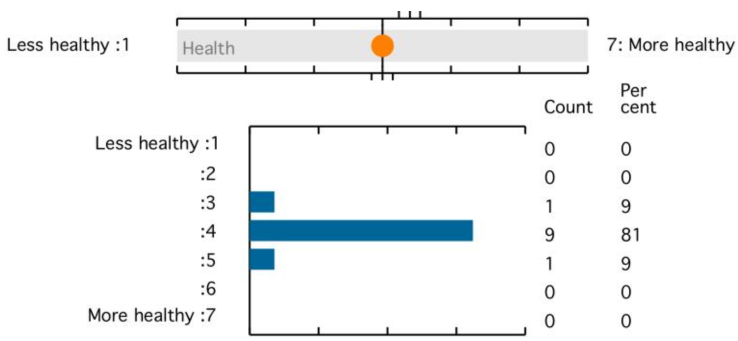


Figure 53 Perceived health, slider and histogram

4.1.16 Aspects that work well or poorly

The main aspects that work poorly for the occupants are the lack of storage space and the downstairs shower room that can only be used as a toilet. The key aspects that work well are considered to be the garden, the layout and the size of the rooms.

Aspects that work poorly
• *Not enough storage space.* • *Wardens do not tend the external area.* • *In the downstairs wet room we can only use the toilet and the sink as the floor is not sloped enough for water to run to the plug when shower is in use.* • *The windows are unpractical when it comes to cleaning, you can't clean it from the outside.* • *Poor design of letterbox.* • *Not enclosed front garden.* • *Living room could have used more of hallway space.*

Aspects that work well
• *Nice garden.* • *Spacious bedrooms, kitchen and living room.* • *Nice, quiet area.* • *Good house size for families.* • *Having a toilet downstairs is good.* • *Having two bathrooms is good.* • *Nice layout.* • *Driveway.*

4.2 Interviews and walkthroughs with occupants

The occupant interviews and walkthroughs were conducted on Tuesday 2nd July 2013 in House 5 and on Tuesday 9th July 2013 in House 11. Both sets of occupants were asked the same questions.

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 (heating and hot water, ventilation, daylight and lighting, noise) 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 for each space.

4.3 Key findings and recommendations

4.3.1 Key findings and recommendations from BUS survey

4.3.1.1 Key findings

Findings from occupant surveys and interviews help to contextualise the environmental conditions in the houses. Temperatures during winter are generally regarded as quite comfortable, whereas summer temperatures are perceived as slightly hot. Occupants complain of poor control over heating with some occupants feeling they cannot control temperatures effectively. Complaints regarding high summer temperatures indicate that the houses are not very adaptable to warm weather conditions. This might be due to the lack of shading devices, lack of cross ventilation and low thermal mass of the houses.

- The overall picture of the survey revealed a positive opinion towards the houses.
- Respondents generally feel that the facilities provided meet their needs well, with the building scoring higher than the benchmark.
- Respondents generally believe that the house has not had any effect on their health.
- Respondents rated the dwelling's appearance favourably with 4 out of 11 finding the appearance 'good'.
- The layout is rated as quite good on average with 5 of the respondents being fully satisfied.
- The location of the houses is rated favourably with 5 of the participants being fully satisfied.
- Space is one of the most appreciated aspects of the development with the majority of the respondents (8 out of 11) being fully satisfied with it.
- The building storage score is close to the scale midpoint. Contradictory answers were received regarding the amount of storage space with 2 of the respondents finding it more than enough and another 3 not finding it enough. This might be due to the fact that some houses are used as two bedroom properties, whereas others are used as three bedroom properties, having converted the attic space into bedrooms. Additionally, the contradictory responses might be a result of the number of occupants living in the house.
- The respondents are generally positive about overall comfort. In terms of comfort the houses score higher than the scale midpoint and towards the upper part of the benchmark.
- Temperatures during winter are generally regarded as quite comfortable, whereas temperatures during summer are regarded as less comfortable, scoring closer to the scale midpoint. During both periods the scores sit within the benchmarks.
- Summer temperatures are perceived as slightly hot, with a mean score below the scale midpoint and close to the benchmark upper confidence limit. Winter temperatures are perceived as slightly cold, with scores higher than the scale midpoint and towards the middle of the benchmark.
- Air quality is regarded as quite satisfactory during summer but less so during winter.
- Air quality in winter is perceived as slightly satisfactory, with only 1 of the respondents being fully satisfied. This parameter scores towards the middle of the benchmark. This potentially indicates issues with the performance of the MVHR in terms of providing the houses with fresh air.
- Air quality in summer was rated favourably, scoring towards the benchmark upper confidence limit.
- Lighting levels overall are one of the most appreciated elements of the building, with 5 of the respondents being fully satisfied. This parameter scores much higher than the benchmark. These results are probably due to the south orientation and high window to floor ratios of the houses.
- Natural lighting scores close to the scale midpoint, with the majority of the respondents (7 out of 11) being fully satisfied with it.

- Noise overall is rated favourably, scoring higher than the scale midpoint and close to the benchmark mean.
- Control over heating is rated positively, scoring higher than the scale midpoint. However, some occupants reported having very limited control over heating suggesting problems with the commissioning of some systems or issues regarding the training of individuals.
- Control over cooling is rated negatively, scoring below the benchmark and scale midpoint.
- Control over ventilation scores close to the scale midpoint; with 5 of the occupants feeling that their control over ventilation is adequate, and 1 feeling that they have very good control over ventilation.
- Control over noise is rated negatively, with the majority of the respondents feeling that they do not have enough control over it.
- Respondents generally feel that electricity costs are higher than those in their previous accommodations.. 2 of the respondents feel that their electricity bills are much higher than what they were previously.
- Respondents generally feel that water costs are similar to the ones in their previous accommodations.
- 7 of the respondents state that living in the house has changed their lifestyle. A few people comment on having a garden, stating that it has allowed them to invite more visitors over as there is more space.
- The majority of the respondents (9 out of 11) feel their house has not had any effect on their health.
- The main aspects that work poorly for the occupants are the lack of storage space and the downstairs shower room that can only be used as a toilet. The key aspects that work well are considered to be the garden, the layout and the size of the rooms.

4.3.1.2 Recommendations

- Maintain good standard of design and layout and generous space standards.
- Maintain good daylight quality in future developments.
- Review induction process to provide more detailed and hands-on experience.
- Take measures to improve the performance of the exhaust air heat pump by training the occupants, re-balancing the system, improving air tightness in houses and addressing breakdowns.
- Review the Home User Guide to provide concise but more accurate and useful information to occupants on how and when to change the settings of the heating system seasonally.
- Review noise specification standards for partition walls between houses.
- Reconsider the storage space in the properties. Dedicated storage space needs to be ‘designed’ properly in line with occupants’ expectations.

4.3.2 Key findings and recommendations from interviews and walkthroughs with occupants

Occupants in House 5 are generally more dissatisfied with the house than occupants in House 11. It should be noted that on several points the opinions of the occupants in Houses 5 and 11 are quite different.

4.3.2.1 Key findings

Energy and water consumption

- Occupants in both houses agree that the electricity bills are high and are not satisfied with the heat pump, in terms of understanding and perceived performance. The same was reported during the BUS survey by occupants of other houses in the development.
- Occupants in House 11 are very conscious with their water consumption and pay a very small bill of £11/month, whereas occupants in House 5 find their bill too high (£204 Aug-Feb).

Occupant satisfaction

- Occupants in both houses agree that all spaces in the house are easy to clean and maintain.
- Occupants in House 11 are very pleased with the design, layout and overall appearance of the house, in contrast to the occupants in House 5 who do not like the open plan kitchen and are not satisfied with the appearance of the house (Figures 54-55). Occupants in both houses agree that room spaces are satisfactory.

Figure 54 House 5 back yard (left). House 11 back yard (right) Occupants are satisfied with the appearance and size of the garden.

Figure 55 House 5 front (left). Occupants are not very satisfied with the appearance of the house. House 11 front (right). Occupants are satisfied with the size of the front space and storage.

Home User Guide & Induction process

- Occupants admit that they do not fully understand all the systems installed in the house and feel that they were not properly explained during the induction process. Occupants would like some more information that would help them understand how to make full use of the PV panels and how to operate the heat pump on a seasonal basis. This suggests that a more hands on approach might be needed in the handover process.
- Regarding the Home User Guide, occupants in House 11 said that they found it easy and helpful, although some of the information included was not accurate. Occupants in House 5 reported that it is hard to understand, long and difficult to read and that it did not include any guidance on how to operate the heat pump. This confirms the findings of the review of the Home User Guide according to which the Home User Guide provides detailed information on the systems and their specifications but does not give simple and straight forward instructions to users on how to operate the systems.

Heating system: operation, comfort and control

- Occupants in House 11 seem to be more at ease with operating the heating system and controlling the thermostats than occupants in House 5, who admitted finding it difficult to set the temperature at desirable levels. Occupants reported that they are confused about how to operate the heat pump and what setting to use during different seasons. This problem was also identified in the review of the Home User Guide.
- Occupants in House 11 are generally satisfied with the temperatures in the house whereas occupants in House 5 complain that it is hard to control the temperatures and that the house often gets ‘ too hot or too cold’ with them having little control over the heating. The review of controls (Phase 1) had indicated that the controls do not provide a good level of fine control as they operate on a scale from 1-7 without indicating the actual temperature. Occupants in House 5 also complain that system responsiveness is too slow.
- There is no temperature indication on the dial and occupants do not know what the numbers on the scale stand for. This results in some confusion on how to control the temperatures in the house and achieve comfort. Occupants had to go through a period of trial and error before being able to set the temperature at comfortable levels. In House 11 occupants are still confused about the thermostat settings they need to use. All the room thermostats are connected to a master thermostat that is connected to the Exhaust Air Heat Pump (EAHP). The room temperature is controlled by a rotary dial with an arbitrary linear scale. The direction in which to turn the switch to heighten or lower the temperature is not graphically indicated. A red light at the bottom right corner of each thermostat indicates the whole system operation rather than the status of the room, as stated by the architect during the walkthrough. In addition, the oversimplified arbitrary line scale without any labelling and numbering could not sufficiently indicate what the scale levels provide in terms of temperature or comfort conditions. In the absence of clear annotation, the user is forced to experiment. When the cover is removed the temperature at which the heating system would operate is revealed.
- Occupants in House 5 leave the heating system on throughout the year, whereas occupants in House 11 turn it off during summer. This indicates that they had not received proper guidance during the induction phase and underlines the fact that the Home User Guide does not include direct instructions on how to operate the heat pumps.
- Occupants in House 11 reported that the Home User Guide gives inaccurate information on how to operate the thermostat dial. This has been verified through the review of the Home User Guide.

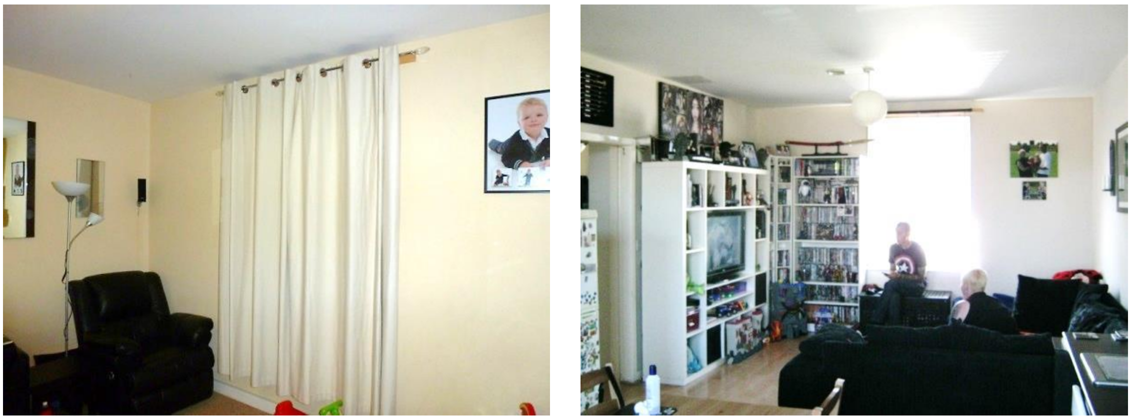


Figure 56 House 5 living room (left). Occupants reported that the heating in this space can be very high and that they find it difficult to adjust the thermostats. Room thermostats fail to provide good levels of fine control. House 11 living room (right). Occupants enjoy the open plan space and are satisfied with the size and daylight of the room.

Figure 57 House 5 south bedroom (left). Occupants are satisfied with the room size and daylight but report that the heating is high. House 11 south bedroom (right). Occupants are satisfied with the room size, air quality and daylight levels but report noise from the MVHR.

Renewable energy systems

- Occupants in both houses do not have any information on how the PV panels perform and do not understand how they work. This again suggests that the Home User Guide is not clear and easy to read and that it does not contain the information necessary for the users.

Lighting

- Occupants in both houses are satisfied with the daylight and the electrical light in the house.
- Lighting controls were reported to be easy to use.

Hot water

- Occupants in both houses agree that there is always hot water when needed and that it is sufficient for their daily needs.
- Occupants are satisfied with hot water temperatures and point out that the system works well, even though they are not fully aware of how the solar thermal panels work and how much they are benefitting from them.
- Heating up the water is automatic, no occupant input is required.

Acoustics

- In House 5 occupants reported that there is often noise coming from the neighbouring houses. Occupants in both houses agree that when the windows are closed they cannot hear any noise from the outside.

Ventilation system

- In both houses, occupants ventilate the house by opening windows and admit that they never change the settings of the MVHR unit but are happy to leave it as it is. Occupants in House 5 were unaware of the boost button. Occupants in House 11, even though they knew about the boost button and where it is located, are confused about its purpose as they believe it can also be used for extra hot water. This indicates that occupants have not received sufficient training and guidance on how to operate the ventilation system.
- Occupants in House 11 rarely feel the need to open the windows during winter and mention that the air quality in the house is always good, whereas occupants in House 5 tend to open the kitchen window even during the winter and complain that the air can be stuffy at times (Figures 58). This might be related with the fact that House 5 is more airtight (5.3m^3/m^{2}h) than House 11(15.8m^3/m^{2}h).

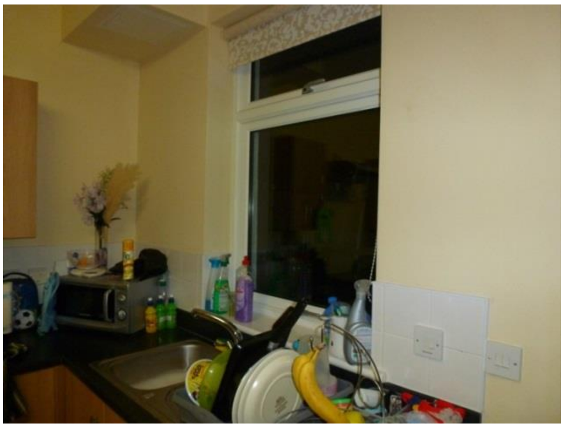



Figure 58 House 5 kitchen (left). Occupants are not satisfied with the open plan and report that the air quality is poor as cooking smells are dispersed. House 11 kitchen (right). Occupants are satisfied with size and storage space and do not have any problems with cooking smells when using the hood.

Maintenance, reliability and breakdowns

- Occupants in both houses described several occasions of breakdowns of both the heat pump and the hot water system and agree that it takes too long for problems to be resolved. Occupants complained that engineers sent out by the council to fix the problems often do not have the technical knowledge required for repairing the heat pumps and the other low carbon technologies. The council is aware of the problems occupants are experiencing with the EAHP and is trying to resolve this issue. However, the BPE research has shown that the Council lacks the technical skills and knowledge to maintain such systems and that more specialised training is required to be able to keep up with the technologies incorporated in sustainable houses. Swindon Council had to liaise with EAHP experts in order to resolve several issues that occurred and to evaluate their performance. After long consideration Swindon Council has decided to remove the EAHP from all the houses in the development and to replace them with gas boilers that are considered more reliable.

- In House 5 occupants do not have any complains about draughts or noise coming from the MVHR, which is in contrast to House 11 where occupants mentioned that the system can be noisy and that they occasionally get some draughts. None of the occupants are fully aware of how to maintain the system or how to change the filters, even though they have been living in the houses for almost two years. This again goes back to the fact that the handover process and Home User Guide were not very clear and did not provide occupants with clear and brief guidance on how to operate the systems on a daily basis and on how to maintain them.

Flexibility and space standards

- Inadequate space storage is one of the key problems for occupants in House 5. However, occupants in House 11 are very happy with storage space as they are using their big attic for storage. It should be pointed out that the houses are of equal size and that they both have similar attic spaces. It is possible that occupants in House 11 have not thought about using the attic for storage. Lack of storage space was reported also in the BUS survey by several users of other houses in the development.
- Room sizes were reported to be satisfactory.
- Occupants believe that the house is flexible and it accommodates their needs. Occupants in House 11 reported that the house could easily be used by a disabled person and by a larger family as it can be expanded to a three-bed.
- Occupants in both houses mentioned that the downstairs shower room cannot be used as it floods the adjacent hall areas. They have both complained about it to the council and are hoping that the issue is resolved soon (Figure 59).

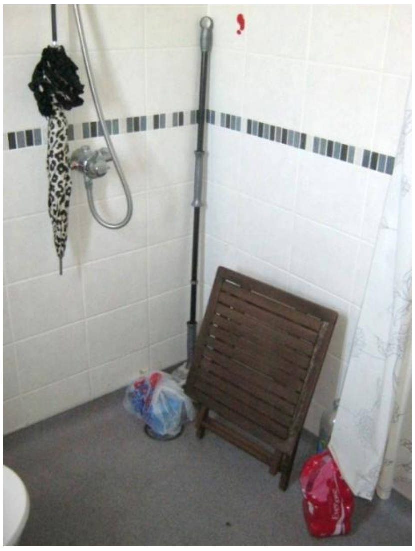


Figure 59 Shower room in both houses cannot be used as it floods the hallway due to poor construction.

4.3.2.2 Recommendations

- Maintain good standard of design and layout. Reconsider the open plan kitchen or provide an intermediate option that would improve the flexibility of the space (semi-open).
- Maintain the high flexibility and space standards.
- Maintain good daylight quality and south orientation in the developments.
- Maintain position of washing machine under the staircase as it prevents noise in the living areas.

- Collect all defect lessons learn on the project (heat pump breakdowns, leaks, renewables installation) and use them for future projects. Communicate lessons to the council, maintenance and design team.
- Review Induction process to provide more detailed and hands-on experience.
- Improve customer care and help service. Provide training to the maintenance personnel on renewables and low carbon technologies. Improve understanding of the use of the ventilation system and its maintenance requirements.
- Review air tightness specifications and construction for future projects. Take measures to improve the air tightness of the existing building to reach the design requirements.
- Take measures to improve the performance of the EAHP by training the occupants, re-balancing the system, improving air tightness in houses and addressing breakdowns.
- Review the Home User Guide to provide more accurate and useful information to occupants on how and when to change the settings of the heating system seasonally.
- Consider re-training of existing occupants to the ventilation system and EAHP to include hands on experience on heating setting, boost button, and filter change, to give familiarity of the symbols and the processes.
- Review noise specification standards for partition walls between houses.
- Reconsider the storage space in the larger properties.

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

Technology Strategy Board guidance on section requirements:	Provide a review of the building energy related systems, including renewables, regulated and unregulated energy and additional energy users that fall in to different areas (such as pumps for grey water use) and any results found. This section should enable the reader to understand the basic approach to conditioning spaces, ventilation strategies, basic explanation of control systems, lighting, metering, special systems etc. Avoid detailed explanations of systems and their precise routines etc., which will be captured elsewhere. The review of these systems is central to understanding why the building consumes energy, how often and when. Where possible this commentary should be split into the relevant system types. Explain what commissioning was carried out, what problems were discovered and how these were addressed. Discuss as to whether the initial installation and commissioning was found to be correct and any remedial actions taken. Prompt for any training scheme or qualifications that were found to be required as part of the study. Comment on whether the original operational strategy for lighting, heating/cooling, ventilation, and domestic hot water has been achieved. Compare original specification with equipment installed, referring to SAP calculations if appropriate. Give an explanation and rationale for the selection and sizing (specification) of system elements. Use this section to discuss the itemised list of services and equipment given in the associated Excel document titled *TSB BPE_characteristics data capture form_v6.xls*. For each system comment on the quality of the installation of the system and its relation to other building elements (e.g. installation of MVHR has necessitated removal of insulation in some areas of roof). Describe the commissioning process Describe any deviation from expected operational characteristics and whether the relevant guidance (Approved Documents, MCS etc.) was followed. Explanation of deviations to any expected process must be commented in this section. An explanation of remedial actions, if any, must also be given. Describe the operational settings for the systems and how these are set. Comment on lessons learned, conclusions and recommendations for future homes covering design/selection, commissioning and set up of systems. Also consider future maintenance, upgrade and repair – ease, skills required, etc. The document for capturing commissioning information is titled *TSB BPE_Domestic_commissioning sheets.doc*, which can be downloaded from `_connect'.

5.1 MVHR testing

The airflow of all extract and inlet vents was measured in both houses. Measurements were taken on 2nd July 2013 for House 5 and on 16th April 2013 for House 11 (Figure 60).

Figure 60 MVHR testing. Measuring the extract rate in the bathroom vent.

The tests revealed a great discrepancy between the supply and extract rates (Tables 4 and 5), suggesting that commissioning of the system was not done properly. Also, the fact that the vents are not locked in a fixed position allows the occupants to shut them off completely, interfering with the balance of the system.

As shown in Table 4 in House 5 there is a 113% discrepancy (at low rate) between the supply and extract rates indicating that the fresh air coming into the house is more than double the amount of hot air being extracted. Similarly, in House 11 (Table 5) There is a 70% discrepancy (at low rate) between the supply and extract rates.

Table 4 Results of air flow rate tests in House 5

House 5		Design air flow high rate (l/s)	Test on 2nd July 2013	
			Measured air flow low rate (l/s)	Measured air flow high rate (l/s)
Supply	Living room	-	17.1	18.4
	Bedroom1	-	8.2	10.5
	Bedroom 2	-	8.6	10.6
Total supply			**33.9**	**39.5**
Extract	Kitchen	13	5.6	5.6
	WC	6	4.8	4.9
	Bathroom	8	5.5	5.6
Total extract			**15.9**	**16.1**

Table 5 Results of air flow rate tests in House 11

House 11		Design air flow high rate (l/s)	Test on 16th April 2013	
			Measured air flow low rate (l/s)	Measured air flow high rate (l/s)
Supply	Living room	-	15.4	22.1
	Bedroom1	-	17.2	19.7
	Bedroom 2	-	15.2	9.3
Total supply			**47.8**	**51.1**
Extract	Kitchen	13	10.8	11.7
	WC	6	8.3	8.6
	Bathroom	8	9	9.6
Total extract			**28.1**	**29.9**

5.1.1 Key findings and recommendations

The MVHR tests revealed great discrepancy between the supply and extract rates:

- In House the balance ration between supply and extract rates is -113%, indicating that the MVHR systems brings in more cold air than the hot air it removes, resulting in energy wastage.

- The same applies for House 11 where the balance ratio between the supply and the extract rates was measured at -70%.

- Additionally, the fact that the vents are not locked in a fixed position, allows the occupants to shut them off completely, interfering with the balance of the system.

The findings indicate that the MVHR installation and commissioning was not up to standard. The systems need to be re-commissioned. Such discrepancies have a negative effect on the energy use of the houses. Seasonal commissioning of systems is recommended in order to avoid such problems in future developments. Swindon Council was informed of the findings in July 2013 but no action has been taken.

6 Monitoring methods and findings

Technology Strategy Board guidance on section requirements:	This section provides a summary breakdown of where the energy is being consumed, based around the first 6 months of metering results and other test results. Where possible, provide a simple breakdown of all major energy uses/producers (such as renewables) and the predicted CO_2 emissions. Explain how finding are affected by the building design, construction and use. This section should provide a review of any initial discoveries in initial performance in-use (e.g. after fine-tuning). If early stage interventions or adjustments were made post handover, these should be explained here and any savings (or increases) highlighted. Does the energy and water consumption of the dwelling meet the original expectations? If not, explain any ideas you have on how it can be improved. Are there any unusual design features that have not been accounted for previously (e.g. grey water recycling pumps). Summarise with conclusions and key findings.

The monitoring equipment was installed at the beginning of September 2012. Most of the data for House 5 began logging from the evening of 3rd September. The following variables were incomplete until the evening of 4th September: Living room CO_2, South bedroom CO_2, North bedroom CO_2, and Solar PV export. Most of the data for House 11 began logging from the morning of 6th September. The South bedroom CO_2 remained unmonitored until the evening of 16th September. Additional electricity sub-metering was installed on 12th February 2014 providing 5 minute data on the electricity consumption of lights and appliances (small plug load).

Table 6 lists the actual variables monitored for each house and date at which the data was available without significant interruption.

Table 6 Complete list of variables monitored in each home and date from which the data was available without significant interruption

House 5	Date*	House 11	Date*
		Universal variables	
Domestic hot water kWh (t)	04/09/12	Domestic hot water kWh (t)	07/09/12
Electricity import kWh	04/09/12	Electricity import kWh	07/09/12
Heat pump energy kWh	04/09/12	Heat pump energy kWh	07/09/12
Heat pump kWh (t)	04/09/12	Heat pump kWh (t)	07/09/12
Solar PV export kWh	04/09/12	Solar PV export kWh	07/09/12
Solar PV total	*05/09/12*	Solar PV total	07/09/12
Solar thermal & immersion. kWh (t)	04/09/12	Solar thermal & immersion. kWh (t)	07/09/12
Solar energy	04/09/12	Solar energy	05/09/12
Water m^3	04/09/12	Water m^3	07/09/12
		Environmental variables	
-	-	External temperature	07/09/12
-	-	External RH%	07/09/12
Backdoor use 1/0	04/09/12	Backdoor use 1/0	07/09/12

Ground bathroom window 1/0	04/09/12	Ground bathroom window 1/0	07/09/12
First floor bathroom window1/0	04/09/12	First floor bathroom window1/0	07/09/12
Living room RH%	04/09/12	Living room RH%	07/09/12
Living room temperature	04/09/12	Living room temperature	07/09/12
Living room CO_2 ppm	*05/09/12*	Living room CO_2 ppm	07/09/12
North bedroom RH%	04/09/12	North bedroom RH%	07/09/12
North bedroom temperature	04/09/12	North bedroom temperature	07/09/12
North bedroom CO_2	*21/09/12*	North bedroom CO_2	07/09/12
North bedroom window 1/0	04/09/12	North bedroom window 1/0	07/09/12
PIR (passive infrared) 1/0	04/09/12	PIR (passive infrared) 1/0	07/09/12
South bedroom RH%	04/09/12	South bedroom RH%	07/09/12
South bedroom temperature	04/09/12	South bedroom temperature	07/09/12
South bedroom CO_2 ppm	*05/09/12*	South bedroom CO_2 ppm**	*17/09/12*
South bedroom window1/0	04/09/12	South bedroom window1/0	07/09/12
-	-	Pyrometer W/m^2	07/09/12
-	-	Solar energy kWh	07/09/12

*first complete day, **significant gaps in data , t=thermal energy

6.1 Energy and environmental performance

6.1.1 House 5

Occupancy pattern: Continuous
Number of occupants: Four, two adults and two children
Weekdays: One of the adults stays at home with the children all day during weekdays while the other leaves the house at 7:00 and returns around 16:00.
Weekends: The occupants are generally in the house

6.1.1.1 Energy balance

Mains electricity consumed in the case study house is 8,528 kWh from October 2013 – September 2014. This equates to an average of 23 kWh/day (365 days). The amount of photovoltaic generated electricity (PV) used in the house and grid electricity import are shown in Figure 61. Total electricity generated by the PVs is 3,108 kWh/annum (8.5 kWh/day), which is 12% lower than the SAP estimate for annual PV generation which is 3,519 kWh. The efficiency of the PV system calculated from October 2013 to September 2014 is about 12%.

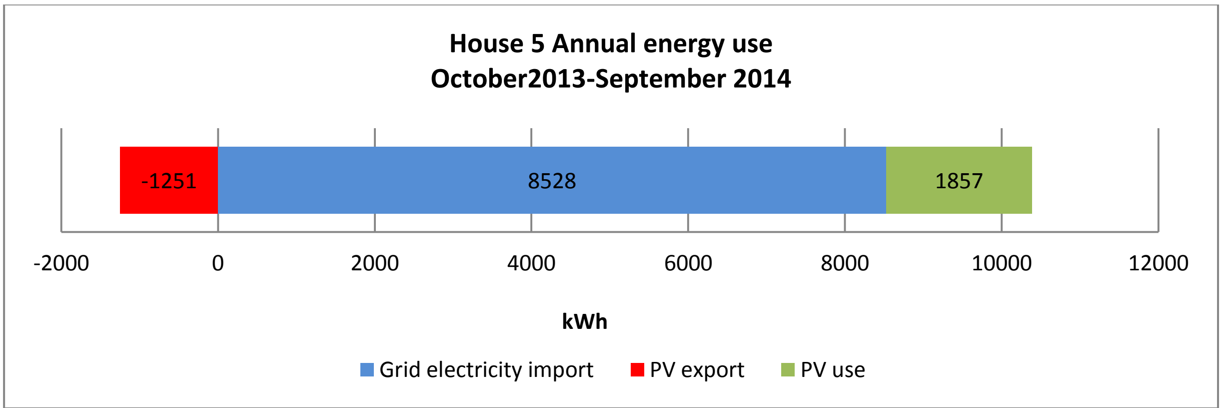


Figure 61Total electricity used and generated in House 5 from October 2013 to September 2014.

	kWh	kWh/m^2
Grid Import	8,528	90
PV Export	1,251	13.3
PV total	3,108	33

Figure 62 shows the monthly electricity use in House 5 from January 2013 to September 2014. Electricity import closely follows external temperature reaching 1700 kWh in January 2013 and 1100 kWh in January 2014. This difference is due to the heat pump electricity use and external temperature being lower in winter 2013 than winter 2014. During the summer months electricity import drops to 330-430 kWh/month.

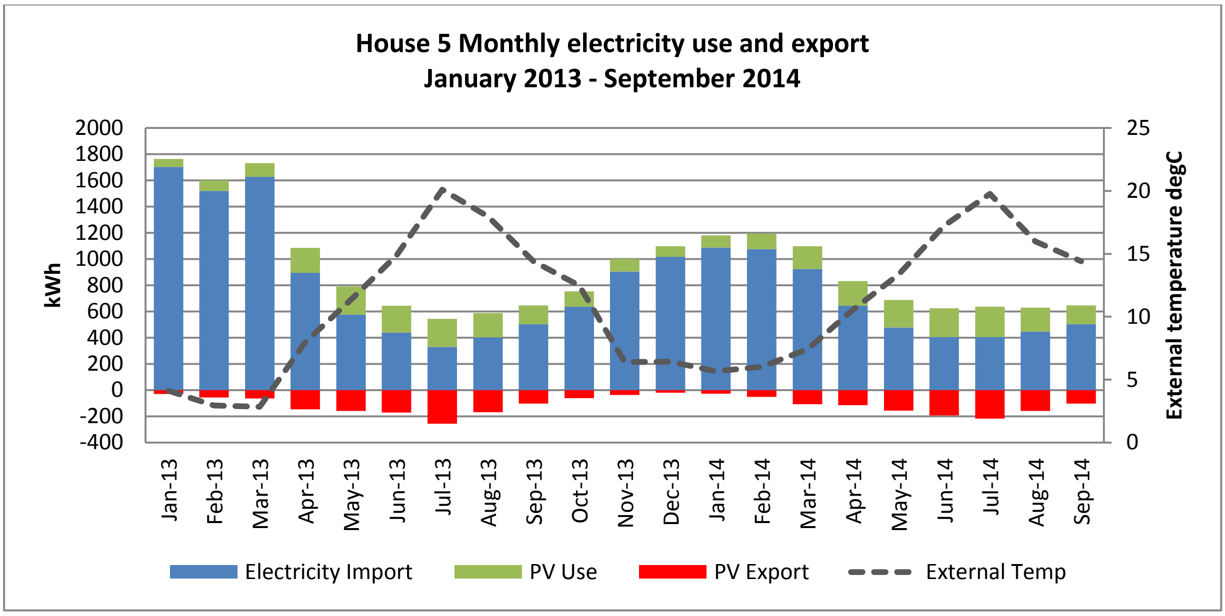


Figure 62 Monthly electricity use in House 5 from September 2012 to September 2014.

On an annual basis, 61% of the total electricity use is consumed by the heat pump while 38% is used by lights and appliances (Figure 63).

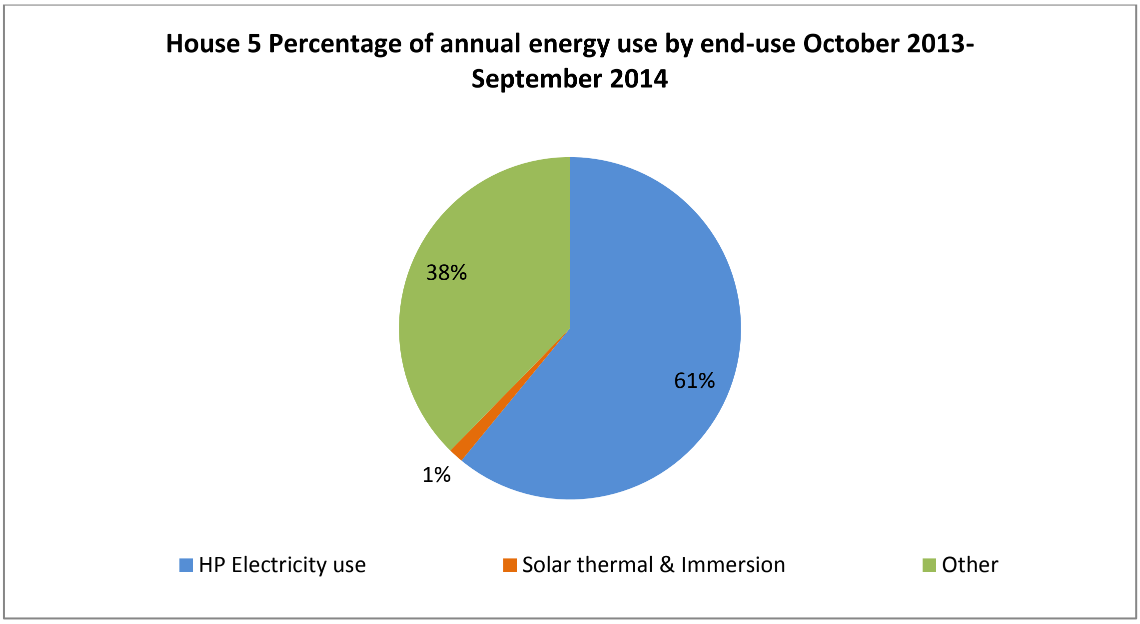


Figure 63 Percentage of annual energy use by end-use from October 2013 to September 2014.

Monthly electricity used by the heat pump ranges between 670-1360 kWh/month during winter and 270 kWh/month during summer. Lights and appliances consume between 260-400 kWh/month (Figure 64), while the electricity used by the solar thermal panels and the immersion heater is minimal.

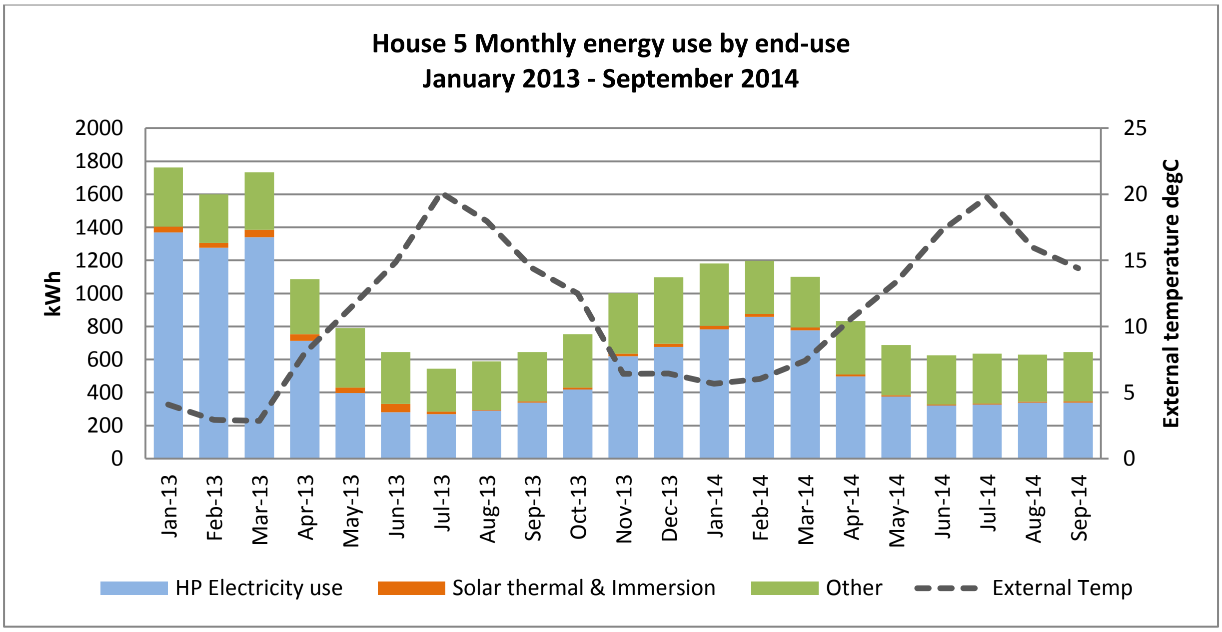


Figure 64 Monthly energy use by end-uses in House 5 from January 2013 to September 2014.

Detailed sub-metering data is available from 12th February 2014. From March to September 2014 the heat pump electricity use was 2,975 kWh, small plug electricity use is 626 kWh, lights electricity use is 193 kWh and electricity use of the washing machine is 425 kWh(Figure 65).. Part of the electricity used in the house is not being sub-metered ('Other'). The monthly electricity use by end-uses is shown in Figure 66. Findings indicate that the heat pump consumes more than half of the total electricity used in the house, even during the summer months.

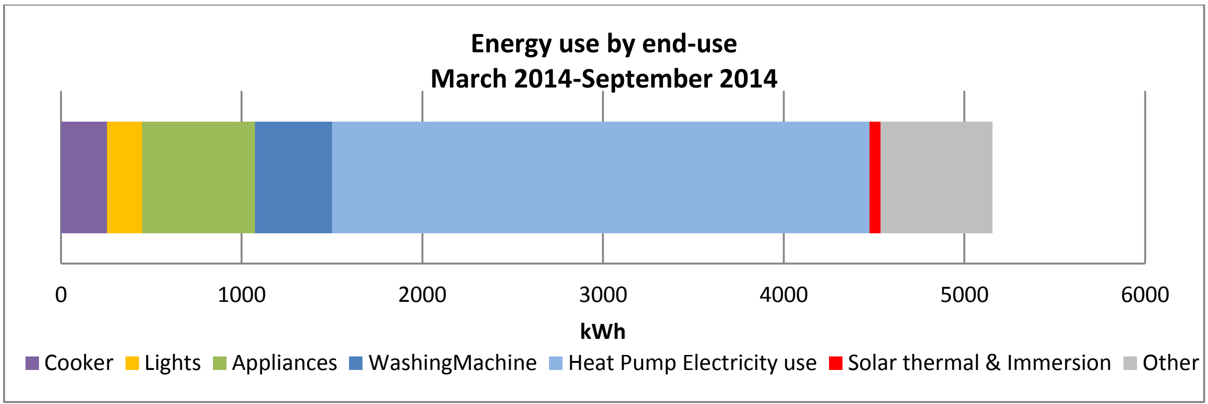


Figure 65 Energy use by end-use from March 2014 to September 2014.

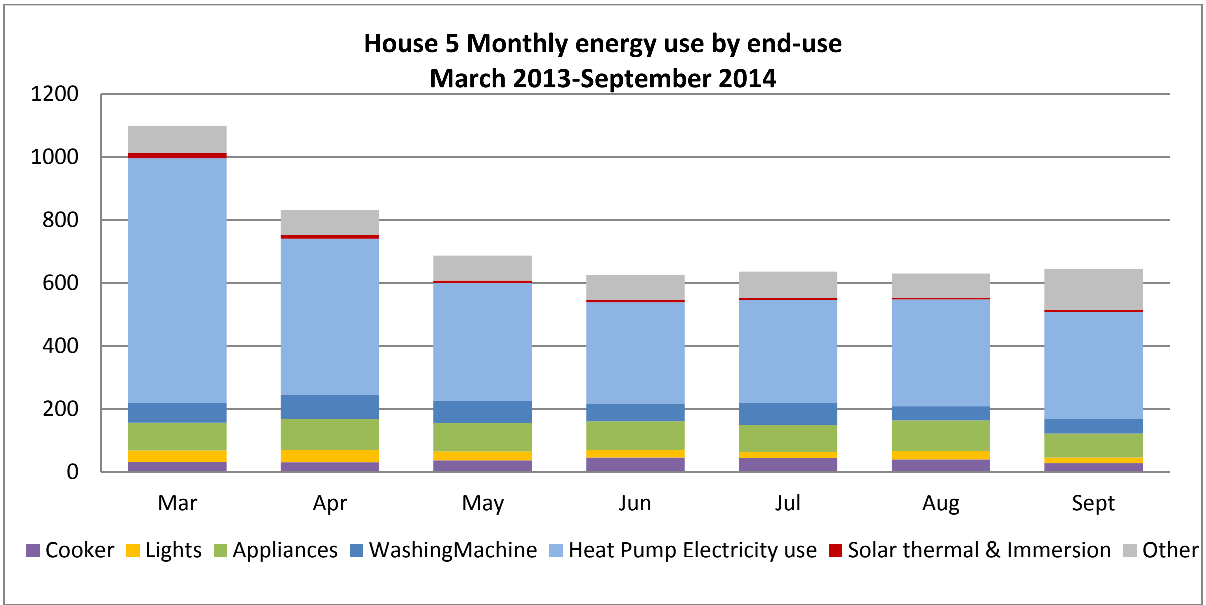


Figure 66 Monthly energy use by end-use from March 2013 to September 2014.

Figure 67 shows the average hourly electricity use, grid import and PV generated electricity use from April 2013 to March 2014. During the night electricity use is around 1 kWh/hour and starts rising from 6:00 when the occupants wake up and then drops again around 12:00 when the children leave the house. Electricity use peaks at 15:00 reaching 1.5 kWh when the occupants return home. Grid electricity import drops during the day when PV generated electricity is used. PV use peaks during midday reaching 0.6 kWh.

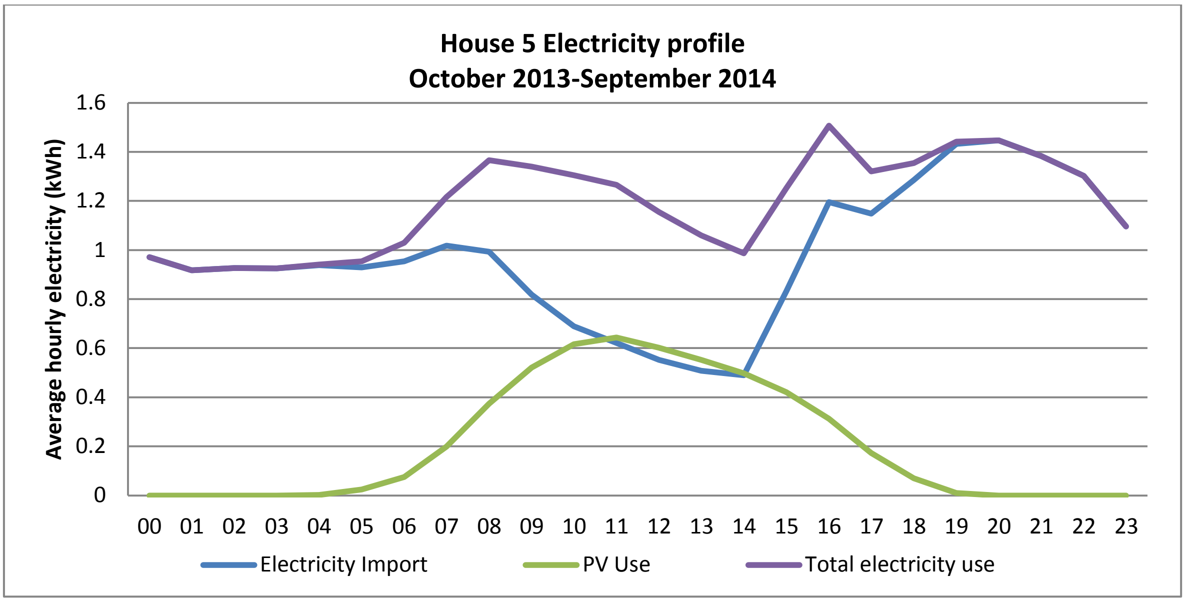


Figure 67 Average hourly electricity profile from October 2013 to September 2014.

Figure 68 shows the hourly average electricity consumption across the week. All days show similar patterns of electricity consumption ranging from 1-1.6 kWh per hour. Electricity use peaks around 8:00 in the morning when the occupants wake up and again around 16:00 when the children return from school.

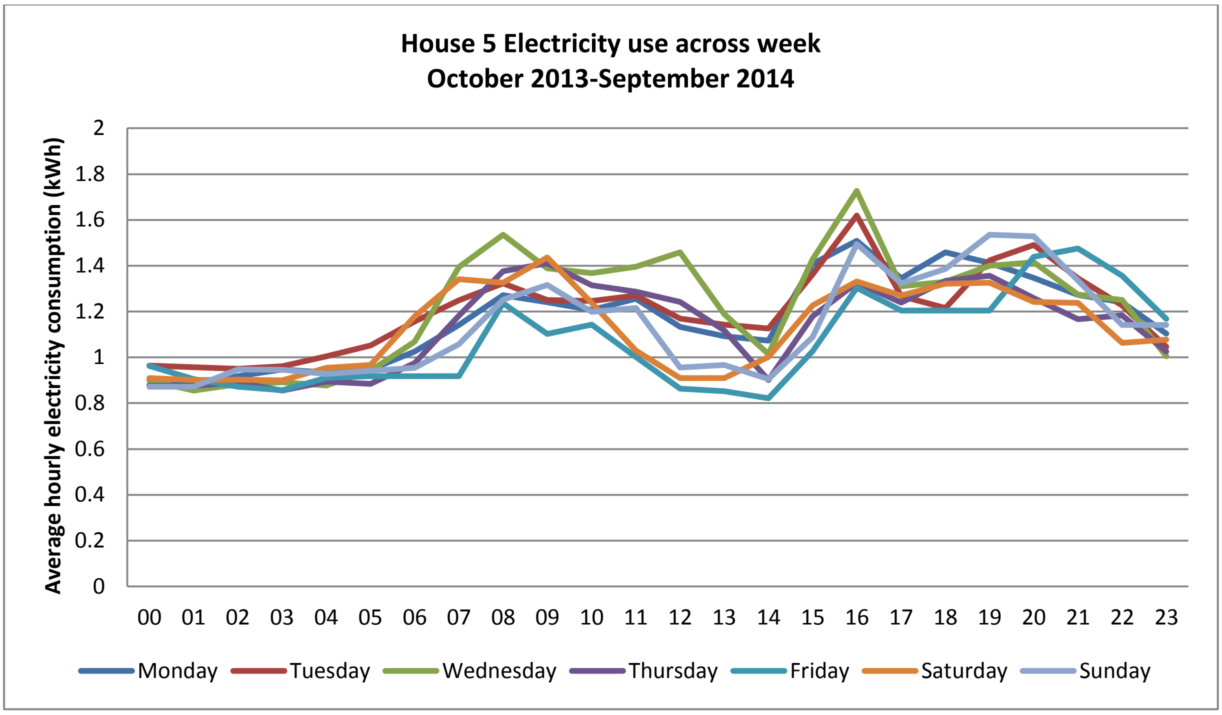


Figure 68 Average hourly electricity consumption across the week from October 2013 to September 2014.

Figures 69 and 70 show the monthly heat pump electricity use against heating degree days. The correlation between them is not optimal indicating excessive use of the heat pump in some cases.

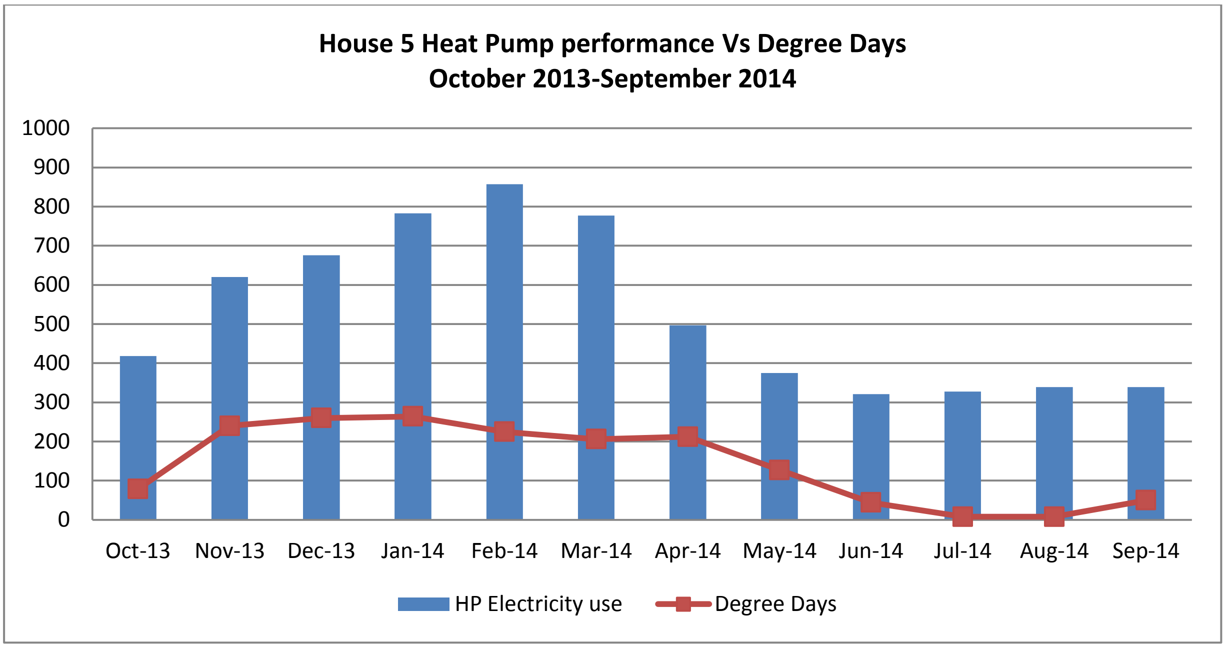


Figure 69 Heat pump performance Vs degree days from October 2013 to September 2014.

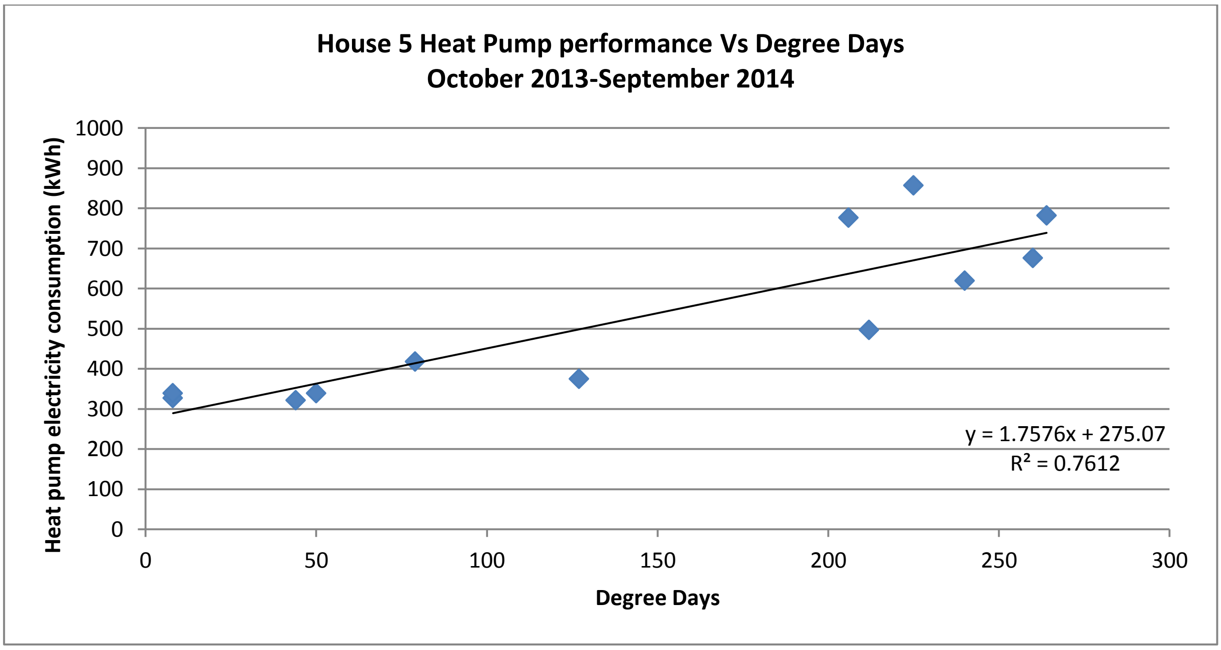


Figure 70 Heat pump performance Vs degree days from October 2013 to September 2014.

6.1.1.2 Water use

Annual water use in House 5 is 167m^3 or 167,000L (457L/day) (365 days). With four occupants this equates to 114 L/day/person. According to the Environment Agency the average person in England and Wales uses 150L of water per day (EA, 2012). No design estimate based on water saving measures was provided. Figure 71 shows the total monthly water use. It can be observed that during the monitoring period water use has remained relatively steady.

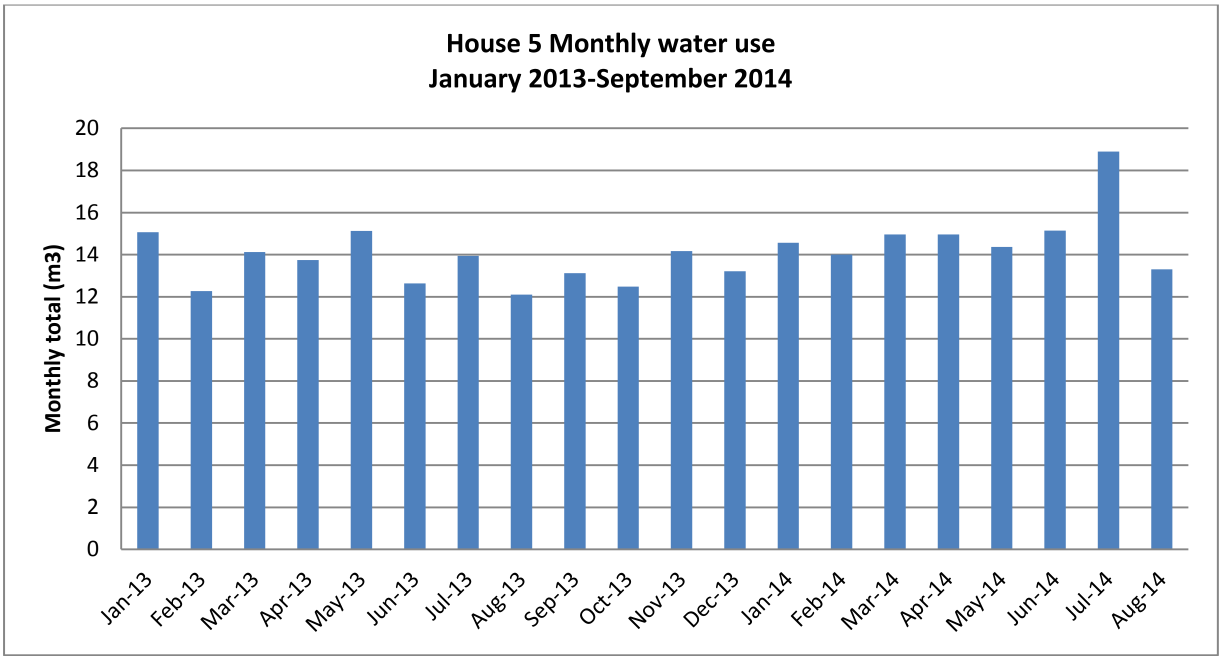


Figure 71 Daily water use (m^3) from January 2013 to September 2014.

6.1.1.3 Internal and external temperature

Over the two-year monitoring period the average daily external temperature drops significantly from 17^{o}C in September to 5^{o}C in December. From December to April it ranges between -2 to 0^{o}C and from mid-April it starts rising again reaching 25^{o}C in July (Figure 72), resulting in a decrease in energy demand. The lowest temperatures were observed during December and January.

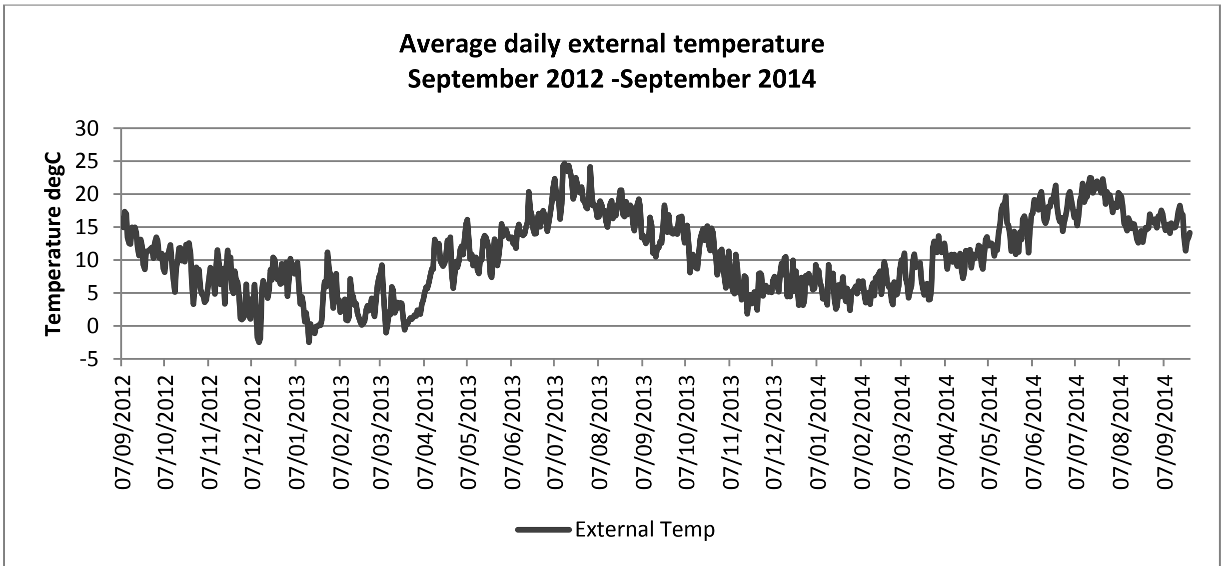


Figure 72 Daily average external temperatures from September 2012 to September 2014.

Figure 73 shows the internal temperatures of three monitored spaces; the living room, north bedroom and south bedroom. The temperatures for each space remain within the comfort band of 20-25^{o}C throughout most of the monitoring period. The temperatures during the winter months (November-March) are closer to the upper limit. This fact, in addition to the occupants mentioning that the house is 'too warm at times' when the heating is on, indicates that heating temperatures could be reduced by a couple of degrees thus reducing energy demand, and that the thermostat setting should be reviewed. The occupants have mentioned that they find it difficult to adjust the thermostats to a comfortable temperature as the thermostats are scaled from 1-7 instead of a temperature scale. Room thermostats do not offer a good level of fine control (See Chapter 7).

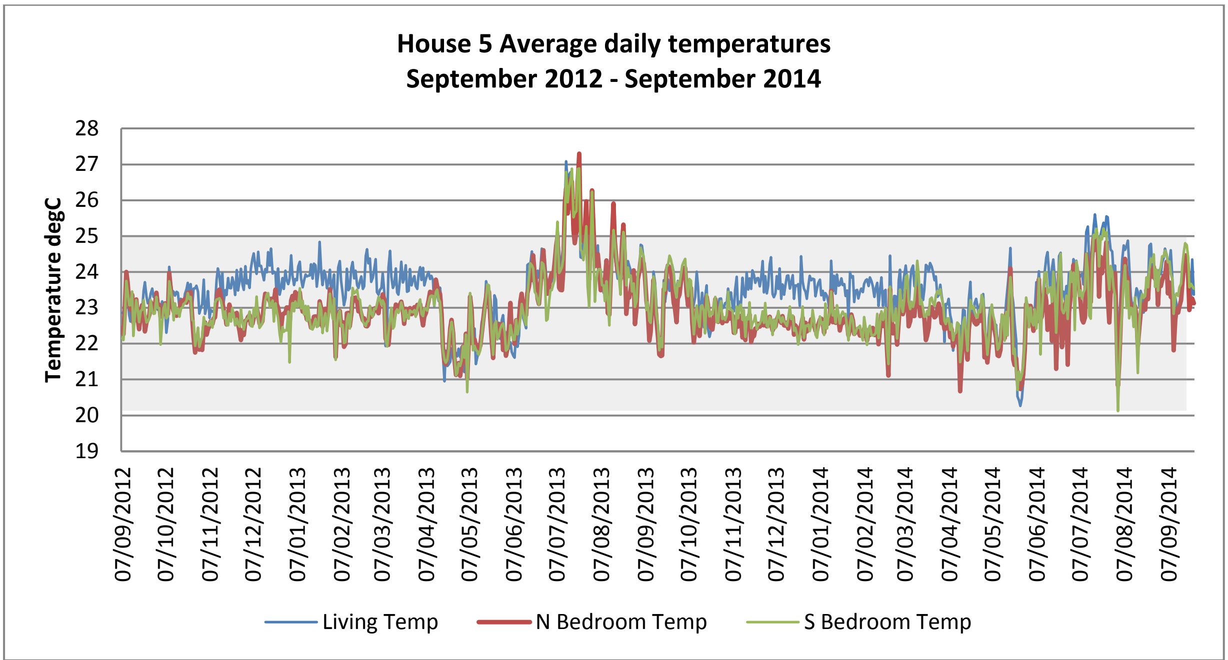


Figure 73 Daily average temperatures from September 2012 to September 2014.

Figure 74 shows the monthly mean, maximum and minimum temperatures recorded in the living room. Minimum temperatures almost never fall below the comfort band and 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 almost reach 28°C suggesting that the house is overheated at times.

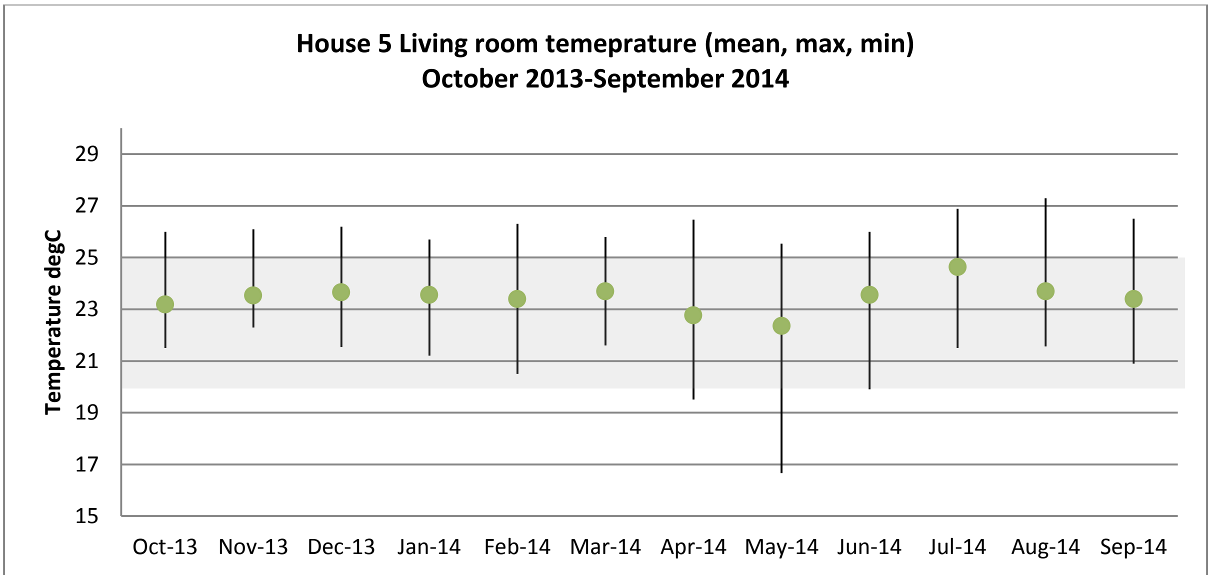


Figure 74 Living room temperatures: monthly mean, max, min (October 2013-September 2014).

Figure 75 shows the daily pattern in living room and bedroom environmental conditions. Temperatures are kept steady throughout the day at 23°C. Relative humidity levels range between 40-45%. CO_2 concentration levels in the living room rise in the afternoon reaching 800ppm. When the rooms are occupied, CO_2 concentration levels in the bedroom rise during the night reaching 900ppm. The graph indicates that the average hourly temperature and RH levels in the living room are within the comfort zone and that CO_2 concentrations are within the acceptable limits.

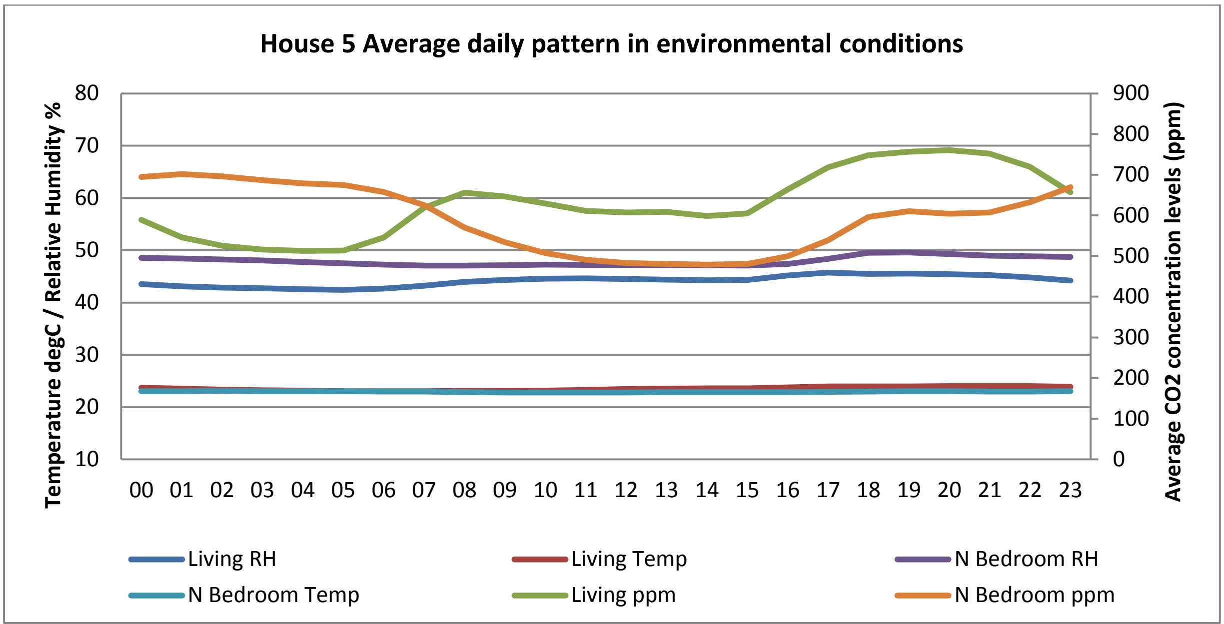


Figure 75 Daily temperature, relative humidity, CO_2 concentration patterns (October 2013-September 2014).

Figure 76 shows the daily variation in living room environmental conditions across seasons. It is noticeable that summer and winter temperatures are higher than spring and autumn temperatures. In all seasons temperatures in the living room seem to rise in the afternoon when all of the occupants are in the house. Relative humidity levels are kept steady throughout the day ranging around 50% during summer and around 40% during winter.

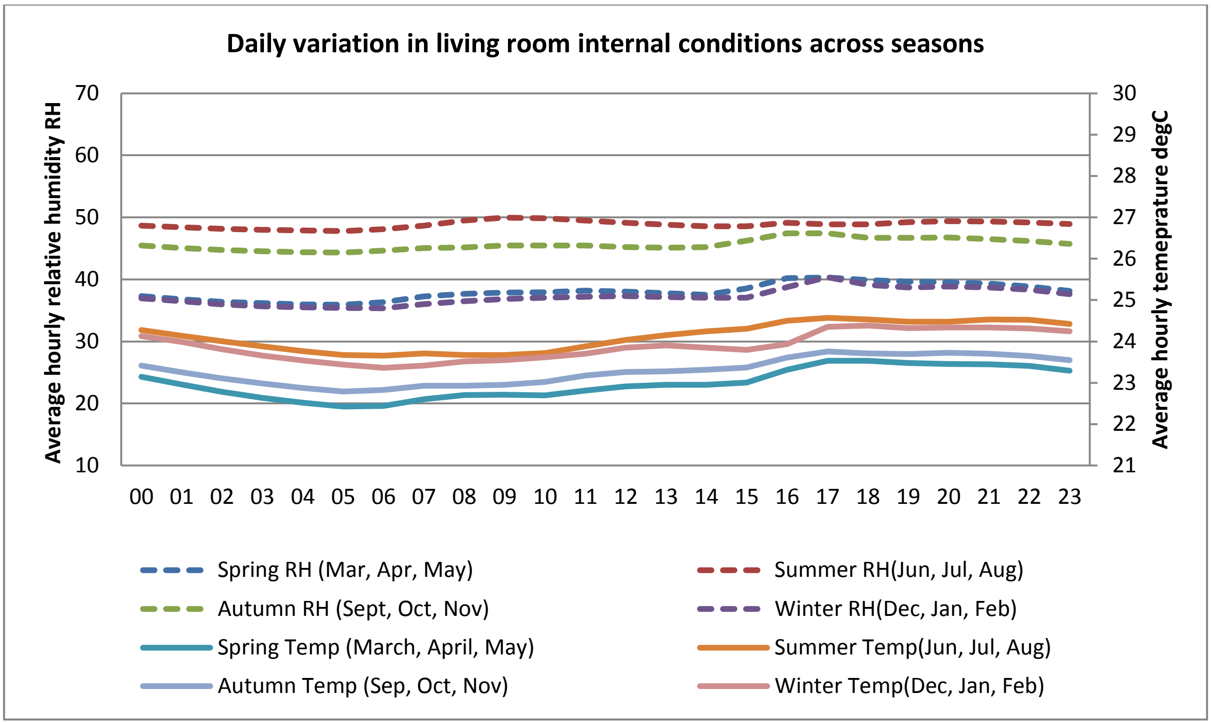


Figure 76 Daily variation in average living room internal conditions across seasons (October 2013-September 2014).

6.1.1.4 Internal relative humidity

RH levels range between 30-60%, reaching their lowest levels during winter months (Figure 77). Of all the rooms, the living room appears to have the lowest RH levels. During the monitoring period RH levels in the living room remain below the CIBSE recommended limit of 40% RH during the winter months. Low RH levels are related to the high temperature recorded in the spaces, especially in the living room and are also related to the low ventilation rates in winter.

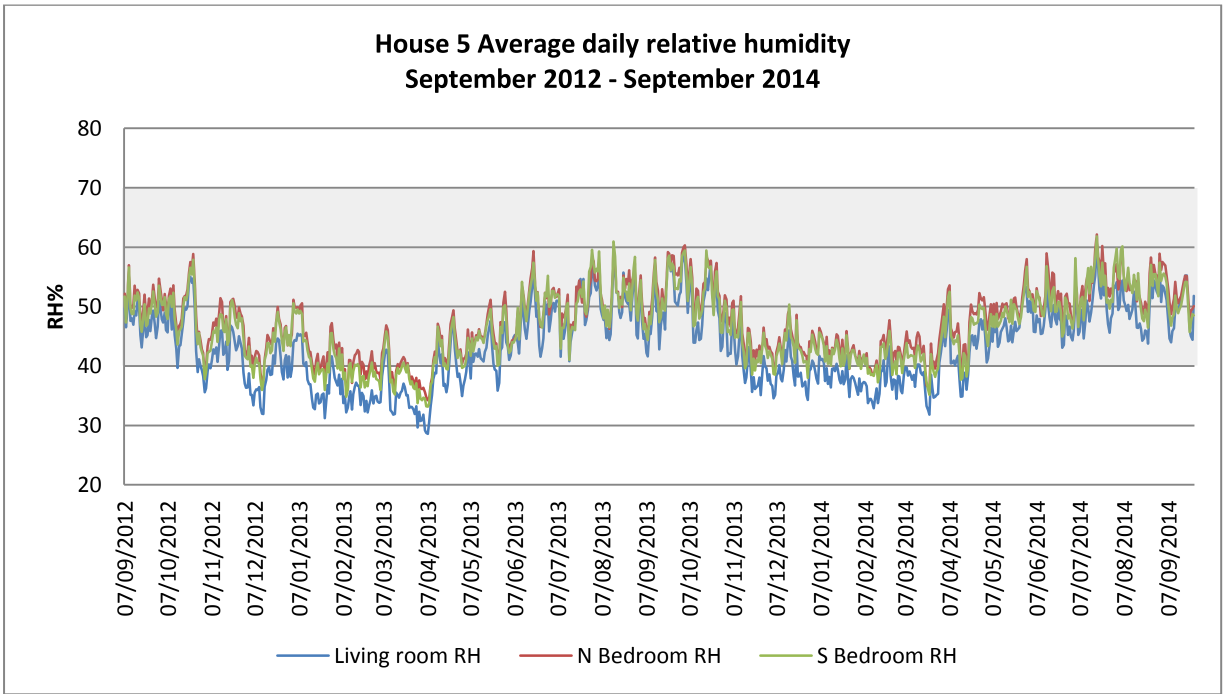


Figure 77 Average daily relative humidity from September 2012 to September 2014.

Figure 78 shows the monthly mean, maximum and minimum relative humidity levels recorded in the living room. It is noticeable that during the winter months average relative humidity levels are below the CIBSE recommended range of 40-70% and that minimum values drop below 30%.

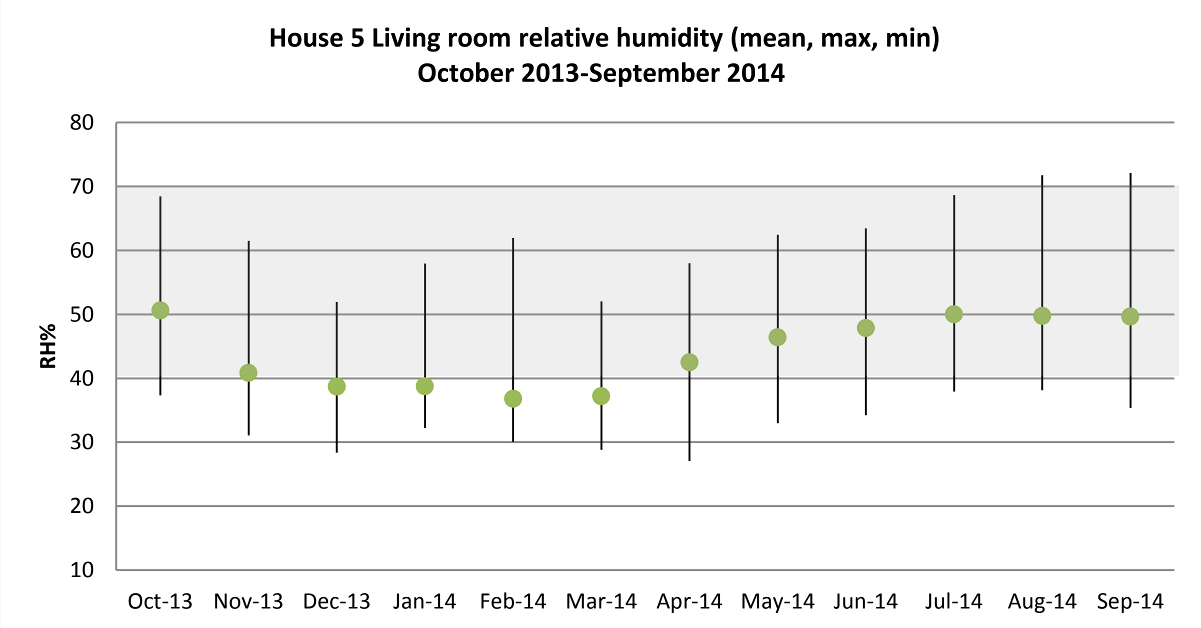


Figure 78 Living room relative humidity: monthly mean, max, min (October 2013-September 2014).

Temperatures remain close to the upper limit of the comfort band throughout the year, ranging between 22-26°C during both winter and summer (Figure 79). Relative humidity levels rise during summer as a result of increased ventilation (Chapter 6.4).

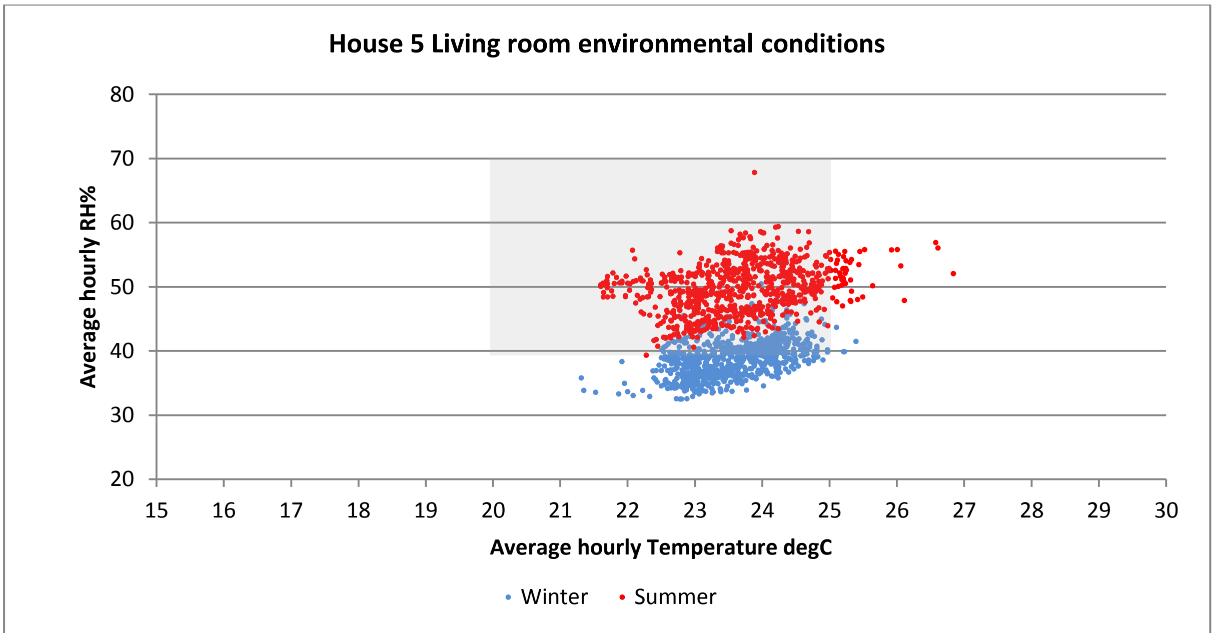


Figure 79 Living room environmental conditions in winter (January 2014) and summer (August 2014).

6.1.1.5 Internal CO_2 as proxy of air quality

Average daily CO_2 levels range between 500-900ppm, reaching their highest values during the winter months (Figure 80). This is related to the doors and windows being opened less frequently and for shorter periods during the winter period. CO_2 levels gradually drop from 800-900ppm in mid-April 2013 to 500-700ppm in summer. Throughout the whole monitoring period CO_2 levels remain below the ASHRAE recommended limit of 1000ppm. The air permeability of House 5 has been measured post construction as 5.3m3/m2h.

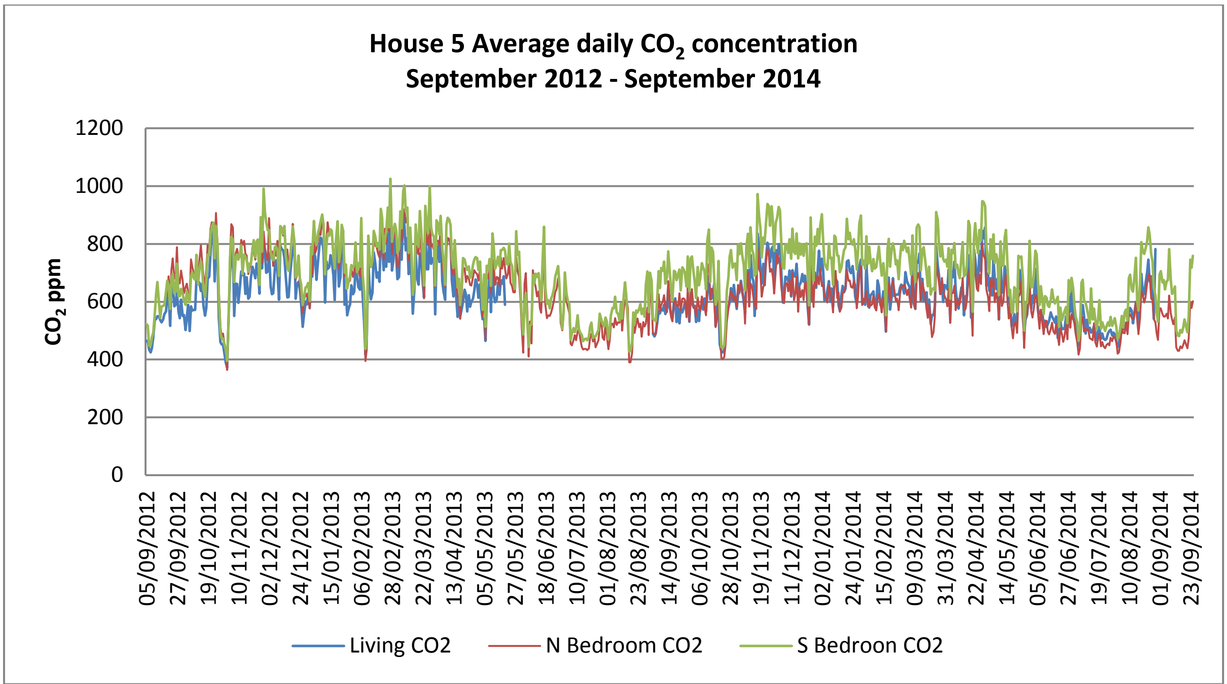


Figure 80 CO_2 concentrations in the living room during monitoring period from September 2012 to September 2014.

CO_2 levels range between 500-1000ppm for 71% of the time in the living room, 68% in the North bedroom (parents), and 78% of the time in the South bedroom (childrens). CO_2 levels remain above 1000ppm for 2.5% of the time in the living room and for nearly 4% of the time in the South bedroom (Figure 81).

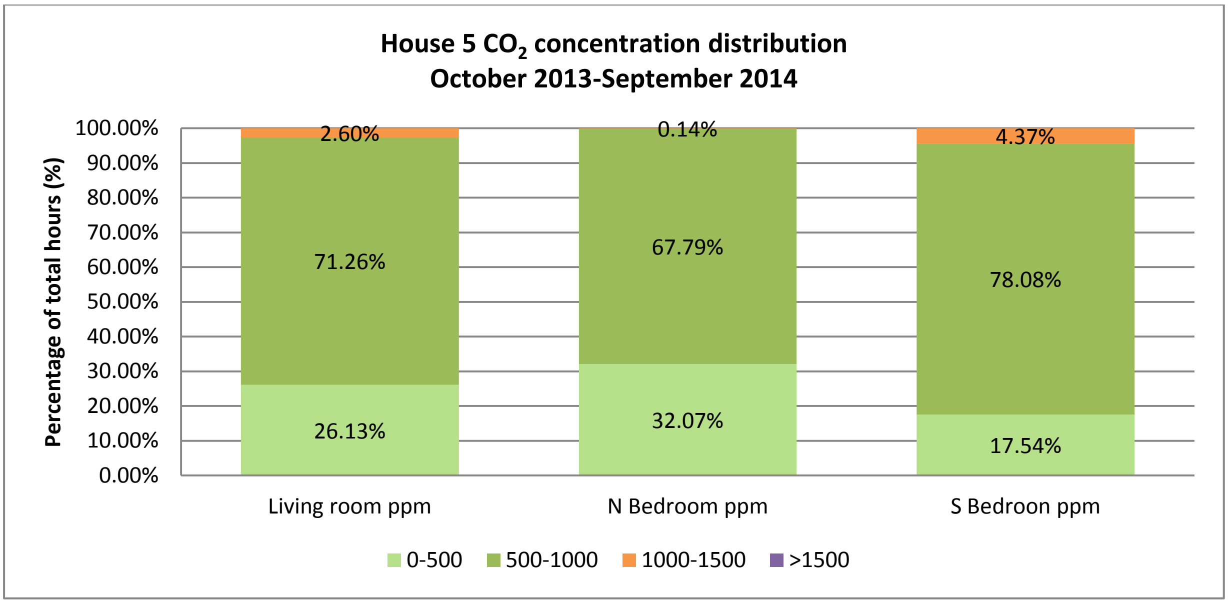


Figure 81 CO_2 concentrations distribution from October 2013 to September 2014.

The distribution of CO_2 levels is similar during both winter and summer, rarely exceeding the limit of 1000ppm (Figures 82, 83).

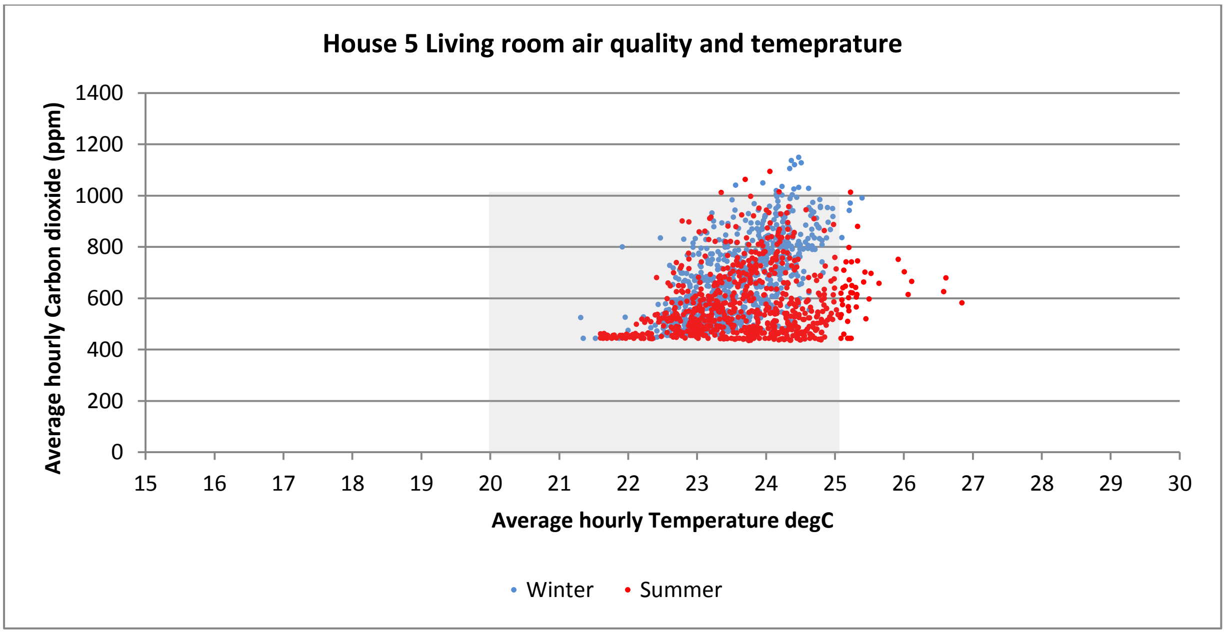


Figure 82 Living room air quality and temperature during winter (January 2014) and summer (August 2014).

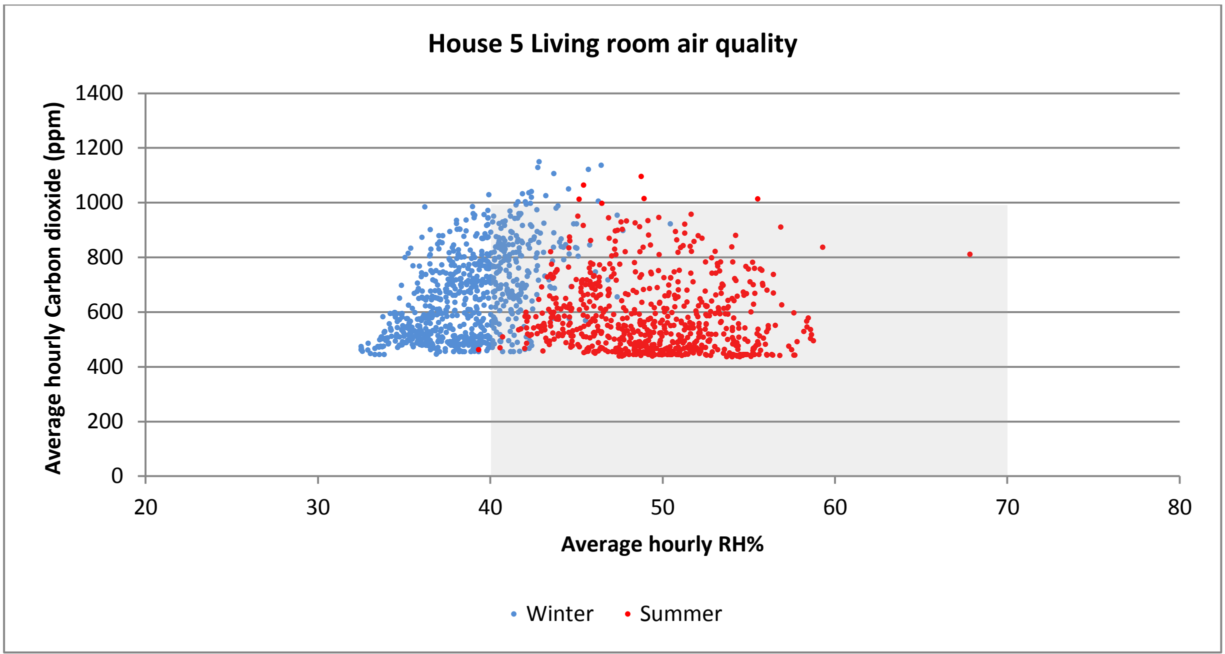


Figure 83 Living room air quality during winter (January 2014) and summer (August 2014).

6.1.2 House 11

Occupancy pattern: Continuous
Number of occupants: Four, two adults and two children
Weekdays: The children go to school at 9:00 and return around 13:00. One of the adults stays at home all day during weekdays while the other leaves the house at 8:00 and returns around 16:00.
Weekends: The occupants are generally in the house all day long.

6.1.2.1 Energy balance

Main electricity consumed in the house is 5,635 kWh from October 2013 to September 2014. This equates to an average of 15.4 kWh/day (365 days). The amount of photovoltaic generated electricity (PV) used in the house and grid electricity import are shown in Figure 84. The total electricity generated by the PV panels is 3,099 kWh (8.4 kWh/day) (similar to House 5), which is 12% lower than the SAP estimate for annual PV generation which is 3,519 kWh. The efficiency of the PV system calculated from October 2013 to September 2014 is about 12%.

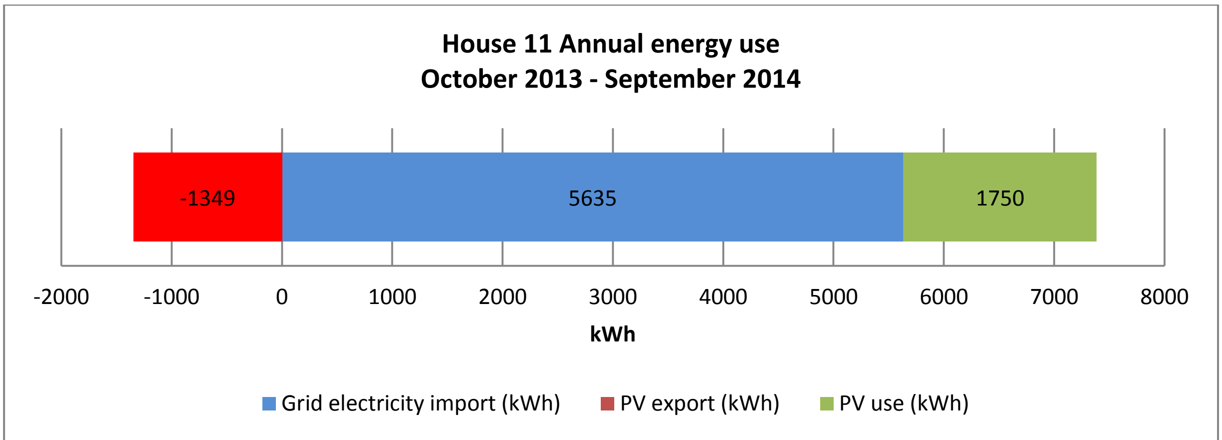


Figure 84 Total electricity used and generated in House 11 from October 2013 to September 2014.

	kWh	kWh/m^2
Grid import	5,635	60
PV export	1,349	14
PV total	3,099	33

Figure 85 shows the monthly electricity use in House 11 from January 2013 to September 2014. Electricity import gradually rises during the winter months following external temperature, reaching 1350 kWh in January. In July electricity import drops to 250 kWh.

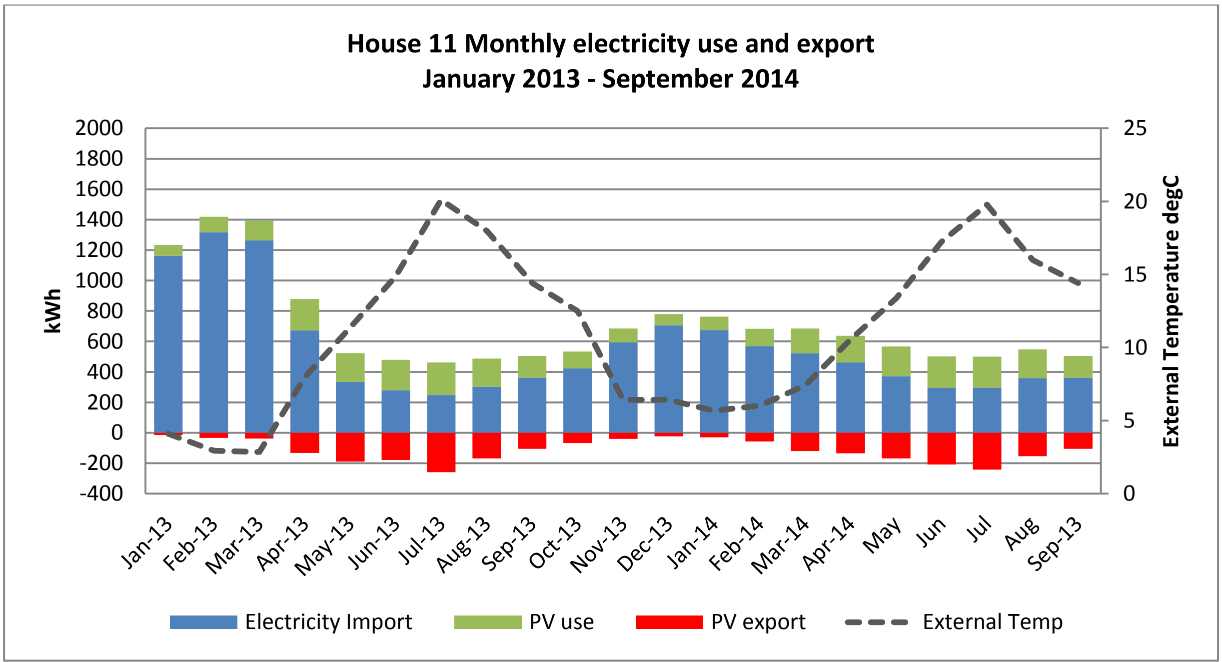


Figure 85 Monthly electricity use in House 11 from January 2013 to September 2014.

On an annual basis, 54% of the total electricity use is consumed by the heat pump while 46% is used by lights and appliances (Figure 86).

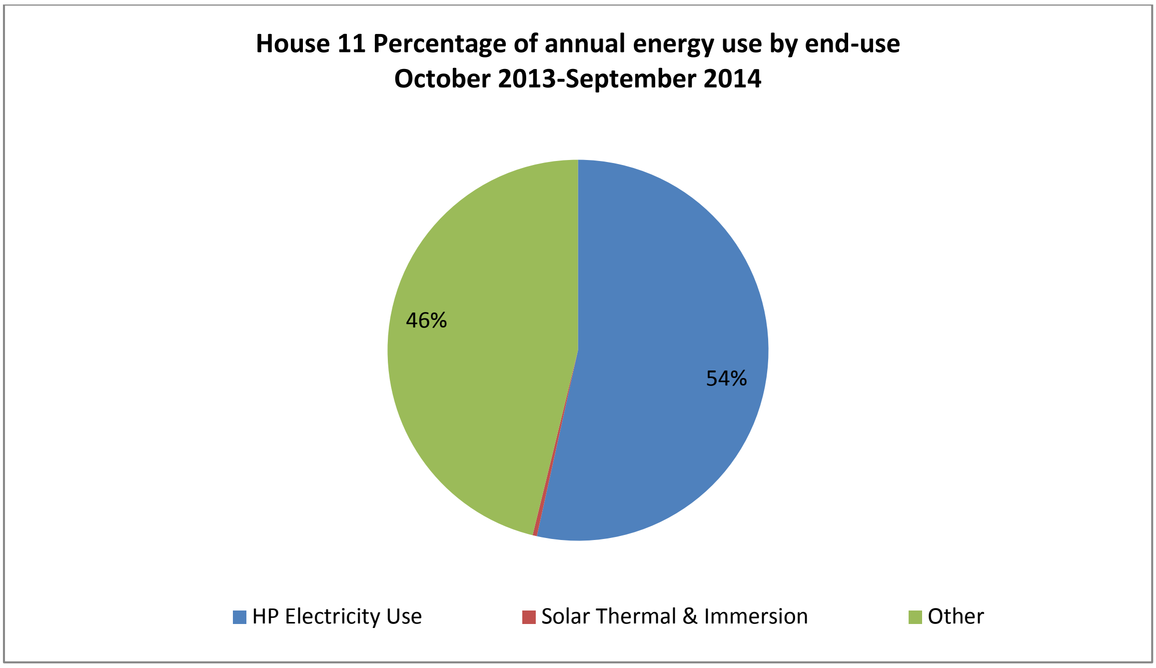


Figure 86 Percentage of annual energy use by end-use from October 2013 to September 2014.

Monthly electricity use by the heat pump ranges between 350-450 kWh/month in winter 2014, whereas in winter 2013, monthly heat pump electricity use was up to 1160 kWh. These values are closely related to external temperatures. Heat pump electricity consumption during summer is around 220 kWh/month. Lights and appliances consume between 230-340 kWh/month (Figure 87).

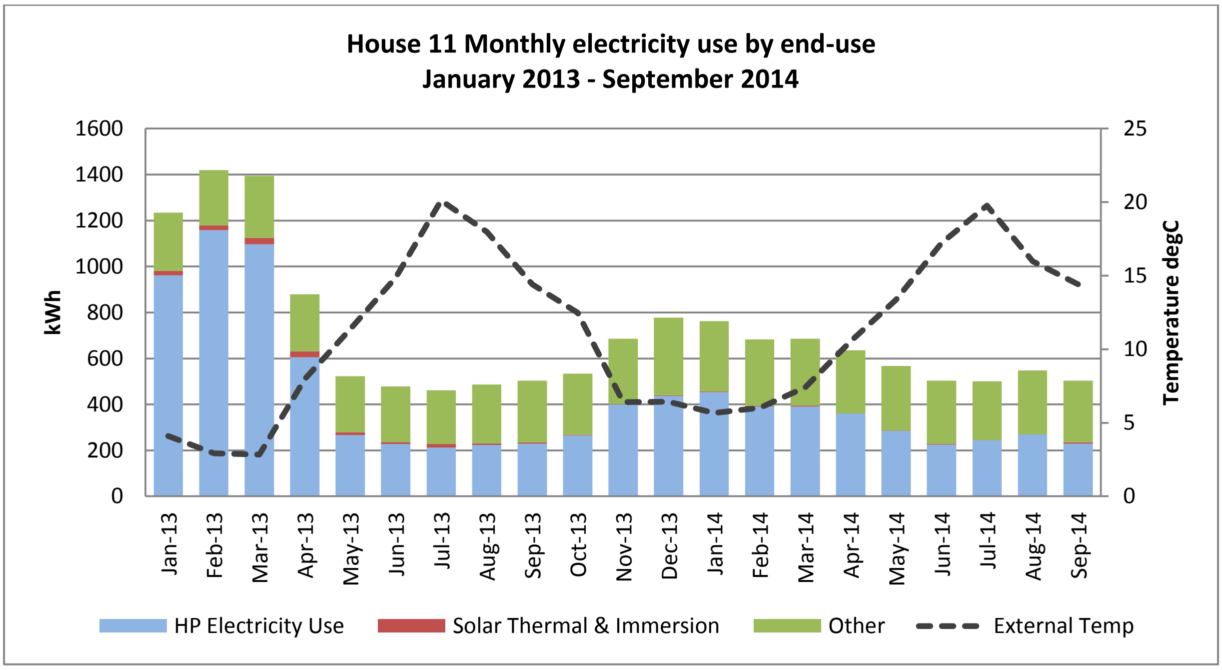


Figure 87 Monthly electricity use by end uses in House 11 from January 2013 to September 2014.

Detailed sub-metering data is available from 12th February 2014. From March to September 2014 the heat pump electricity use was 1,775 kWh, small plug electricity use is 590 kWh, lights electricity use is 102 kWh and electricity use of the washing machine is 116 kWh (Figure 88). Part of the electricity used in the house in not being sub-metered ('Other'). The monthly electricity use by end-uses is shown in Figure 89. Findings indicate that the heat pump consumes more than half of the total electricity used in the house, even during the summer months.

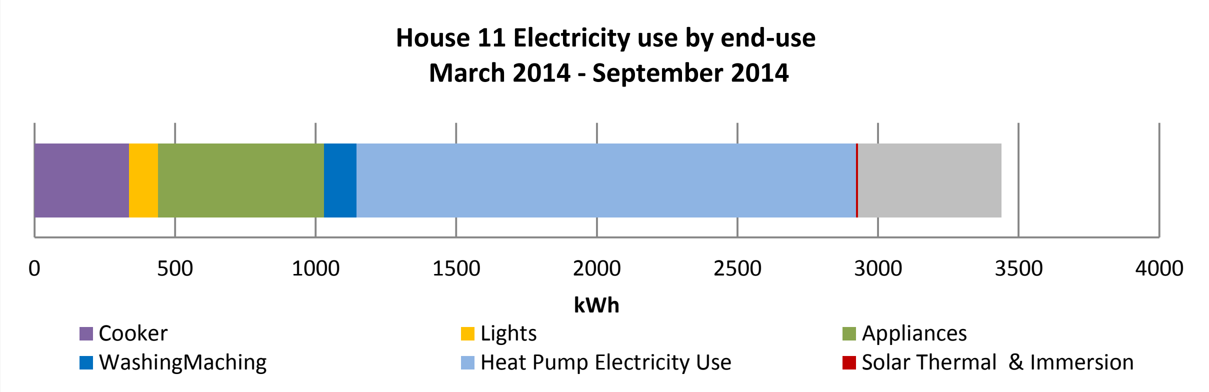


Figure 88 Electricity use by end-use from March 2014 to September 2014.

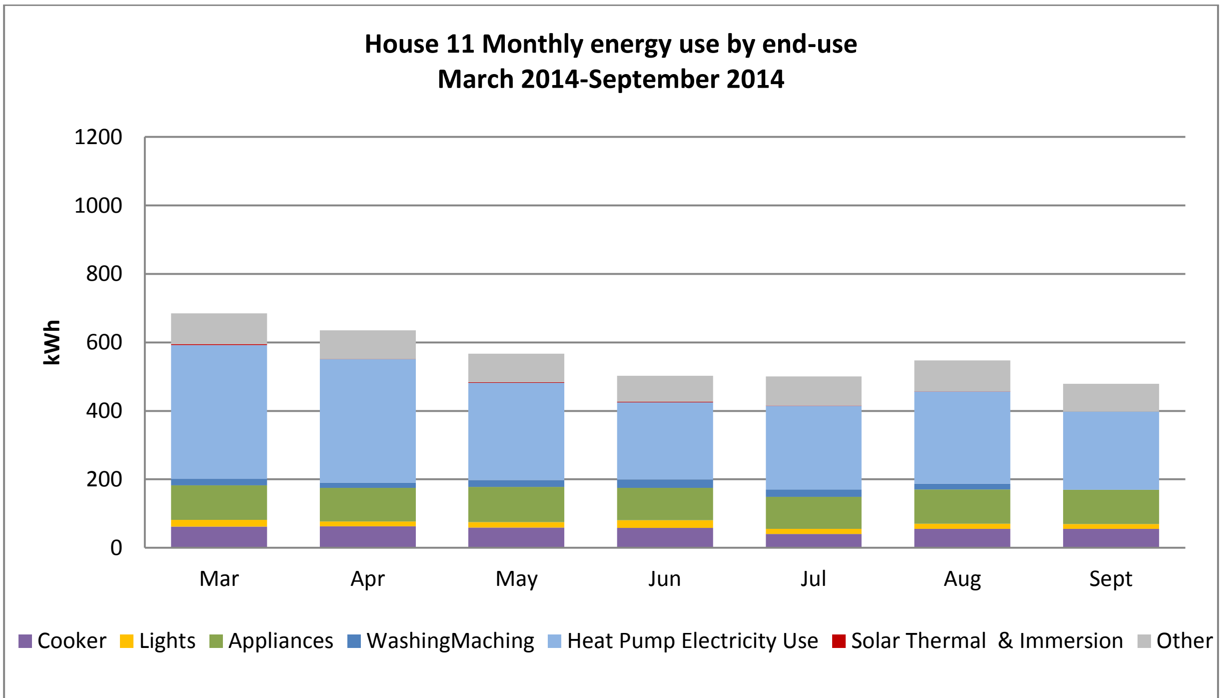


Figure 89 Monthly energy use by end-use from March 2014 to September 2014.

Figure 90 shows the average hourly electricity use, grid import and PV generated electricity use from April 2013 to March 2014. During the night electricity use is around 0.7 kWh/hour and starts rising from 7:00 when the occupants wake up and peaks at 14:00 reaching 1.2 kWh when the occupants return home. Grid electricity import drops during the day when PV generated electricity is used. PV use peaks around 13:00 reaching 0.6 kWh.

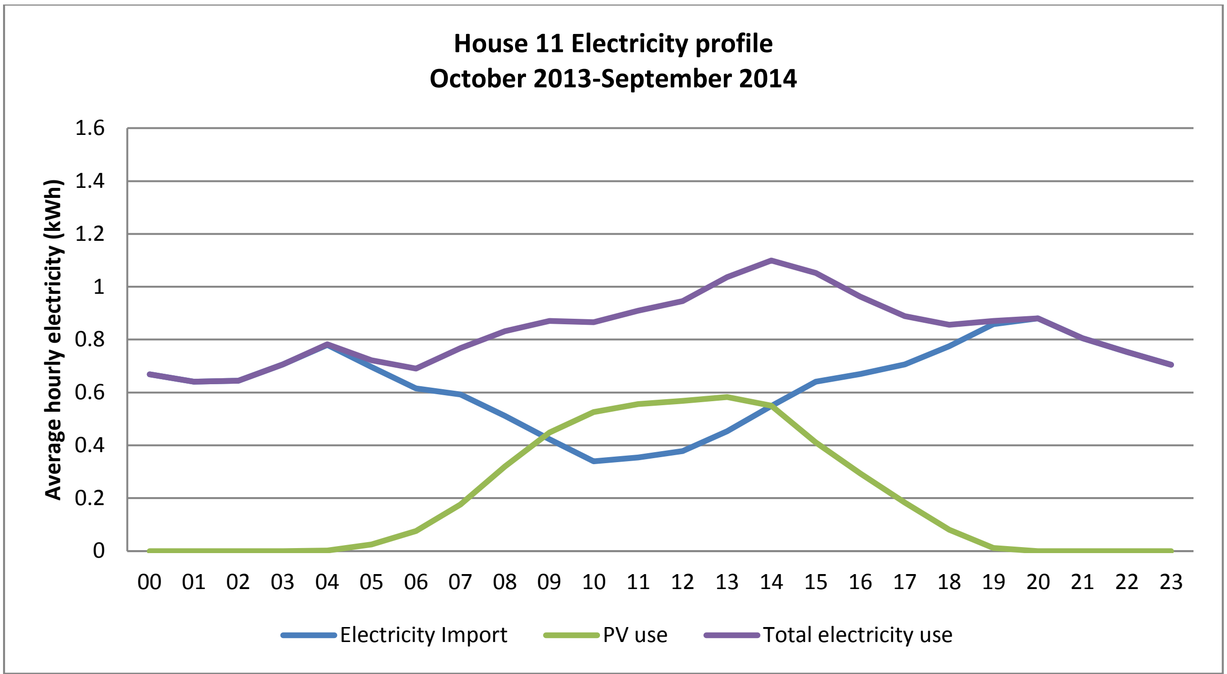


Figure 90 Average hourly electricity profile from October 2013 to September 2014.

Average hourly electricity consumption across the week is plotted in Figure 91 ranging between 0.6-1.4 kWh/hour. The same pattern is observed from Monday to Friday. Electricity consumption peaks on Sunday around midday when the whole family is gathered in the house.

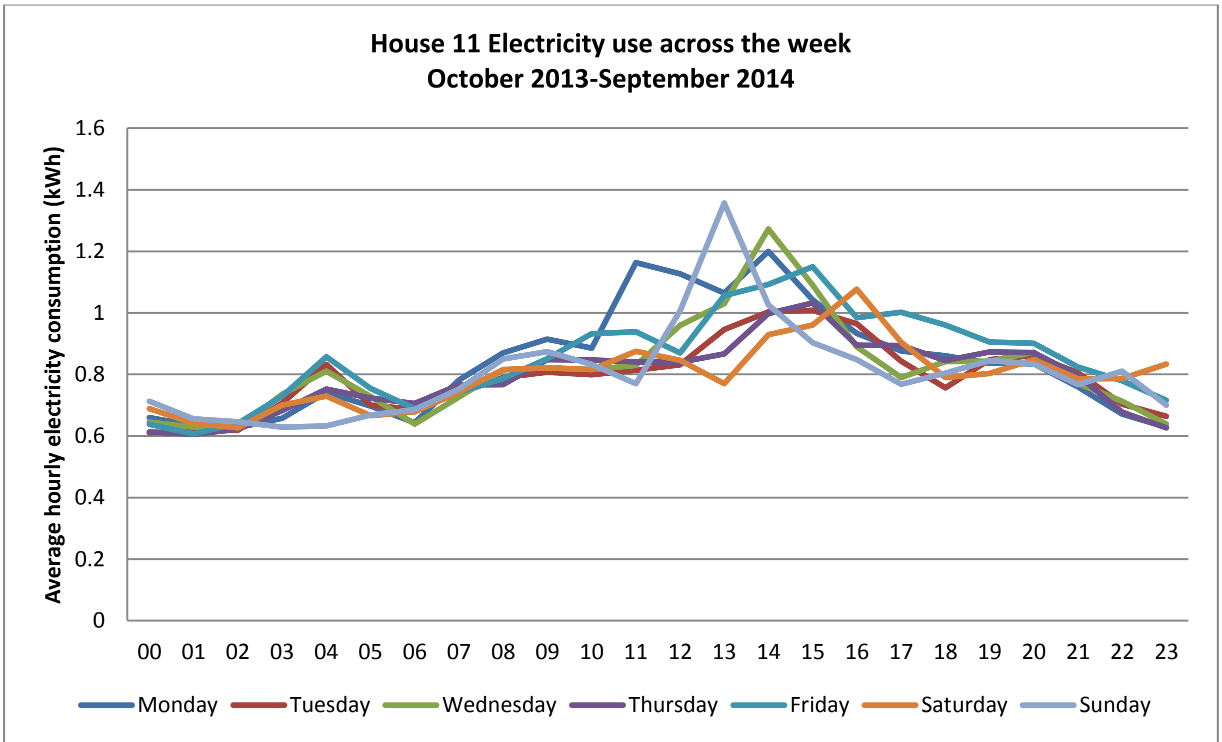


Figure 91 Average hourly electricity consumption across the week from October 2013 to September 2014.

Figures 92 and 93 show the monthly heat pump electricity use against heating degree days. The correlation between them is good indicating good use of the heat pump in the winter.

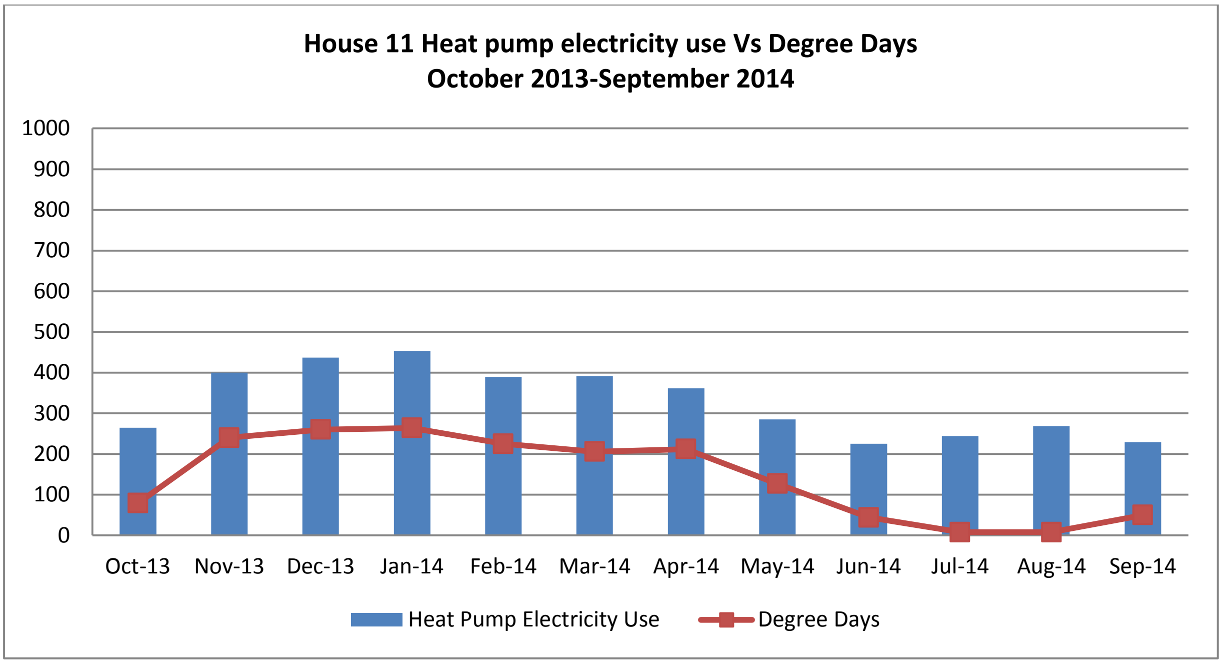


Figure 92 Heat pump electricity use Vs degree days from October 2013 to September 2014.

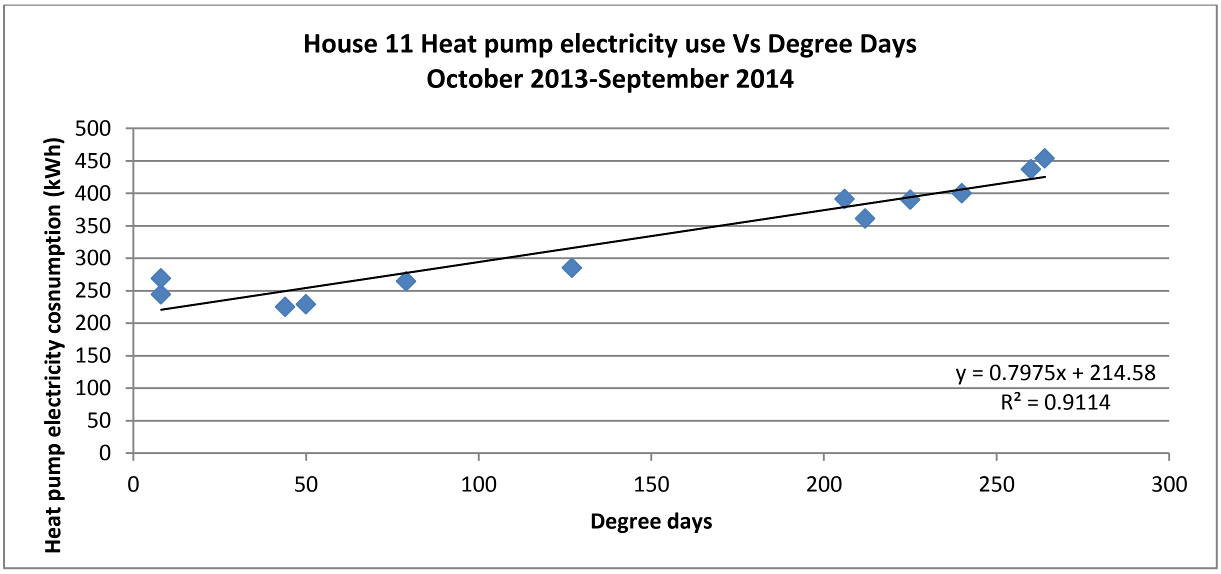


Figure 93 Heat pump electricity use Vs degree days from October 2013 to September 2014.

6.1.2.2 Water use

The annual water use (October 2013-September 2014) is 84m^3 or 84,000L (230L/day) (365 days). With four occupants this equates to 57 L/day/person. According to the Environment Agency the average person in England and Wales uses 150L/day (EA2012). No design estimate based on water saving measures was provided. Figure 94 shows the monthly total water use indicating that water consumption is kept steadily low throughout the whole monitoring period. This is a result of the occupants being very conscious about their water consumption and taking great care in not consuming a lot of water.

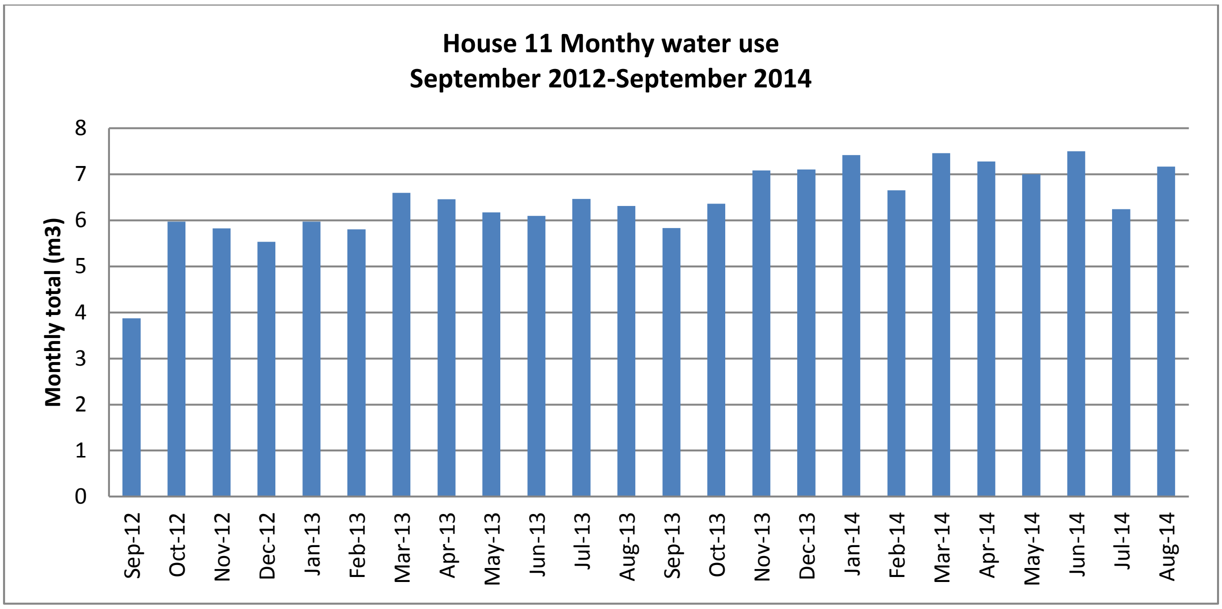


Figure 94 Monthly water use from September 2012 to September 2014.

6.1.2.3 Internal and external temperature

In contrast to House 5, the internal temperatures in House 11 present great variation throughout the monitoring period (Figure 95). This can be related with the heating patterns of the occupants, a fault with the living room's ground floor heating system during winter 2013, and with the high air permeability rate of house 11 ($15.7m^3/m^2h$). Despite this fact, temperatures are kept relatively within the comfort zone.

Bedroom temperatures recorded in the house from October to December 2013 are lower than those recorded the year before and fall below the comfort zone, reaching 15^{o}C. The occupants informed us that they have decided to keep the first floor (bedrooms) unheated and heat the ground floor (living room and kitchen) as they prefer their bedrooms to be cooler. Living room temperatures range between 20-26^{o}C.

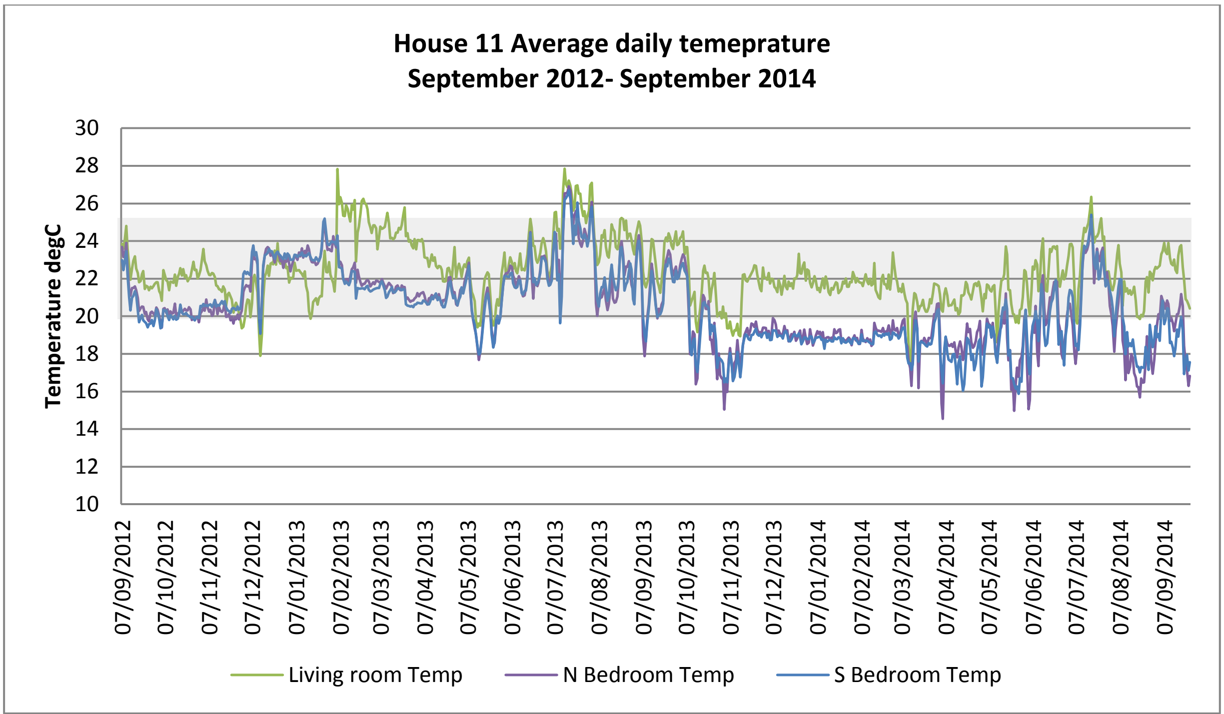


Figure 95 Average daily temperature from September 2012 to September 2014.

Figure 96 shows the monthly mean, maximum and minimum temperatures recorded in the living room from October 2013 to September 2014. Minimum temperatures rarely fall below the comfort band and monthly mean temperatures vary between 21-25°C. Mean temperatures range between 21-23°C during the winter months suggesting the living room is comfortably warm. Mean temperatures in February, July and August 2013 are close to the upper part of the comfort band and maximum temperatures reach 30°C showing that the house is overheating at times in the summer.

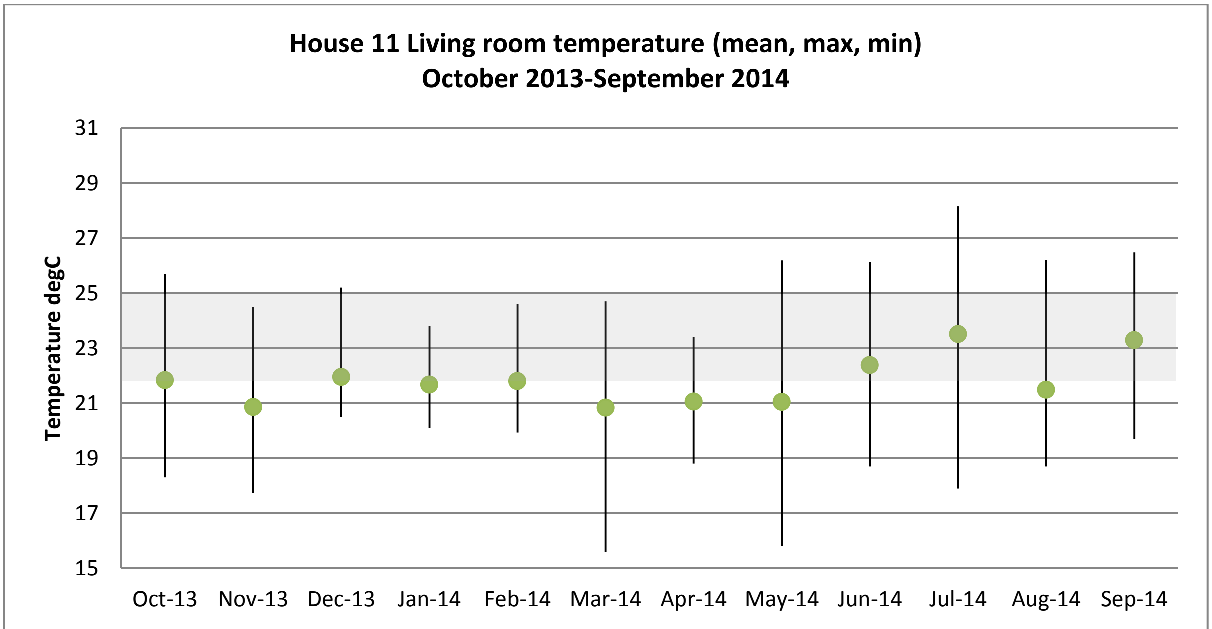


Figure 96 Living room temperatures: monthly mean, max, min from October 2013 to September 2014.

Figure 97 shows the daily pattern in living room and bedroom environmental conditions. Temperatures are kept steady around 22-23°C throughout the day. Relative humidity levels range between 40-45%.

When the room is occupied, CO_2 concentration levels in the bedroom rise during the night reaching 800ppm. CO_2 concentration levels in the living room steadily rise during the day reaching 700ppm at 9pm. The graph indicates that the average hourly temperature and RH levels in the living room are within the comfort zone and that CO_2 concentrations are within the acceptable limits.

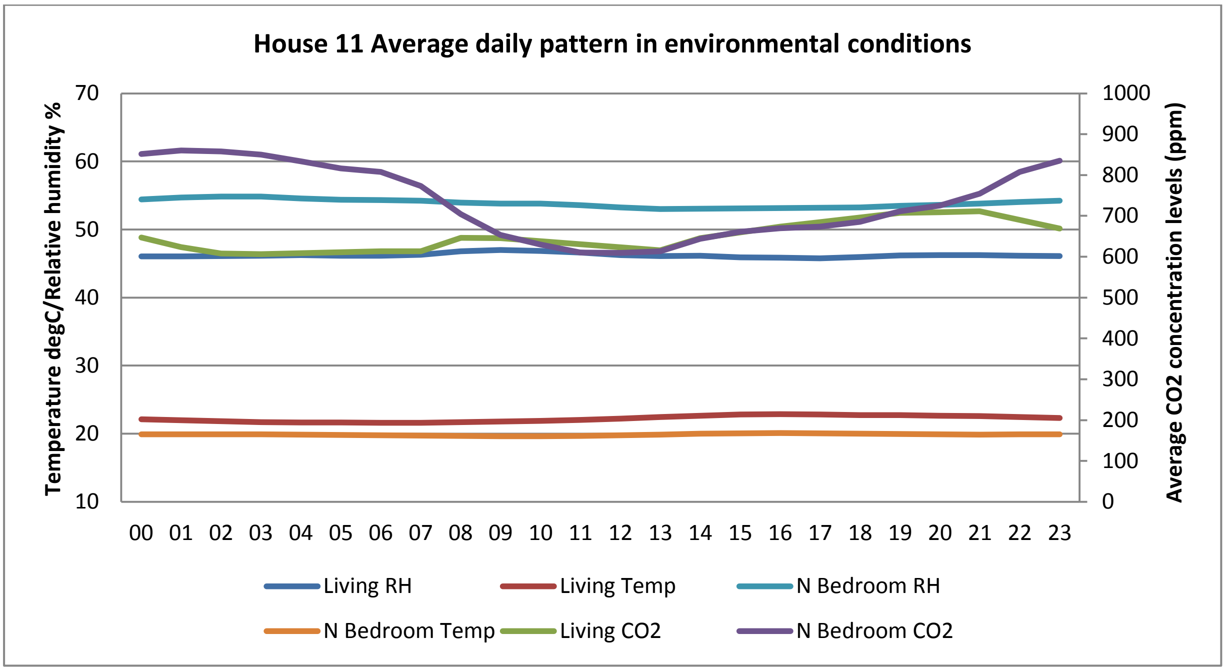


Figure 97 Daily temperature, relative humidity, CO_2 concentration patterns(October 2013-September 2014).

Figure 98 shows the daily variation in living room environmental conditions across seasons. It is noticeable that summer temperatures (24-25°C) are higher than the temperatures recorded during the other seasons: autumn (21-22°C), winter and spring (22-23°C). In all seasons temperatures in the living room seem to rise in the afternoon when all of the occupants are in the house. Relative humidity levels are kept steady throughout the day ranging around 50% during summer and around 35% during winter.

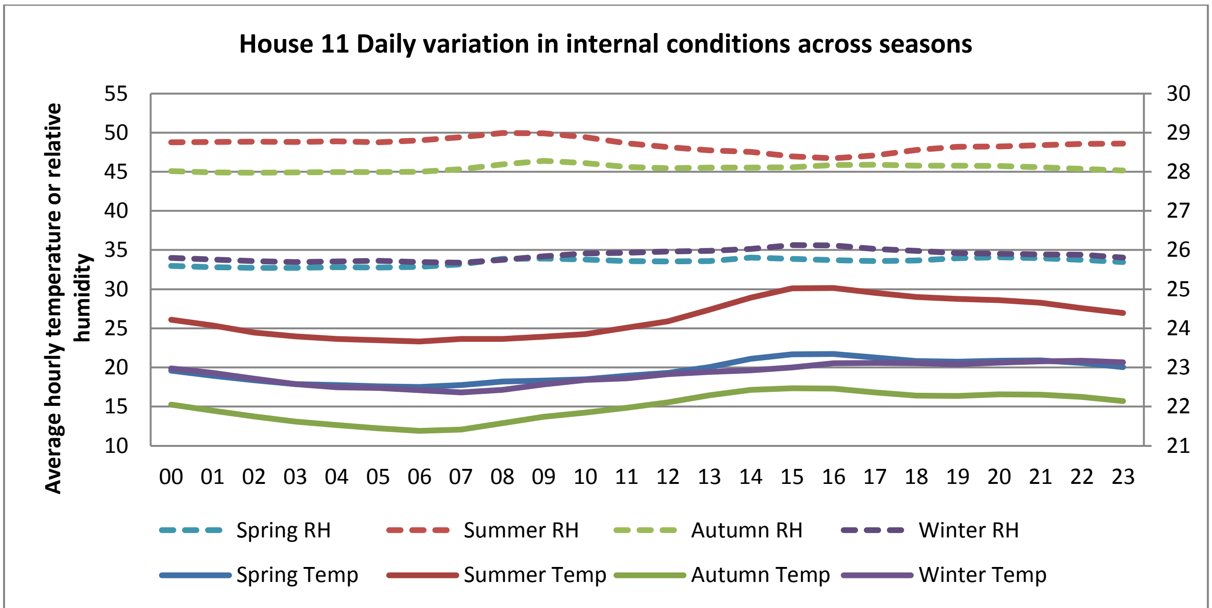


Figure 98 Daily variation in living room internal conditions across seasons (October 2013-September 2014)

6.1.2.4 Internal and external relative humidity

According to Figure 99 relative humidity within the house gradually falls during the winter period reaching 20% in March-April 2013. The graph indicates that since December 2013 the average daily relative humidity in the house is below the CIBSE recommended range of 40-70%. This may be related to the high air permeability of the house (15.7m^3/m^{2}h) and the Exhaust Air Heat Pump (EAHP) not performing well during that period. It should be noted that the back door and windows are rarely opened by the occupants during winter and that the MVHR boost is never used. From mid-April 2014 RH levels gradually start to rise again reaching an acceptable 60% in June 2014.

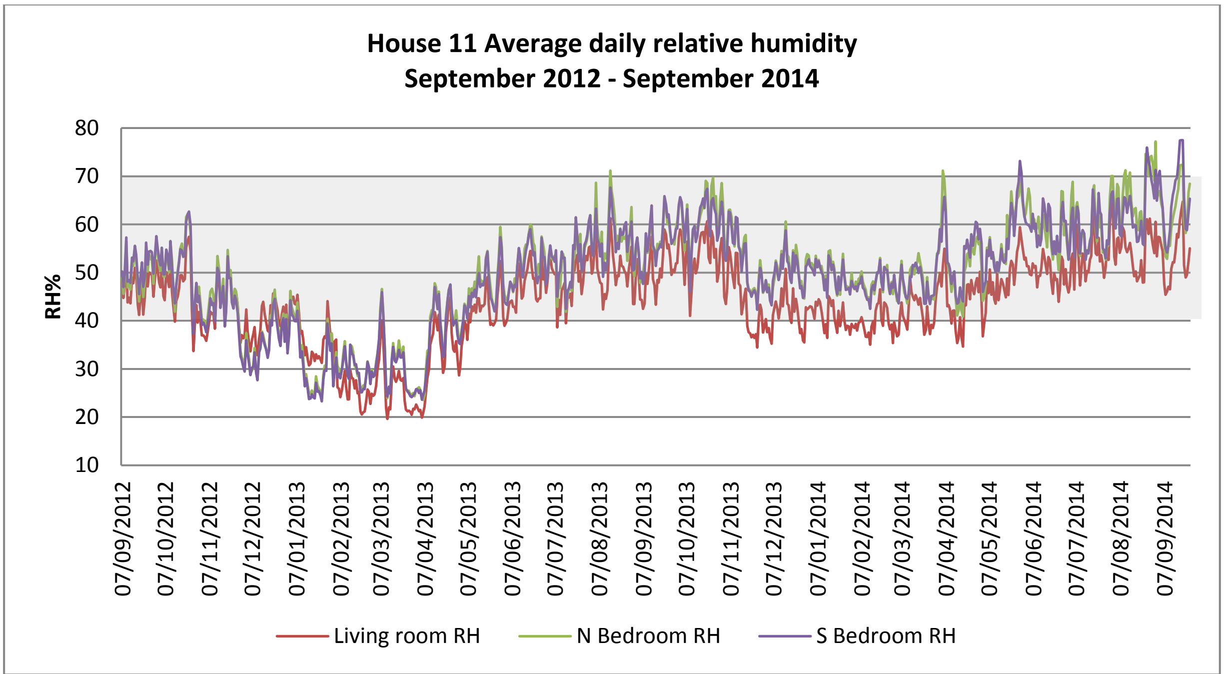


Figure 99 Internal and external RH. Relative humidity falls below CIBSE recommended boundaries after December 2012, reaching 20% in March and April 2013. This might be related to the high air permeability of the house and the Exhaust Air Heat Pump not performing well during that period. It should be noted that the backdoor and windows are rarely opened by the occupants during winter and that the MVHR boost is never used. From mid-April 2014 RH levels gradually start to rise again reaching 60% in June.

Figure 100 shows the monthly mean, maximum and minimum relative humidity levels recorded in the living room. During winter, average relative humidity levels are close to the lower edge of the CIBSE recommended range of 40-70% and minimum values drop below 30%. Maximum relative humidity levels never exceed 65%.

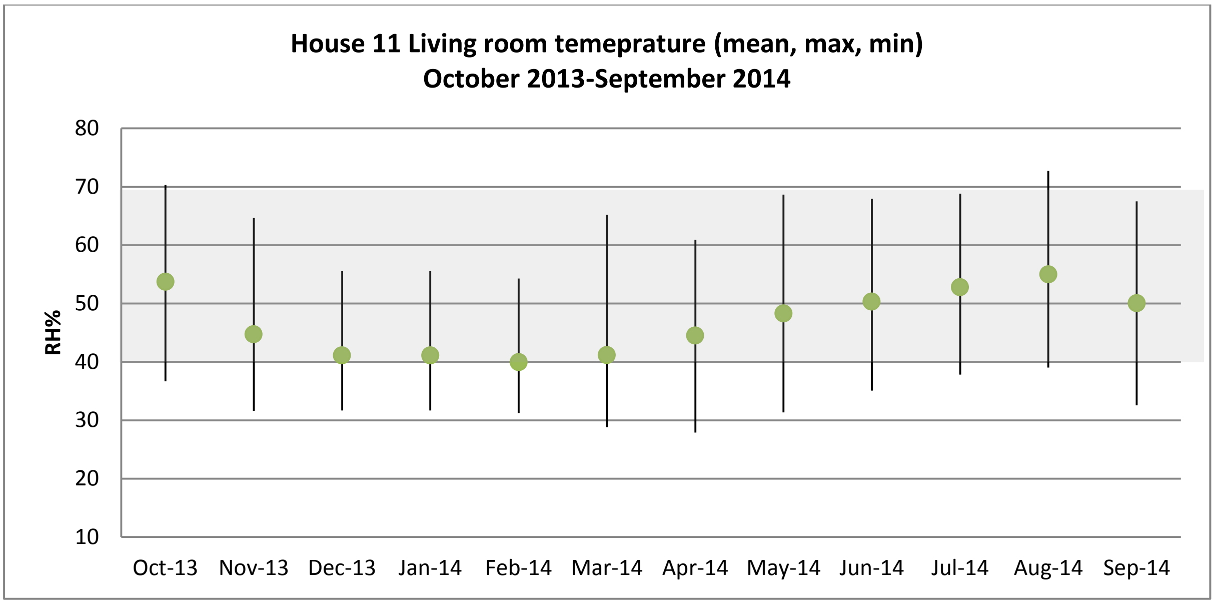


Figure 100 Living room relative humidity: monthly mean, max, min from October 2013 to September 2014.

When analysing RH in relation to temperatures, in winter, both temperature and RH are towards the lower end of the comfort band (Figure 101). During the summer, there is a greater dispersion in temperature, and generally higher RH levels than in the winter. Relative humidity levels rise during summer as a result of increased ventilation (Chapter 6.4). Winter relative humidity levels often fall below the recommended limit of 40%, most likely due to the lack of window opening, and increased heating.

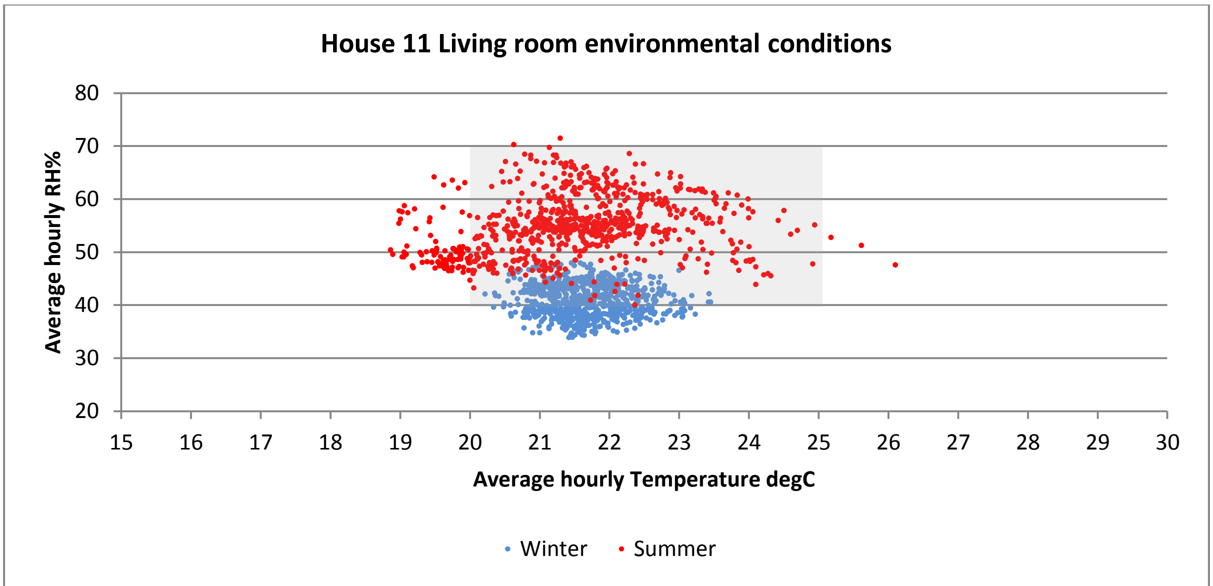


Figure 101 Living room environmental conditions during summer (August 2014) and winter (January 2014)

6.1.2.5 Internal CO_2 as proxy of air quality

CO_2 concentrations during the monitoring period range between 500-900ppm, thus not exceeding the ASHRAE recommended limit of 1000ppm, indicating relatively good air quality (Figure 102). This might also result from the high air-permeability of the house (15m^3/m^2.h). The occupants rarely use the windows or back door for additional ventilation during winter. MVHR test performed mid-April showed a great discrepancy between the supply and extract rates with the supply rates being more than double than the extract rates. In order to re-balance the system and reduce that discrepancy supply vents were re-adjusted resulting in a rise in CO_2 levels from April onwards. From July to September 2013 CO_2 levels in all rooms range between 400-700 ppm as the windows are left open for longer periods. CO_2 levels gradually rise again from September 2013 onwards indicating reduced incidence of window opening.

Since the MVHR system was rebalanced, the CO_2 levels in the house have risen during the winter months, reaching the upper limit of 1000ppm. This, combined with the fact that the house has higher air permeability than the design target, suggests that CO_2 levels in the house could have been higher had the design target been achieved and had the MVHR system been commissioned properly from the beginning. Such findings question the suggested settings for the MVHR fresh air supply and indicate the importance of careful design and commissioning of the ventilation system to ensure adequate levels of indoor air quality.

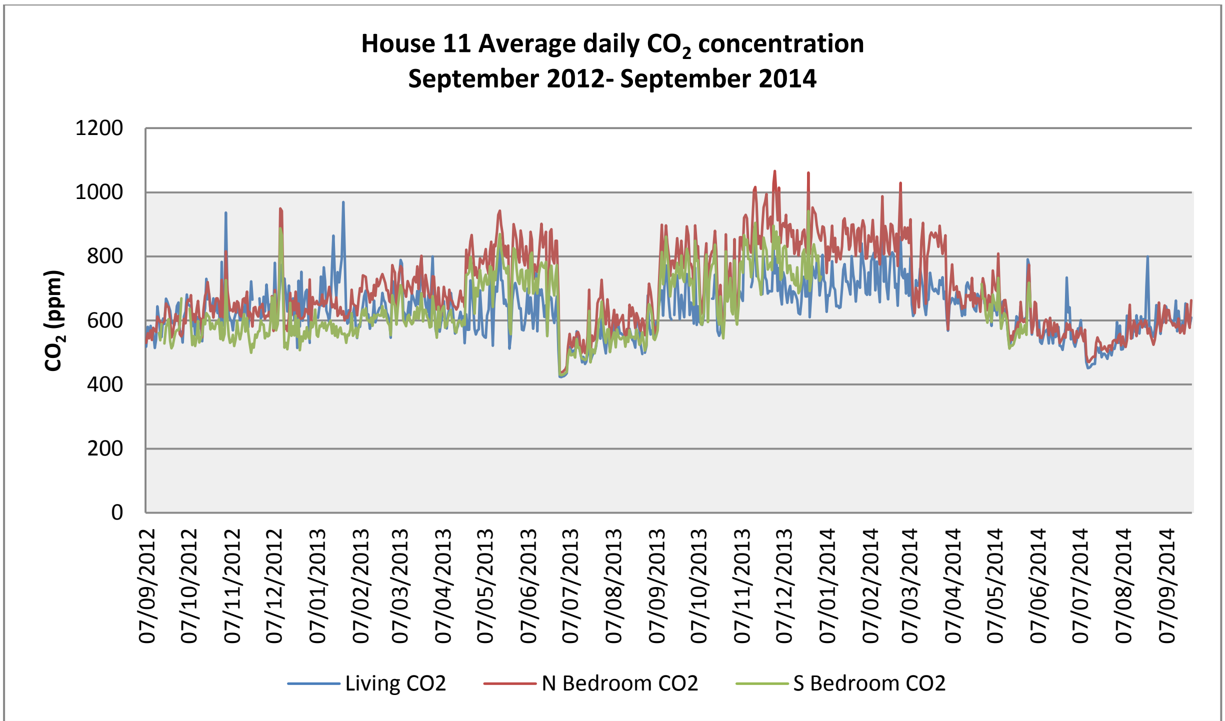


Figure 102 CO_2 levels in House 11 from September 2012 to September 2014. CO_2 levels are kept well within the ASHRAE recommended limits (400-1000ppm) due to the high air permeability rate of the house (15.7 m^3/m^2h).

Figure 103 shows the CO_2 concentration distribution for the different rooms as a percentage of total hours. Living room CO_2 levels range between 500-750 ppm for 64% of the time and between 750-1000 ppm for 13.5% of the time. CO_2 levels in the north bedroom range between 750-1000 ppm for 21% of the time and between 1000-1250 ppm for 5% of the time.

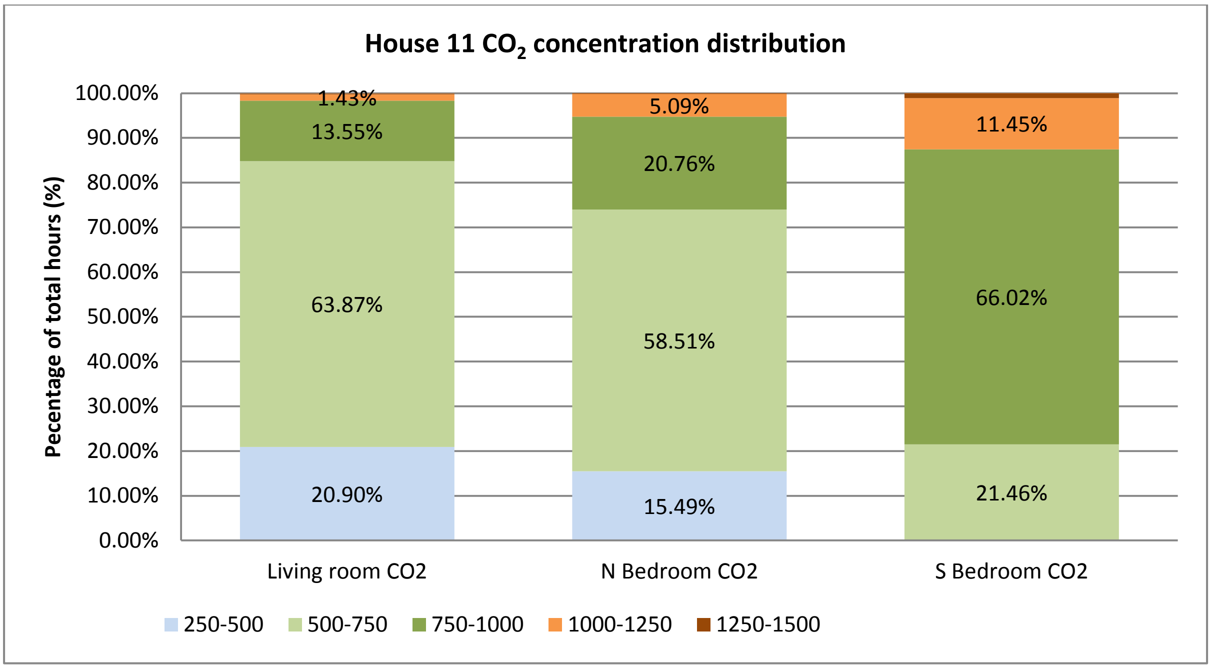


Figure 103 CO_2 concentrations as percent of total occupied hours from October 2013 to September 2014.

CO_2 levels are higher in winter than summer as a result of limited ventilation. Despite this, CO_2 levels rarely exceed the limit of 1000ppm indicating good air quality (Figures 104-105).

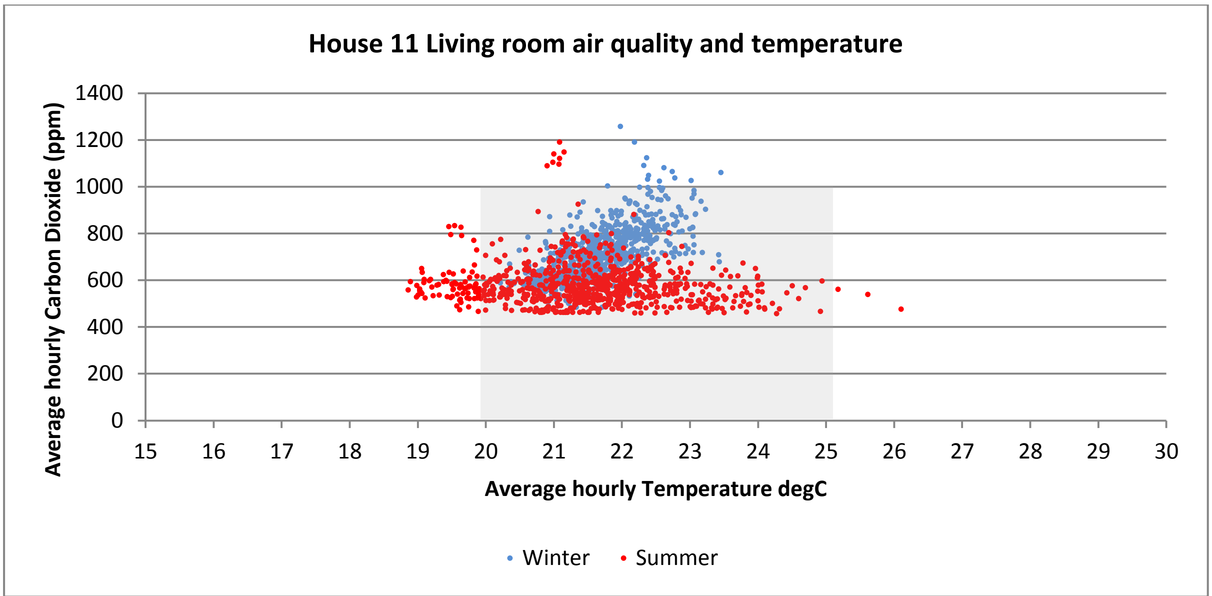


Figure 104 Living room air quality and temperature in winter (January 2014) and summer (August 2014).

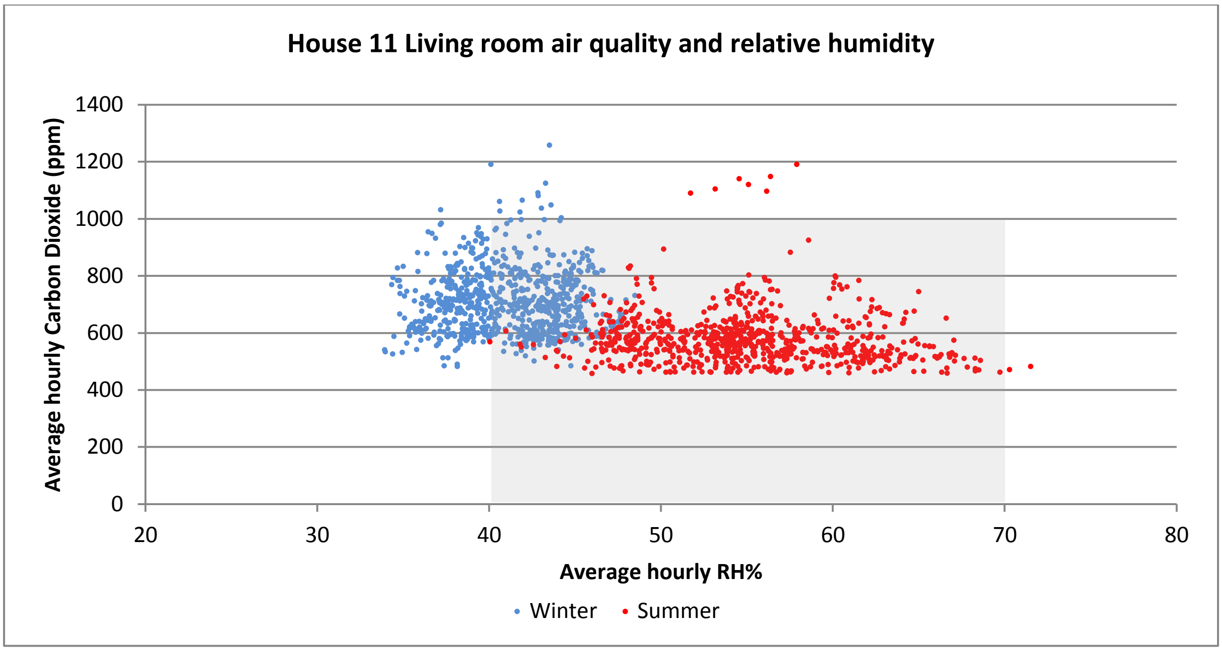


Figure 105 Living room air quality in winter (January 2014) and summer (August 2014).

6.2 Benchmarking and DomEarm energy audit

The DOMEARM spreadsheet was used to compare the annual energy performance of Houses 5 and 11 with current benchmarks.

Actual grid electricity use in both case study houses is lower than the UK average housing and the Part L compliant benchmark (Figures 106-107). Electricity consumption in House 5 is higher than that in House 11, despite the high air-permeability levels in House 11. This indicates the effect of occupant behaviour in the domestic energy use. As a result electricity use in House 5 is higher than the CSH Level 4 despite the houses being designed for CSH Level 5.

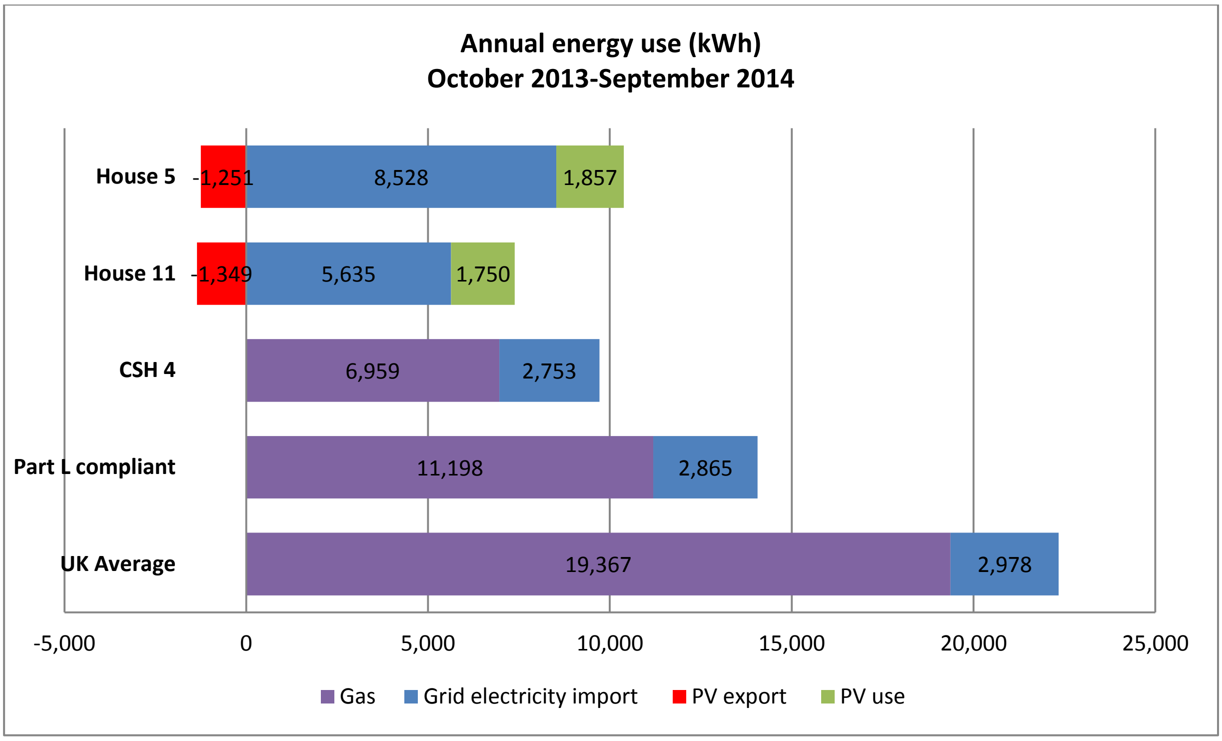


Figure 106 Annual energy use (kWh)from October 2013 to September 2014 and comparison with DomEarm benchmarks.

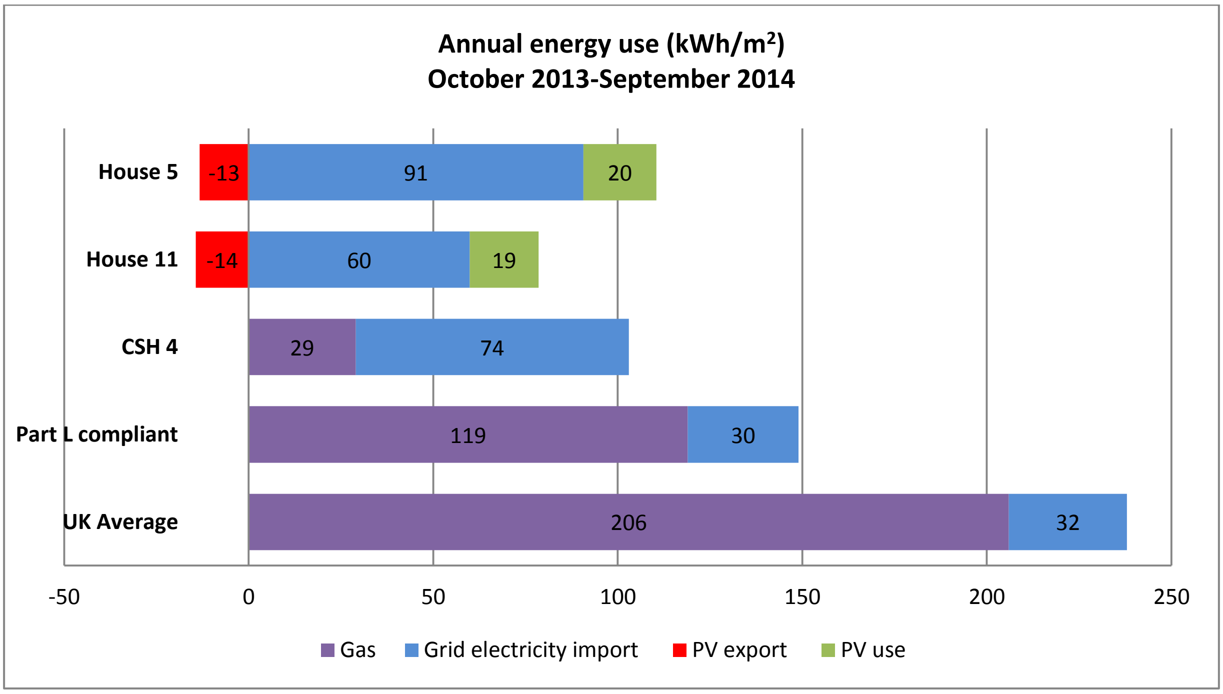


Figure 107 Annual energy use (kWh/m^2) from October 2013 to September 2014 and comparison with DomEarm benchmarks.

Annual CO_2 emissions in the case study houses are higher than the CSH Level 4 benchmark and in the case of House 5, higher than the Part L compliant benchmark. This is because of the houses being electrically heated, resulting in higher carbon footprint than a gas heated house (Figure 108). However, if the grid was de-carbonised the carbon footprint of these electrically heated houses would significantly reduce.

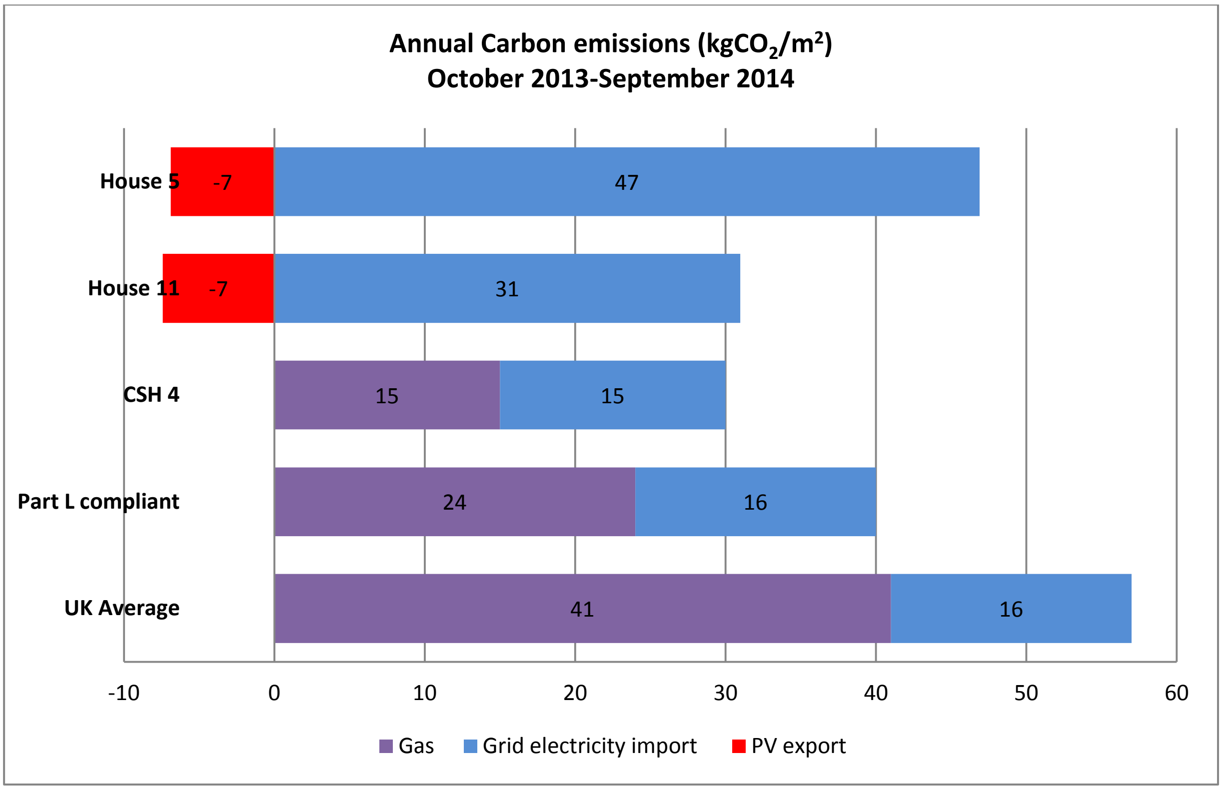


Figure 108 Annual carbon emissions from October 2013 to September 2014 and comparison with DomEarm benchmarks. Carbon emissions factors: Electricity 0.517 $kgCO_2e$, Gas 0.198 $kgCO_2e$.

Additionally, energy costs in both houses are high and are comparable to a UK average dwelling due to the higher price of electricity compared to gas (Figure 109). 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 'too high'.

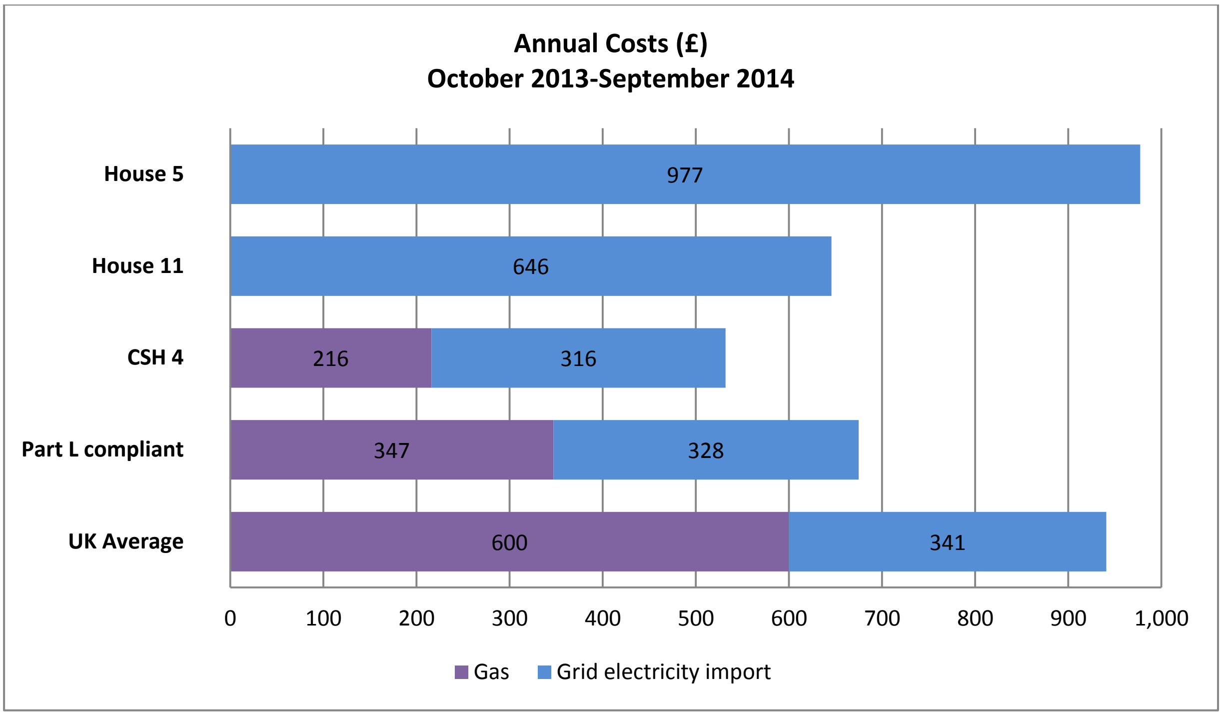


Figure 109 Annual costs from October 2013 to September 2014 and comparison with DomEarm benchmarks. Estimated price 0.11p/kWh.

A bottom-up energy audit was conducted in both houses. The appliance's schedule was determined after discussion with the occupants. In House 5 (Figure 110) the electricity use of appliances is higher than that of a typical UK house and Part L compliant benchmarks, whereas in House 11 (Figure 111) the electricity use of appliances does not exceed the benchmarks.

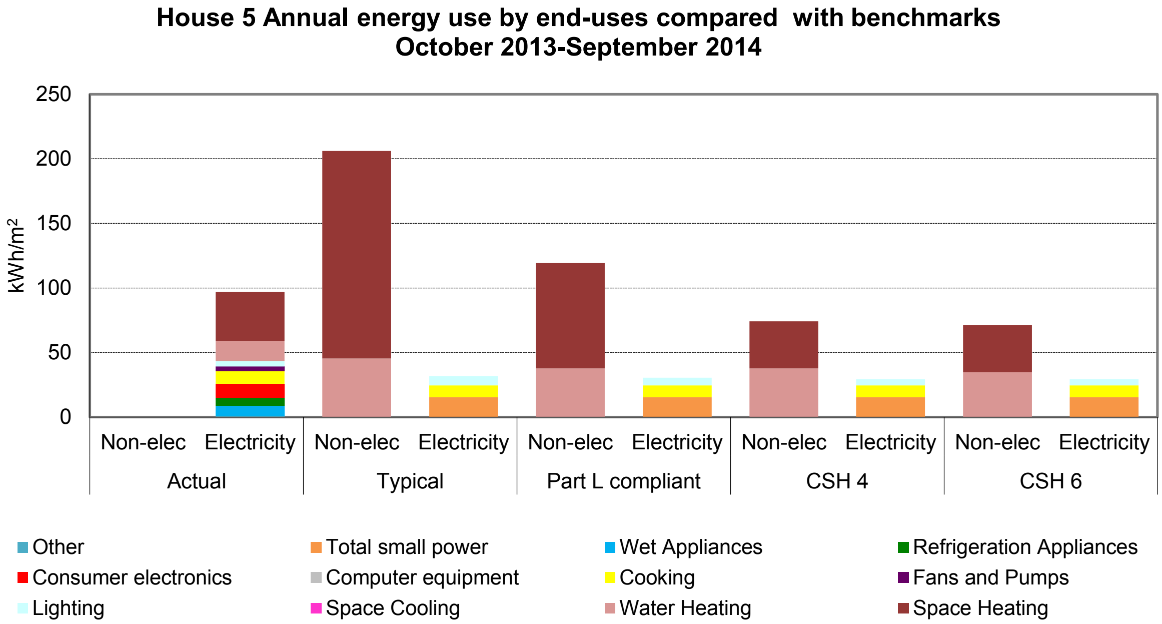


Figure 110 Annual energy use by end-use (based on energy audit data) (October 2013-September 2014) compared with DomEarm benchmarks.

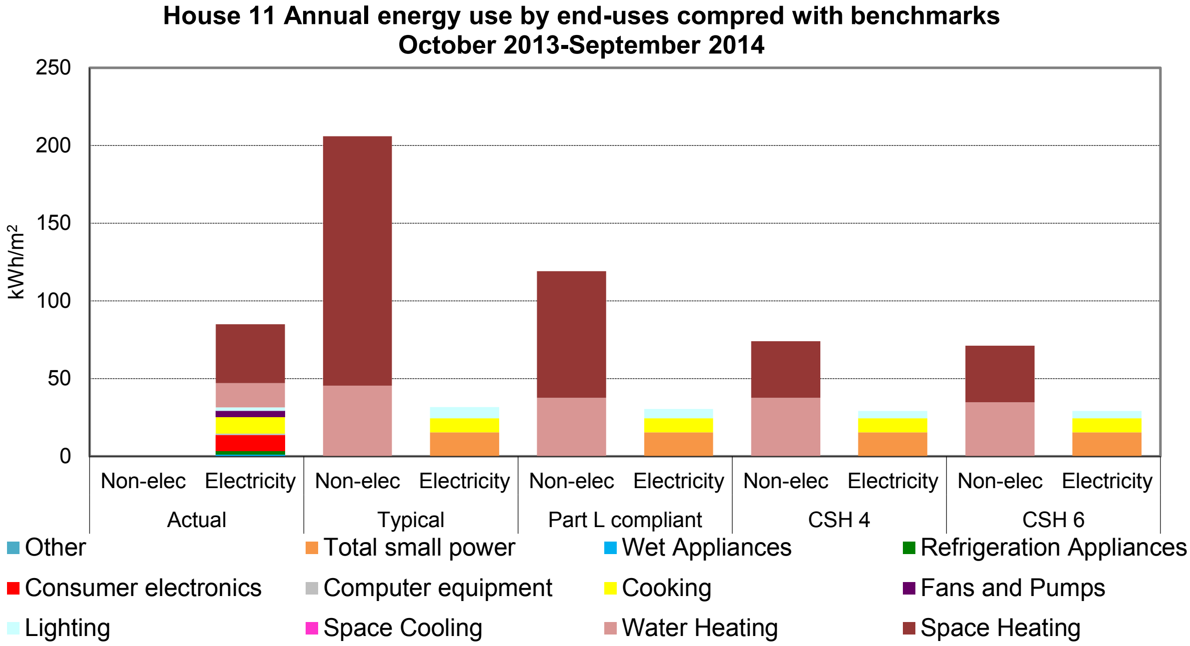


Figure 111 Annual energy use by end-uses (based on energy audit data) (October 2013-September 2014) compared with DomEarm benchmarks.

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 7 and 8).

Both houses share similar occupancy patterns with occupants leaving the house in the morning and returning in the afternoon. However, the heating patterns and use of appliances vary between the two houses.

Table 7 Occupancy patterns in Houses 5 and 11

		9:00-14:00	14:00-18:00	18:00-22:00	22:00-02:00	02:00-08:00
House 5	Weekdays					
	Weekends					
House 11	Weekdays					
	Weekends					

Table 8 Schedule of activities in Houses 5 and 11

	Heating (hours/day)	Cooking (hours/day)	TV (hours/day)	Windows open (in winter)	No. of showers/day	No. of washing & drying/week
House 5	At all times	1h (wday) 4h (wknd)	4h (wday) 10h (wknd)	When feeling hot	2-3	5 (2.5h each with tumble dryer)
House 11	2-4h (usually ground floor)	1h (wday) 2h (wknd)	8-10 h	Bathroom after shower	1-2	2-3 (rarely using tumble dryer)

6.3.1 House 5

6.3.1.1 Typical winter week

During a typical winter week, occupants in House 5 feel 'comfortably warm' for most of the time, reaching the 'too warm' end of the scale on some occasions. Activity levels range from walking inside the house and standing (active) to sitting (passive). Occupant is usually active inside the house. Regarding adaptive opportunities, during the recorded week the occupant mostly wore short sleeve shirts, long trousers and socks. Windows were mostly closed and internal doors were open while heating was constantly on. The occupants usually open the window in the afternoon.

During the study there has been a change in occupancy as the family welcomed a new baby during winter 2013. Later in the year (summer 2013) the number of occupants was reduced as one of the adults moved out of the house.

According to the activity logging sheets, in winter 2013 the occupancy pattern was:

- Weekdays: 1 adult with 2 children in the house in the morning, 2 adults and 2 children in the house in the evening. On some occasions another adult would visit the family during the day.
- Weekends: 2 adults with 2 children in the house in the morning and evening, the house is empty during the day. On some occasions the family would stay at home all day on Sundays.

In winter 2014 the occupancy pattern was:

- Weekdays: 1 adult with 2 children early in the morning and in the evening, house empty during midday and early afternoon.
- Weekends: 1 adult with 2 children in the morning and afternoon. Occupants out during the day.

On a daily basis:

- The heating is on at all times according to the occupant.
- The occupant opens the windows when feeling hot and uses the extract fan when cooking.
- The hob/oven (electric) is used for cooking 30min-1hour/day during weekdays and Saturdays and 4-5hours/day on Sunday.
- About 2-3 showers are taken every day.

- Washing involves one 30min load/day. The tumble dryer is used for about 2hours/day.
- TVs are on for about 4 hours or more per day during weekdays and for more than 10hours during weekends.

6.3.1.2 Typical summer week

During a typical summer week, in House 5, the thermal comfort of the occupants appears to vary ranging from ‘comfortably warm’ to ‘too cool’ in some cases. Activity levels range from walking inside the house to sitting (passive). Regarding adaptive opportunities, during the week the occupant mostly wore short sleeve shirts, long trousers and socks, switching to a long-sleeved shirt or cardigan when feeling colder. Windows were mostly closed and internal doors were open while heating was on most of the time according to the occupant. The occupants kept the blinds and windows closed.

According to the activity logging sheets, in summer 2013 the occupancy pattern was:

- Weekdays: 1 adult with 2 children in the house in the morning and evening, the house is empty during midday and afternoon. The occupants stay in the house all day on some occasions.
- Weekends: Occupants mostly out of the house in the morning and afternoon. 1 adult and 2 children in the evening.

On a daily basis:

- The heating is on at all times according to the occupant.
- The occupant opens the kitchen window and uses the extract fan when cooking.
- The hob/oven (electric) is used for cooking 30min-1hour/day during weekdays and Saturdays and 6hours/day on Sunday.
- About 2 showers are taken every day.
- Washing involves one 30min load/day (5 days a week). The tumble dryer is used for about 2hours/day each time.
- TVs are on for about 4 hours or more per day during weekdays and weekends.

6.3.2 House 11

6.3.2.1 Typical winter week

During the winter week the occupant in House 11 reported feeling between ‘comfortably neither warm nor cool’ to ‘comfortably warm’ and rated the overall comfort as ‘moderately comfortable’. Occupant activity mainly involved standing (active). The occupant wore short sleeve shirts and trousers or leggings with slippers throughout the week. The internal doors were kept open but windows were kept closed. Occupants pull the blinds down during the night.

According to the activity logging sheet the house is occupied most of the time:

- Weekdays: 1 adult with 2 children in the house in the morning, house empty until 13:00 when children return from school, 2 adults and 2 children in the evening. 1 adult and 2 children stay in the house all day on some occasions.
- Weekends: Occupants mostly in the house. House empty 3-4hours/day around midday.

Occupants in House 11 have actively been trying to reduce their energy demand by adjusting their heating patterns. In winter 2013 the heating was constantly on but in winter 2014 occupants decided only to heat the ground floor for 3-4hours/day and leave the top floor (bedrooms) unheated.

On a daily basis:

- Windows are kept closed. Occupants open the bathroom window after taking a shower.
- Extract fan is used when cooking.
- The hob/oven is used for cooking 1hour/day.
- 1 shower per day and 1 bath every other day.
- Washing involves 2-3 loads per week. Tumble drier is not used often.
- TV is on between 8-10 hours per day depending on occupancy.
- The computer is being used 1-2 hours/day.

6.3.2.2 Typical summer week

During the summer week the occupant in House 11 reported feeling between 'comfortably neither warm nor cool' and rated the overall comfort as 'acceptable'. The occupant wore short sleeve shirts and trousers or leggings with slippers throughout the week. The internal doors and windows were kept open. Occupants pull the blinds down during the night.

Summer occupancy patterns are similar to the winter ones.

- Weekday: 1 adult continuously in the house. Children return from school around 13:00. 2 adults in the house from 14:00 onwards.
- Weekends: Occupants mostly in the house. House empty 3-4hours/day around midday.

On a daily basis:

- Windows are opened when temperatures are high and bathroom window open after shower.
- Heating is off.
- Extract fan is used when cooking.
- The hob/oven is used for cooking 1hour/day.
- 2 showers per day and 1 bath every other day.
- Washing involves 2-3 loads per week. Tumble drier not used.
- TV is on between 8-10 hours per day depending on occupancy.
- The computer is being used 1-2 hours/day.

6.4 Window opening behaviour

Open-close state of the principal windows in living rooms and bedrooms are monitored concurrently with environmental conditions to better understand the performance of the houses. The hourly percentage of window opening in living rooms and bedrooms for the heating and non-heating seasons is plotted against hourly average internal temperatures in Figures 112 and 113.

During winter, occupants in both houses tend to mostly keep their windows closed and indoor hourly temperatures are kept steady throughout the day.

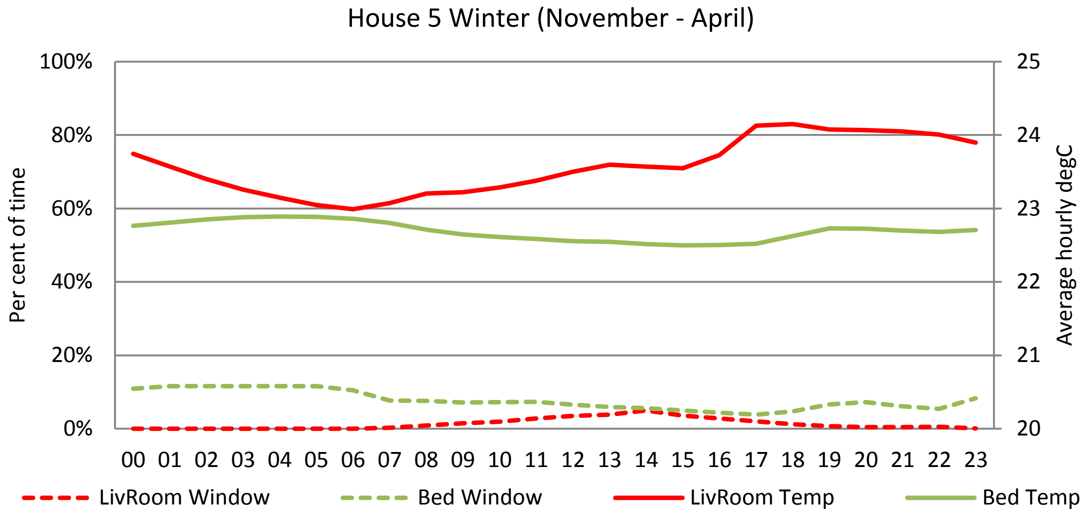


Figure 112 Hourly average temperatures and hourly percentage of window opening in House 5 across a winter day.

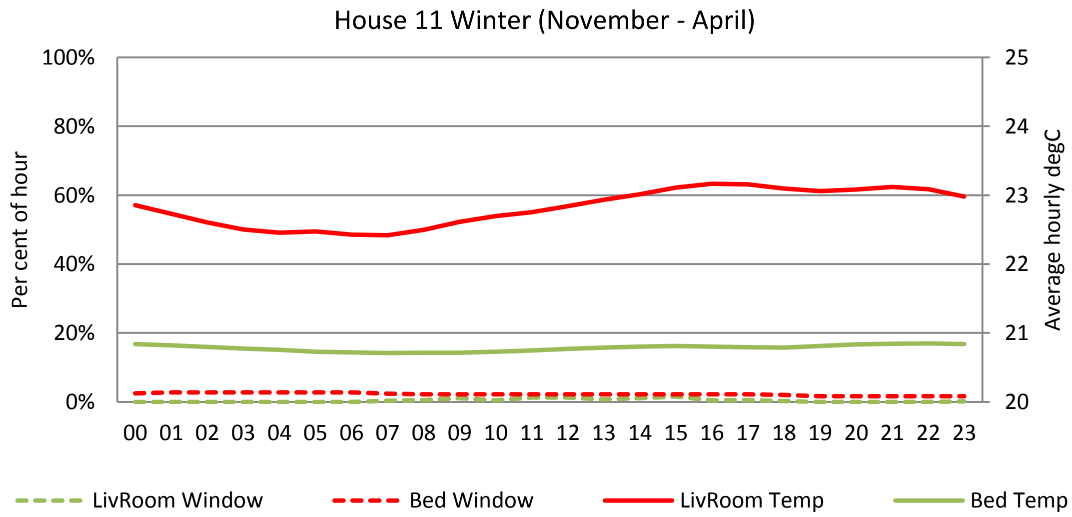


Figure 113 Hourly average temperatures and hourly percentage of window opening in House 11 across a winter day.

Between May to September, occupants in both houses open their windows for longer periods of time in order to get rid of excess internal gains (Figure 114, 115). 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 of all the case study houses 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.

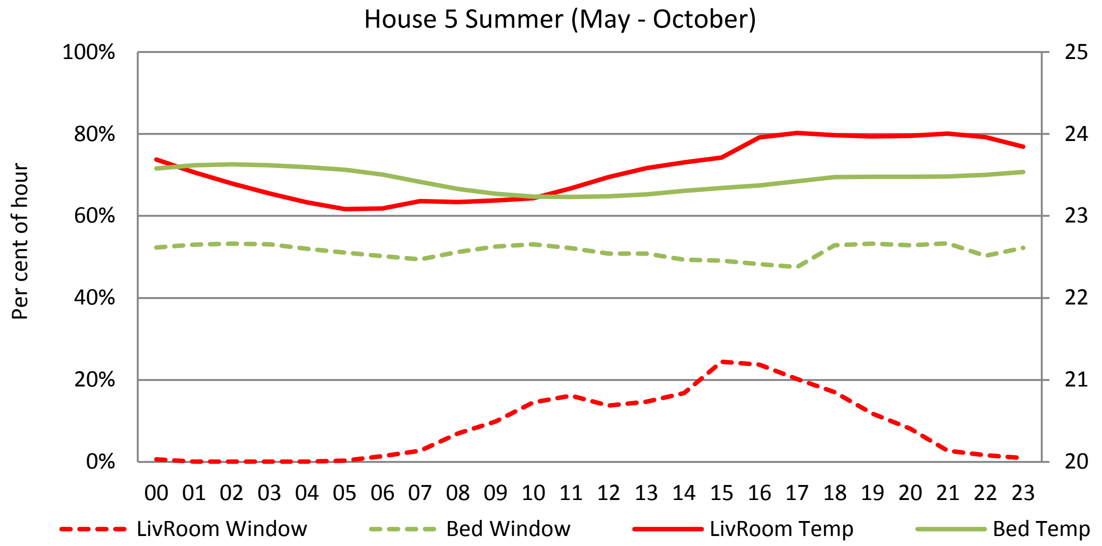


Figure 114 Hourly average temperatures and hourly percentage of window opening in House 5 across a summer day.

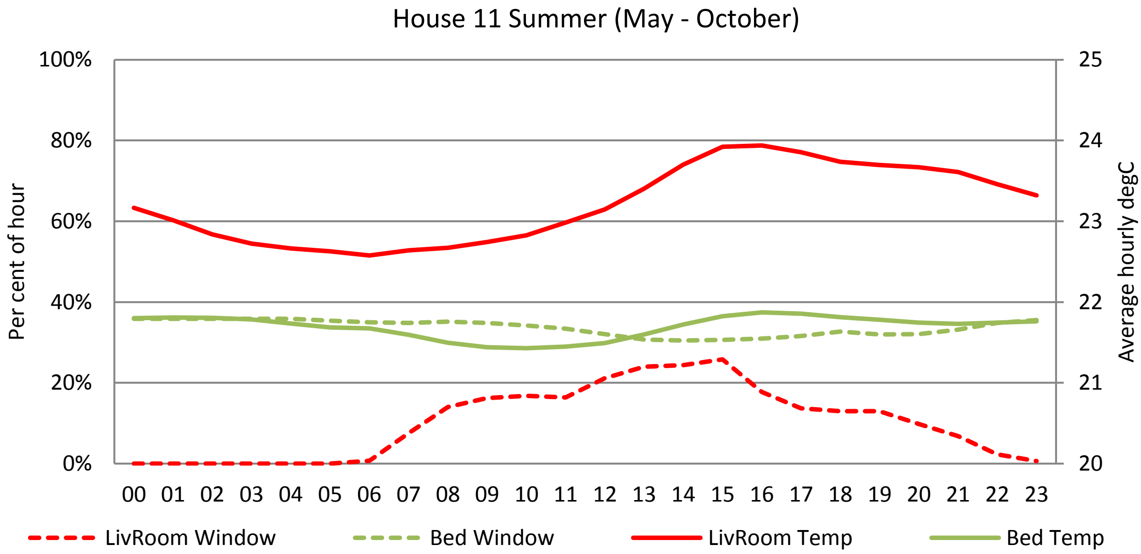


Figure 115 Hourly average temperatures and hourly percentage of window opening in House 11 across a summer day.

6.5 Overheating assessment

CIBSE (2006) suggests values for overheating criteria for a range of building types. 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. Environmental Design Guide A provides static benchmark summer peak temperatures and overheating criteria (Table 9). However, while these 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 adaptive thermal comfort, the BS EN 15251 criteria were developed resulting in a dynamic metric that takes the outdoor conditions and adaptation into account (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).

Table 9 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 in both case study houses is shown in Figures 116 and 117. Following the Environmental Design, Guide A (CIBSE, 2006) static overheating criteria, the House 11 living room shows instances of overheating during the non-heating season with temperatures above 28°C for more than 1% of occupied hours. Bedrooms temperatures remain above 26°C for far more than 1% of occupied hours (House 5: 4.5%, House 11: 3%) indicating that the houses overheat.

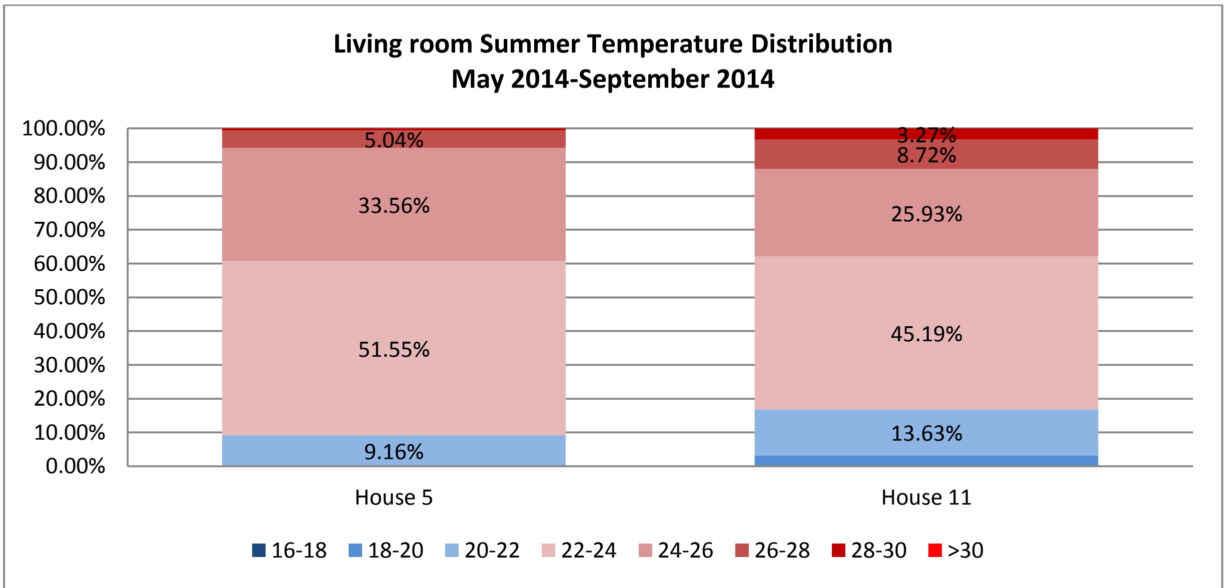


Figure 116 Temperature distribution from May to September during occupancy hours in living rooms.

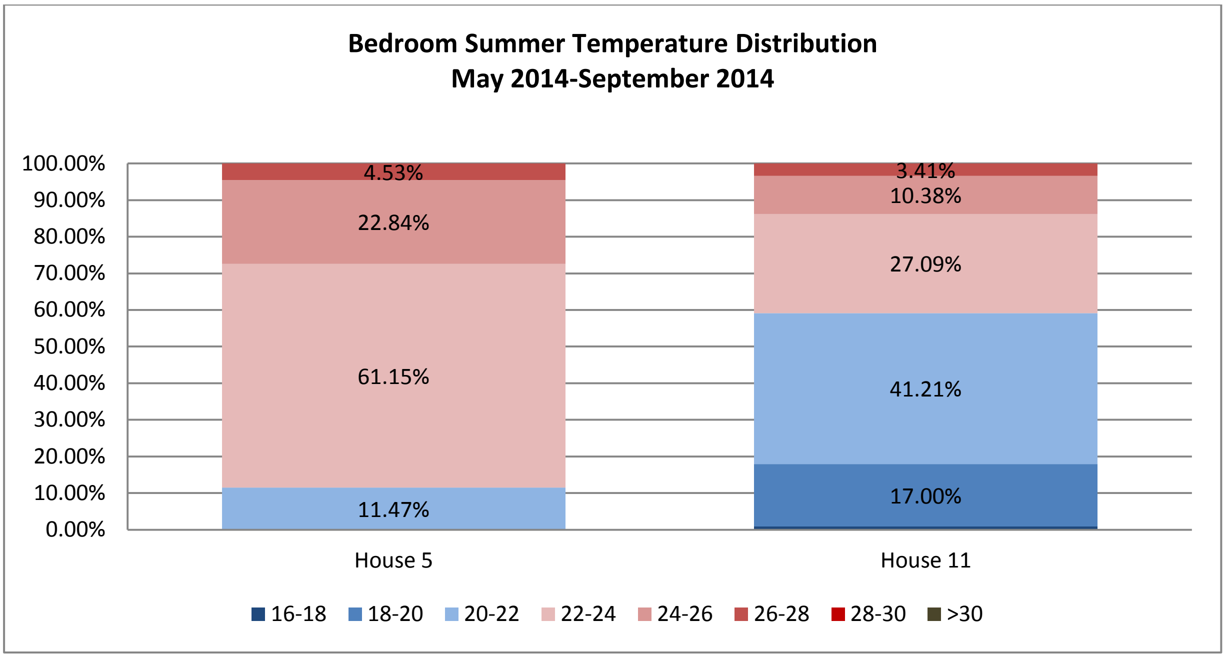


Figure 117 Temperature distribution from May to September during occupancy hours in bedrooms.

Following the dynamic metric for assessing overheating suggested by CIBSE TM52 document (CIBSE, 2013), the percentage of overheating and hours of temperature exceedence of the adaptive comfort upper limit in living rooms and bedrooms across the case studies were plotted in Figures 118 and 119. The percentage of occupied hours where internal temperatures exceed the upper comfort limit by 1K is below 1%. It is evident that according to the BS EN 15251 and TM52 the spaces do not overheat.

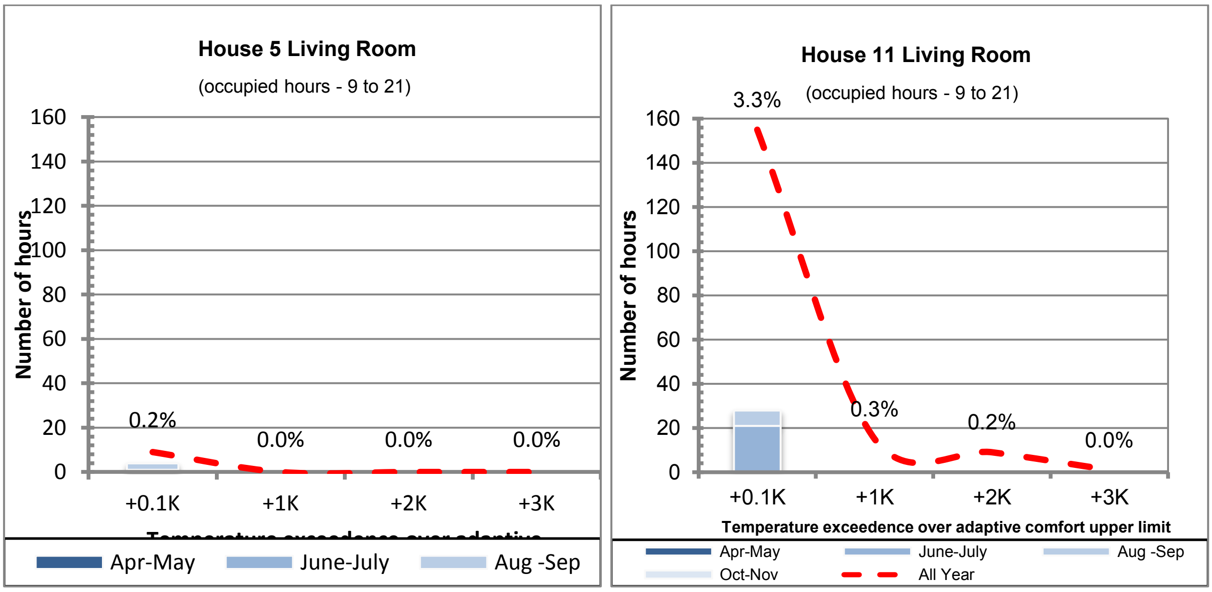


Figure 118 Percentage of overheating and temperature exceedence over adaptive comfort upper limit in living rooms.

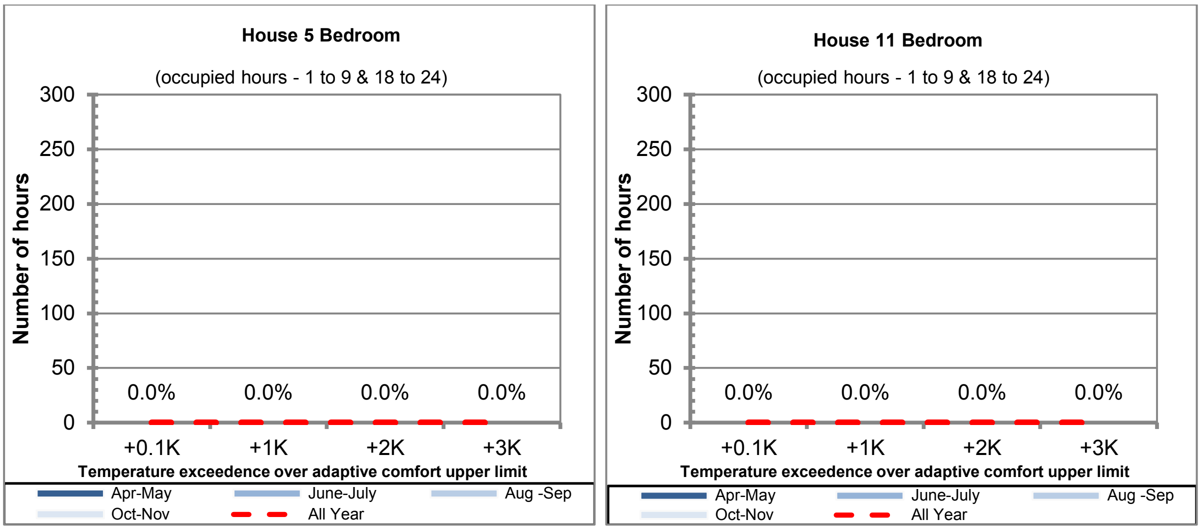


Figure 119 Percentage of overheating and temperature exceedence over adaptive comfort upper limit in bedrooms.

6.6 Key findings

- Actual grid electricity use in both case study houses are lower than the UK average housing and the Part L compliant benchmark. Electricity consumption in House 5 is higher than that in House 11, despite the high air-permeability levels in House 11. This indicates the effect that occupant behaviour can have on domestic energy use.
- Annual CO_2 emissions in the case study houses are higher than the CSH Level 4 benchmark and in the case of House 5, higher than the Part L compliant benchmark. This is because of the houses being electrically heated, resulting in higher carbon footprint than gas heated houses.
- Energy costs in both houses are high and are comparable to a UK average dwelling due to the higher price of electricity compared to gas. 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 'too high'.
- Differences in the energy and environmental performance of the two houses are a result of occupant behaviour.
- Annual grid electricity consumption is 91 kWh/m^2 in House 5 and 60 kWh/m^2 in House 11.
- Annual carbon emissions are 47kgCO_2/m^2 for House 5 and 31kgCO_2/m^2 in House 11.
- Total electricity generated by the PVs in House 5 is 3,108 kWh/annum (8.5 kWh/day), which is 12% lower than the SAP estimate for annual PV generation which is 3,519 kWh
- In House 11, the total electricity generated by the PV panels is 3,099 kWh (8.4 kWh/day), which is 12% lower than the SAP estimate for annual PV generation which is 3,519 kWh.
- In House 5, 61% of the total electricity use is consumed by the heat pump while 38% is used by lights and appliances. In House 11, 54% of the total electricity use is consumed by the heat pump.
- Heat pump performance in House 11 appears to be well correlated with external temperature in contrast to House 5.

- Temperatures in House 5 remain close to the upper limit of the comfort band throughout most of the monitoring period, ranging between 22-26°C during both winter and summer. This fact, in addition to the occupants mentioning that the house is 'too warm at times' when the heating is on, indicates that heating temperatures could be reduced by a couple of degrees thus reducing energy demand, and that the thermostat setting should be reviewed.

- In contrast to House 5, the internal temperatures in House 11 present great variation throughout the monitoring period. This can be related with the heating patterns of the occupants, a fault at the living room's ground floor heating system during winter 2013, and with the high air permeability rate of House 11 ($15.7m^3/m^2h$). Despite this fact, temperatures are kept relatively within the comfort zone.

- Relative humidity levels in both houses are low during winter as a result of high internal temperatures and reduced ventilation. Relative humidity levels rise during summer as a result of increased ventilation.

- Throughout the whole monitoring period CO_2 levels remain below the ASHRAE recommended limit of 1000ppm in both houses indicating good air quality.

- Following the EN 15251 adaptive comfort criteria, no overheating is observed in the houses. In addition to this, occupants did not complain of high summer temperatures.

- Window opening during summer is successful in reducing high internal temperatures. Occupants tend to leave bedroom windows open through the day during summer, whereas living room windows are open only during occupancy hours for safety purposes.

- The distribution of CO_2 levels in House 5 is similar during both winter and summer, rarely exceeding the limit of 1000ppm.

6.7 Recommendations

- Careful commissioning of all systems and controls after construction is needed. Provide seasonal commissioning to ensure that all systems are performing according to their specifications.

- The design and construction team should ensure that there is a sufficient post-installation support and maintenance guarantee.

- Control interfaces need to be easy to use and intuitive. Oversimplified controls lead to occupant confusion and may have a negative effect on energy use.

- Occupants need to familiarize themselves with the systems and low carbon technologies installed in the house and ask for guidance whenever necessary.

- Occupants need to have sufficient guidance and training. The Home User Guide should include clear guidance on the daily operation of the heating system and on the purpose of the ventilation.

7 Other technical issues

Technology Strategy Board guidance on section requirements:	This section should review the underlying issues relating to the performance of the building and its systems that have not been adequately captured elsewhere in this report. These could be technical issues detected through through testing, building use data and occupant issues etc. What technical issues have been discovered which could be leading to comfort or energy problems? Are the automated or manual controls being used effectively by the occupants or are they still becoming familiar with their operation? Did the commissioning process actually setup the systems correctly and, if not, what is this leading to? Are there design related technical issues, which are already becoming apparent and need to be highlighted for a future Phase 2 BPE study? Are there challenges being created through the dwelling usage or operation patterns? Summarise with conclusions and key findings.

7.1 Review of control interfaces

Control interfaces are the part at which the users meet the technology of the building. The usability of local controls for lights, heating, cooling and ventilation largely dictate the performance of a house in terms of:

- User satisfaction
- Avoiding discomfort
- Rapid response
- Thermal comfort
- Assisting management
- Energy efficiency

A review of the control interfaces took place during the Phase 1 study of Malmesbury Gardens. The survey was undertaken some days before the official handover to investigate the relationship between the design and usability of controls and the potential effect that they could have during the dwelling's occupancy. Key information collected through that survey is included in this report in order to provide some explanation regarding the usability and operation of the heating system controls.

The control's design principles were evaluated in terms of their:

- location
- clarity of purpose
- degree of fine control
- intuitive switching
- indication of system response
- useful annotation

The usability grading is not absolute, but made by the authors based on the knowledge of the applications where the controls have been used.

7.1.1 Thermostats

A thermostat was placed next to the entrance of each room in order to control the room temperature. All the room thermostats were connected to a master thermostat placed on the first floor hallway which had the overall control of the house heating system. The master thermostat was connected to the Exhaust Air Heat Pump (EAHP) which was not accessible by the tenants and was functioning in an auto mode setting.

The room temperature was controlled by a rotary dial with an arbitrary linear scale (Figure 120). The direction in which you had to turn the switch to heighten or lower the temperature was not graphically indicated. A red light at the bottom right corner of each thermostat was on, indicating the whole system operation rather than the status of the room as stated by the architect during the walkthrough. In addition, the oversimplified arbitrary line scale without any labelling and numbering could not sufficiently indicate what the scale levels will provide in terms of temperature or comfort conditions. In the absence of clear annotation, the user is forced to experiment. When the cover was removed the temperature in which the heating system would operate was revealed.

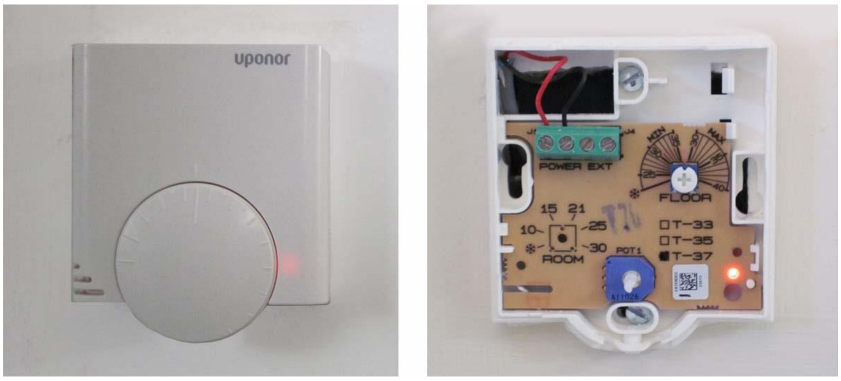


Figure 120 **Room thermostat with and without the cover.**

Table 10 Evaluation of room thermostat

Usability criteria	Poor	Excellent
Clarity of purpose		
Intuitive switching		
Labelling and annotation		
Ease of use		
Indication of system response		
Degree of fine control		

The master thermostat (Figure 121) was also operated by a rotary switch with a numeric scale from 1 to 9, setting the temperature range in which all the individual stats will operate. However, a temperature indication to provide tenants detailed information on their heating status was missing. It could not provide a clear feedback indicating to the user the control's operation since there was no light, sound or temperature indication on it.

Figure 121 Master thermostat

Table 11 Review of master thermostat

Usability criteria	Poor Excellent
Clarity of purpose	
Intuitive switching	
Labeling and annotation	
Ease of use	
Indication of system response	
Degree of fine control	

7.2 Key findings and recommendations

7.2.1 Key findings

- The room thermostat had an oversimplified interface lacking clear labeling and annotation.
- The master thermostat could not provide a clear feedback to the user since there was no light, sound or temperature indication on it.
- The room and the master thermostat had significantly different displays and approaches.
- The tenants do not have control of the temperature setting.
- The lack of clarity may reduce the sense of control felt by the tenants and the confidence of running their house efficiently.

7.2.2 Recommendations

- Consider improving the master thermostat’s interface in order to have some indication as to system status, and feedback to the user when the system is on. Without status indication, there is a risk that the system will not be used properly.
- Review the room thermostat interface in order to provide a temperature or hot and cold indication.
- Get the tenants familiar with the EAHP interface, properties and abilities in a level that does not compromise the commissioning set-up, in order to be able to use it in its maximum efficiency.

8 Key messages for the client, owner and occupier

Technology Strategy Board guidance on section requirements:	This section should investigate the main findings and draw out the key messages for communication to the client / developer and the building owner / occupier. Drawing from the findings of the rest of the report, specifically required are: a summary of points raised in discussion with team members; recommendations for improving pre and post handover processes; a summary of lessons learned: things to do, things to avoid, and things requiring further attention/study. Try to use layman's terms where possible so that the messages are understood correctly and so are more likely to be acted upon.

Table 12 presents a summary of the key initial findings associated with the BPE study elements.

Table 12 key findings across all study elements

BPE Study Elements	Phase 2 Findings	Key messages
Air permeability testing	• Both houses failed to meet the design air permeability of $2m^3/hm^2$ and were measured to have between 6 and 15 m^3/hm^2 in Houses 5 and 11 respectively. • The smoke pencil test revealed several air leakage paths through skirting boards, electrical outlets, plasterboards, light fittings loft hatch.	Greater attention to detail during the design and construction stages is needed for achieving advanced levels of air-tightness. Rapid diagnostics for instance, using thermal imaging surveys, can help in identifying faults with workmanship.
Thermographic survey	• Air leakage paths around window frames and plasterboard soffits. Thermal bridges across sills and thresholds. Heat loss through external walls.	
Review of control interfaces	• Thermostat controls were found to be poor in terms of labelling, indication of system response and intuitive switching.	Oversimplified controls lead to confusion and poor control over heating.
Occupant satisfaction survey, interviews and walkthroughs	• Occupants positive about overall comfort, temperatures & air quality. • Some complaints about lack of designated storage space. • Bills considered high. • Noise and draughts coming from MVHR. • Confusion about daily/seasonal operation of heat pump and MVHR.	A well-defined strategy on systems, services and controls early in the design process could result in better integration with building fabric and spaces.
Commissioning review	• The MVHR system in both properties needs to be re-balanced.	
Spot checks and recording measurements	• Actual grid electricity use in both case study houses is lower than the UK average housing and the Part L compliant benchmark. • Electricity consumption in House 5 is higher than that in House 11, despite the high air-permeability levels in House 11. This indicates the effect of occupant behaviour in the domestic energy use. Individual heating patterns and use of appliances explain the discrepancy. • Annual CO2 emissions in the case study houses are higher than the benchmarks. As a result of the houses being electrically heated.	Poor commissioning of the MVHR system leads to increased energy use, noise and draughts that reduce occupant comfort. The use of MVHR systems needs to be reviewed in buildings that are not as air tight as specified.

	• Energy costs in both houses are high and are comparable to a UK average dwelling due to the higher price of electricity compared to gas. 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 'too high'. • Temperatures in both houses are within comfort levels through the year. Higher temperatures were recorded in House 5. • Low relative humidity levels are a result of high temperatures during the heating season and reduced ventilation.	.

8.1 Recommendations

8.1.1 Recommendations for designers

- Maintain high flexibility, generous space standards, good daylight quality and north-south orientation in low energy developments (passive design).
- 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. Especially when working with hempcrete take into account the shrinking of the material that can affect the air-tightness levels of the construction. Take extra care in detailing and finishes during construction to avoid air leakage paths and construction flaws.
- Review air tightness specifications and ventilation requirements during the briefing stage, and develop appropriate design expectations. Mechanical ventilation systems in homes with air-permeability levels >3 are not necessary and add to the electricity demand.
- Design dedicated storage space needs in line with occupants' expectations and needs.
- 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.
- Avoid complexity in services and systems especially those which require synchronisation of multiple systems, For instance, in the case study dwellings, the solar thermal system was connected to exhaust air heat pump systems which was also connected to MVHR system.
- 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.

8.1.2 Recommendations for owners/developers (housing associations)

- Careful commissioning of all systems and controls after construction is essential.
- Opt for rapid diagnostics to quickly identify mistakes and omissions during the construction phase. This also acts as a quality regime.
- Avoid unmanageable complexity for both householder and the local authority. Complicated systems and lack of personnel training in new technologies results in issues not being effectively addressed and lead to higher energy use and occupant dissatisfaction.
- 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.
- Ensure that the MVHR system in properly commissioned, balanced and outlets and inlets are locked in a fixed position in order to prevent the occupants from unbalancing the system.
- More specifically, works need to be done to seal air leakage paths and improve the airtightness of Houses 5 and 11, especially in the NIBE cupboards. Also the MVHR system in both case study dwellings need to be re-balanced.
- Review handover, induction and training process to provide more graduated handover and hands-on experience.
- 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 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.
- Collate all lessons learnt on the project from issues raised (heat pump breakdowns, leaks, renewables installation) and use them as feedback to future projects.

9 Wider Lessons

Technology Strategy Board guidance on section requirements:	This section should summarise the wider lessons for the industry, including, but not limited to clients, other developers, funders, insurance bodies, skills and training groups, construction team, designers and supply chain members to improve their future approaches to this kind of development. Provide a detailed insight in to the emerging lessons. What would you definitely do, not do, or do differently on a similar project. Include consideration of costs (what might you leave out and how would you make things cheaper); improvement of the design process (better informed design decisions, more professional input, etc.) and improvements of the construction process (reduce timescale, smooth operation, etc.). What lessons have been learned that will benefit the participants' businesses in terms of innovation, efficiency or increased opportunities? These lessons need to be disseminated through trade bodies, professional Institutions, representation on standards bodies, best practice clubs etc. Please detail how dissemination will be carried out for this project. As far as possible these lessons should be put in layman's terms to ensure effective communication with a broad industry audience.

The BPE study of homes at Malmesbury Gardens 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 greatly exceeds their design predictions. 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.

10 Appendices

10.1 Air-permeability tests

10.1.1 House 5

Dwelling Airtightness Testing Report

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

Report N°: DAT-OXF01-NA001-LYN01-1-PL5-T2N

Date:	23/07/2012	Airtightness Engineer:	S Osborne
Accreditation Body:	ATTMA	Registration Number:	0005

Client:	Oxford Brookes Enterprises	Plot N°:	5
Region:	N/A	Developers Type:	N/A
Address:	Headington Campus Gipsy Lane Oxford Oxfordshire OX3 0BP	Development Name:	5 Malmesbury Gardens
		Development Address:	Lyndhurst Cresent Park North Swindon Wiltshire SN3 2SP
Telephone:			
Facsimile:			

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	1271
Measured Air Permeability (m³/(h.m²)):	5.27	Design Air Permeability (m³/(h.m²)):	

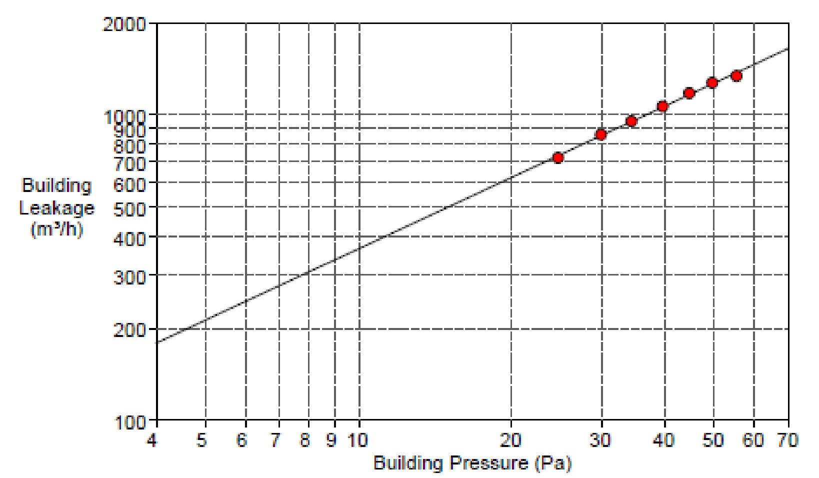
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	61.0	Air Leakage Coefficient (C_L):	61.1
Exponent (n):	0.78	Correlation Coefficient (r²):	0.9980

Test Information

		TS1 Leakage Area (m²):	0.063
Type of Test:	Depressurisation	Test Method:	B
Test Standard:	TS1	Regulation Complied With:	N/A



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Date:	23/07/2012	Airtightness Engineer:	S Osborne
Accreditation Body:	ATTMA	Registration Number:	0005

Client:	Oxford Brookes Enterprises	Plot N°:	5
Region:	N/A	Developers Type:	N/A
Address:	Headington Campus Gipsy Lane Oxford Oxfordshire OX3 0BP	Development Name:	5 Malmesbury Gardens
Telephone:		Development Address:	Lyndhurst Cresent Park North Swindon Wiltshire SN3 2SP
Facsimile:			

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	1317
Measured Air Permeability (m³/(h.m²)):	5.46	Design Air Permeability (m³/(h.m²)):	

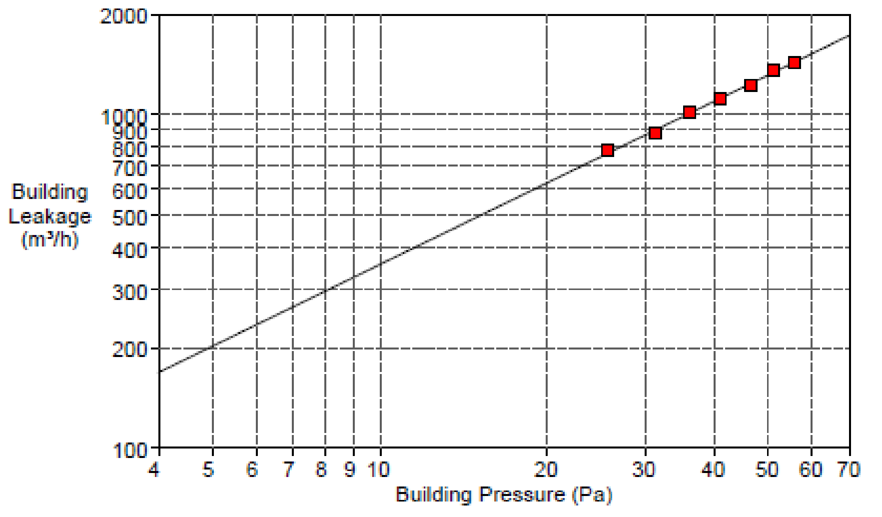
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	54.4	Air Leakage Coefficient (C_L):	54.5
Exponent (n):	0.81	Correlation Coefficient (r²):	0.9978

Test Information

		TS1 Leakage Area (m²):	0.066
Type of Test:	Pressurisation	Test Method:	B
Test Standard:	TS1	Regulation Complied With:	N/A



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Report N°: DAT-OXF01-NA001-LYN01-020714-PL5-T3N

Date:	02/07/2014	**Airtightness Engineer:**	C Knights
Accreditation Body:	ATTMA	**Registration Number:**	0005

Client:	Oxford Brookes Enterprises	**Plot N°:**	5
Region:	N/A	**Developers Type:**	N/A
Address:	Headington Campus Gipsy Lane Oxford Oxfordshire OX3 0BP	**Development Name:**	Malmesbury Gardens
Telephone:		**Development Address:**	Lyndhurst Crescent Park North Swindon Wiltshire SN3 2SP
Facsimile:			

Test Results at 50 Pascals

		Q_{50}: Airflow (m^3/h):	1558
Measured Air Permeability ($m^3/(h.m^2)$):	6.46	**Design Air Permeability ($m^3/(h.m^2)$):**	

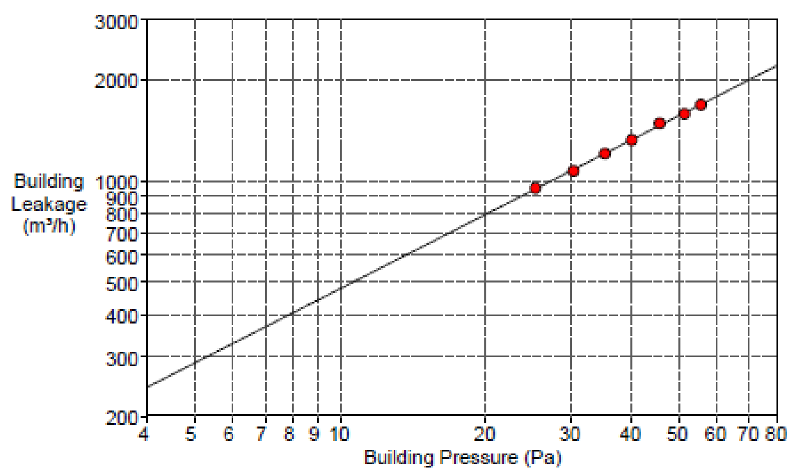
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	88.5	**Air Leakage Coefficient (C_L):**	88.3
Exponent (n):	0.73	**Correlation Coefficient (r^2):**	0.9993

Test Information

		TS1 Leakage Area (m^2):	0.078
Type of Test:	Depressurisation	**Test Method:**	B
Test Standard:	TS1	**Regulation Complied With:**	N/A



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Report N°: DAT-OXF01-NA001-LYN01-020714-PL5-T4P

Date:	02/07/2014	**Airtightness Engineer:**	C Knights
Accreditation Body:	ATTMA	**Registration Number:**	0005

Client:	Oxford Brookes Enterprises	**Plot N°:**	5
Region:	N/A	**Developers Type:**	N/A
Address:	Headington Campus Gipsy Lane Oxford Oxfordshire OX3 0BP	**Development Name:**	Malmesbury Gardens
		Development Address:	Lyndhurst Crescent Park North Swindon Wiltshire SN3 2SP
Telephone:			
Facsimile:			

Test Results at 50 Pascals

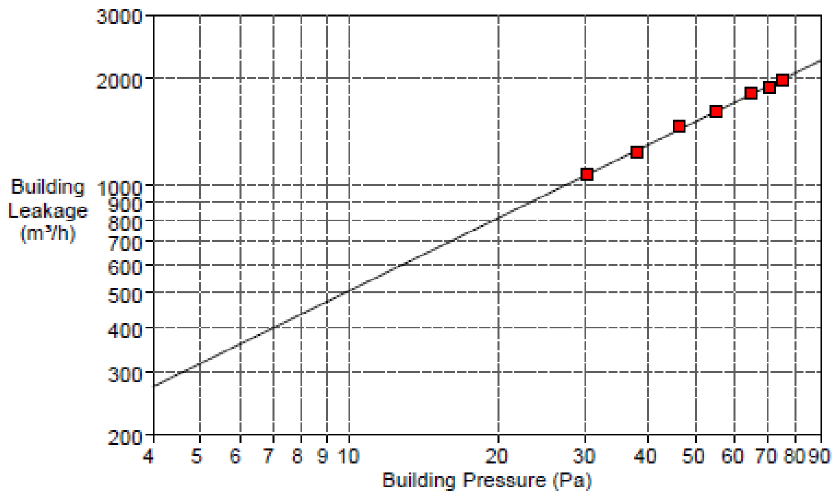
		Q_{50}: Airflow (m³/h):	1505
Measured Air Permeability (m³/(h.m²)):	6.24	**Design Air Permeability (m³/(h.m²)):**	
Did the dwelling achieve the required air permeability as specified in the SAP calculations?			

Building Leakage Curve

Air Flow Coefficient (C_{env}):	107.8	**Air Leakage Coefficient (C_L):**	107.3
Exponent (n):	0.68	**Correlation Coefficient (r²):**	0.9984

Test Information

		TS1 Leakage Area (m²):	0.075
Type of Test:	Pressurisation	**Test Method:**	B
Test Standard:	TS1	**Regulation Complied With:**	N/A



10.1.2 House 11

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Report N°: DAT-OXF01-NA001-LYN01-1-PL11-T1N

Date:	23/07/2012	Airtightness Engineer:	S Osborne
Accreditation Body:	ATTMA	Registration Number:	0005

Client:	Oxford Brookes Enterprises	Plot N°:	11
Region:	N/A	Developers Type:	N/A
Address:	Headington Campus Gipsy Lane Oxford Oxfordshire OX3 0BP	Development Name:	11 Malmesbury Gardens
		Development Address:	Lyndhurst Crescent Park North Swindon Wiltshire SN3 2SP
Telephone:			
Facsimile:			

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	3797
Measured Air Permeability (m³/(h.m²)):	15.74	Design Air Permeability (m³/(h.m²)):	

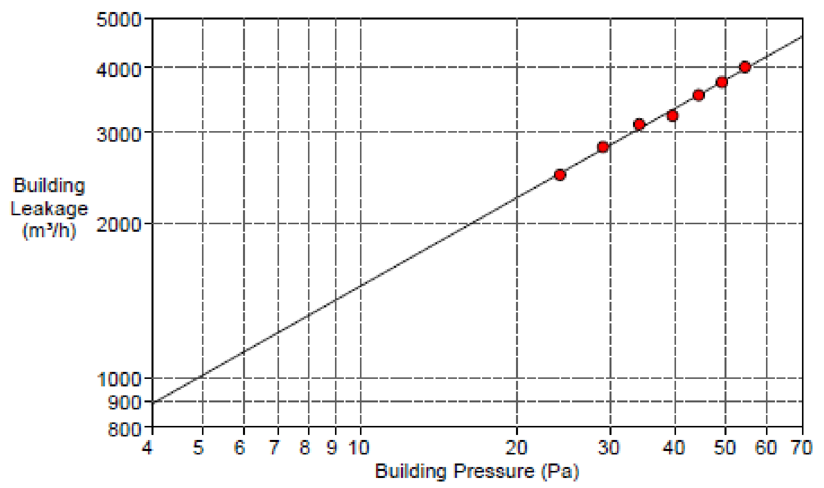
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	398.3	Air Leakage Coefficient (C_L):	399.8
Exponent (n):	0.58	Correlation Coefficient (r²):	0.9961

Test Information

		TS1 Leakage Area (m²):	0.189
Type of Test:	Depressurisation	Test Method:	B
Test Standard:	TS1	Regulation Complied With:	N/A



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Accreditation Body:	ATTMA	**Registration Number:**	0005

Client: Oxford Brookes Enterprises
Region: N/A
Address: Headington Campus, Gipsy Lane, Oxford, Oxfordshire, OX3 0BP
Telephone:
Facsimile:

Plot N°: 11
Developers Type: N/A
Development Name: 11 Malmesbury Gardens
Development Address: Lyndhurst Crescent, Park North, Swindon, Wiltshire, SN3 2SP

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	3811
Measured Air Permeability (m³/(h.m²)):	15.81	**Design Air Permeability (m³/(h.m²)):**	

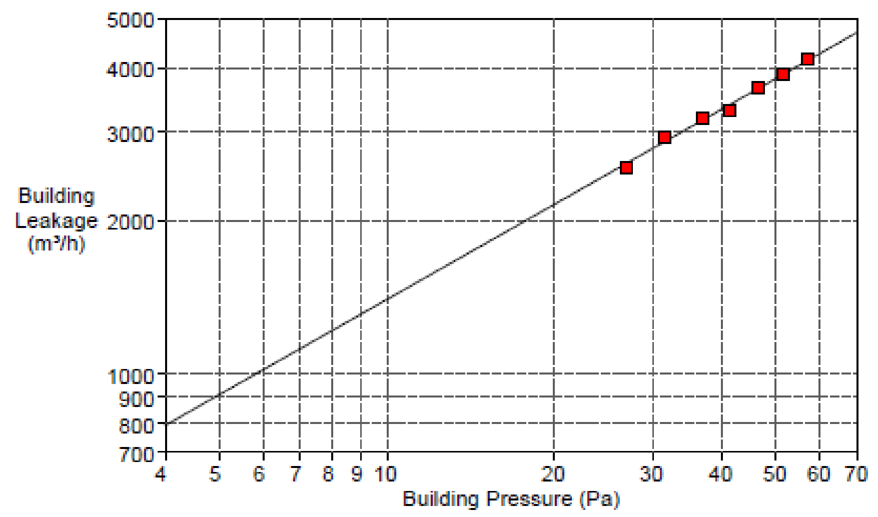
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	334.6	**Air Leakage Coefficient (C_L):**	334.0
Exponent (n):	0.62	**Correlation Coefficient (r²):**	0.9954

Test Information

		TS1 Leakage Area (m²):	0.190
Type of Test:	Pressurisation	**Test Method:**	B
Test Standard:	TS1	**Regulation Complied With:**	N/A



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Report N°: DAT-OXF01-NA001-LYN01-020714-PL11-T3N

Date:	02/07/2014	**Airtightness Engineer:**	C Knights
Accreditation Body:	ATTMA	**Registration Number:**	0005

Client: Oxford Brookes Enterprises
Region: N/A
Address: Headington Campus, Gipsy Lane, Oxford, Oxfordshire, OX3 0BP
Telephone:
Facsimile:

Plot N°: 11
Developers Type: N/A
Development Name: Malmesbury Gardens
Development Address: Lyndhurst Crescent, Park North, Swindon, Wiltshire, SN3 2SP

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	3976
Measured Air Permeability (m³/(h.m²)):	16.49	**Design Air Permeability (m³/(h.m²)):**	

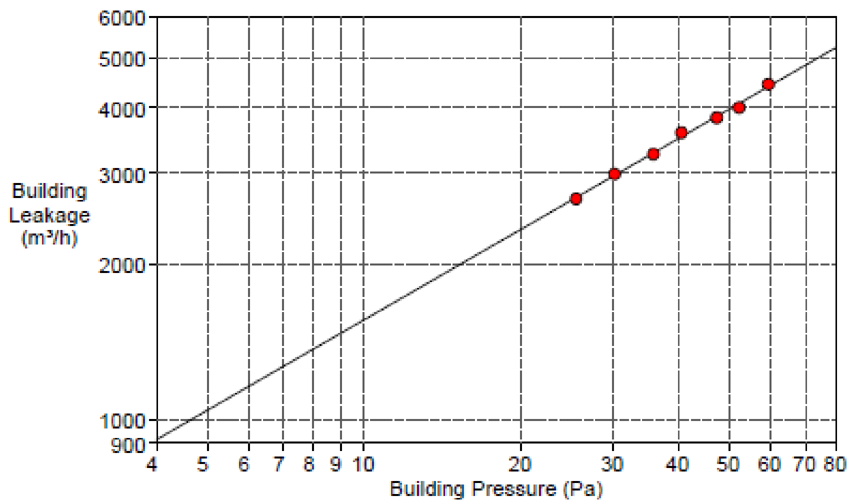
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	409.5	**Air Leakage Coefficient (C_L):**	407.6
Exponent (n):	0.58	**Correlation Coefficient (r²):**	0.9976

Test Information

		TS1 Leakage Area (m²):	0.198
Type of Test:	Depressurisation	**Test Method:**	B
Test Standard:	TS1	**Regulation Complied With:**	N/A



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Date:	02/07/2014	**Airtightness Engineer:**	C Knights
Accreditation Body:	ATTMA	**Registration Number:**	0005

Client:	Oxford Brookes Enterprises	**Plot N°:**	11
Region:	N/A	**Developers Type:**	N/A
Address:	Headington Campus Gipsy Lane Oxford Oxfordshire OX3 0BP	**Development Name:**	Malmesbury Gardens
		Development Address:	Lyndhurst Crescent Park North Swindon Wiltshire SN3 2SP
Telephone:			
Facsimile:			

Test Results at 50 Pascals

		Q_{50}: Airflow (m³/h):	3974
Measured Air Permeability (m³/(h.m²)):	16.48	**Design Air Permeability (m³/(h.m²)):**	

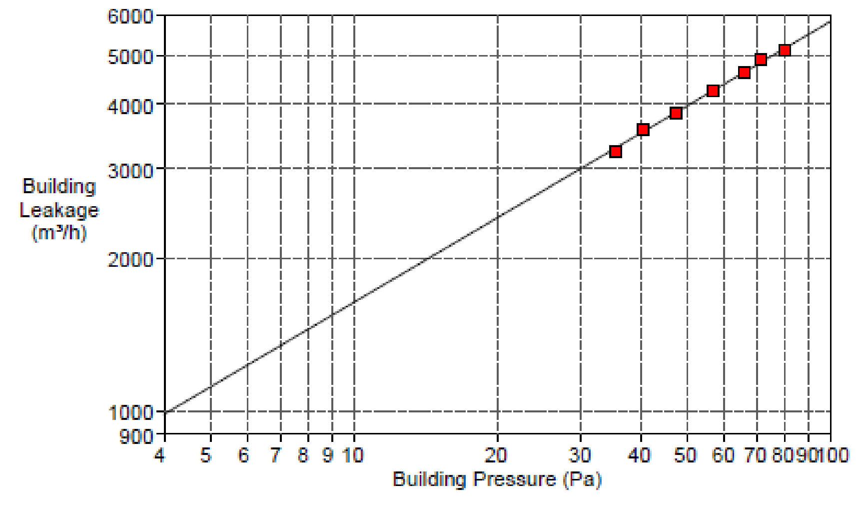
Did the dwelling achieve the required air permeability as specified in the SAP calculations?	

Building Leakage Curve

Air Flow Coefficient (C_{env}):	461.3	**Air Leakage Coefficient (C_L):**	458.1
Exponent (n):	0.55	**Correlation Coefficient (r²):**	0.9983

Test Information

		TS1 Leakage Area (m²):	0.198
Type of Test:	Pressurisation	**Test Method:**	B
Test Standard:	TS1	**Regulation Complied With:**	N/A



10.2 Interviews with occupants

Table 13 presents the views of the occupants of Houses 5 and 11.

Table 13 Interviews with occupants of Houses 5 and 11

	HOUSE 5	HOUSE 11
SATISFACTION		
Appearance, layout, liveability	• 'We are not satisfied with the appearance of the house. The painting is peeling off.' • 'We do not like the layout because of the open plan kitchen.' • 'The house is not very family friendly'.	• 'We are happy with the layout and design of the house: the openness, the big windows, the big spaces'. • 'The houses look nice from the outside'. • 'The house is very family friendly. The wide doors are good when using a baby buggy and the downstairs toilet s is good for a family house'. • 'Having the washing machine under the stairs is good as the noise does not disturb the people in the bedroom or the living room'.
Induction	• 'The induction process was not very good. There was only one group meeting held showing how it all worked and it was very rushed and things, like the PV panels, were not explained properly'.	• 'At the time we were satisfied until we realised that the information about how the solar panels and the electricity work was not clearly laid out and what we were told was not always accurate. Every other aspect went very well, we were shown everything and how things worked'. • 'It was not fully explained how to make full use of the systems.'
Home User Guide	• 'The Home User Guide is not very easy to understand'. • 'Not everything was explained. No guidance on how to operate the heat pump'. • 'It was too long and difficult to read.'	• 'It is quite helpful. It is laid out clearly'. • 'It is easy to read and understand'. • 'Some of the information provided in it was not completely accurate, for example the thermostat dial'.
Cleaning & Maintenance	• 'It is fine. No problem.'	• 'It is easy'.
Systems Understanding	• 'We do not understand how all the systems work, including the PVs and the heat pump'. • 'We do not know how to operate the MVHR system and did not know there is a boost button for it'. • 'We are confused about how to operate the heat pump and what setting to use during different seasons. 'Thermostats are not	• 'We do not fully understand how the PV panels and hot water works. Heating is straightforward and user input is little: occupants choose the temperature on the main dial upstairs and then choose the temperatures on the individual rooms'. • We use the boost button when extra ventilation is needed.

	very good because it takes long for the temperatures to settle'.	
OPERATION, COMFORT & CONTROL		
Heating performance	• 'Heating system takes too long to settle and reach comfortable temperatures'. • 'We are not satisfied with the room temperatures; either too hot or too cold'. • 'There are no temperatures on the controls; the masterstat goes from 1 to 9. We usually leave the masterstat at 5 depending on the weather and leave the room thermostats half way round. During summer room thermostats are left on halfway through and the main one at 3 or 4 now. When it is a hot day we turn it down to 1 and when it is a cold day turn it up to 5'.	• 'Generally satisfied with the room temperatures apart from a period when the heat pump had broken down and there was no heating in the living room. Then there was a period when the heat pump was out of balance and the room temperature was extremely high'. • 'The operation of the dial is not very clear as the user guide shows gives wrong information on how to operate it. There is one round dial in the living room, one in the kitchen, one in each bedroom. The corridors and bathrooms are controlled by the main dial'. • There is no temperature indication on the dial and occupants do not know what the numbers on the scale stand for. • Occupants change the settings seasonally. During summer the heating is turned off from the masterstat. During winter it is set on about 5.
Heating use & usability	• 'System responsiveness is very slow'. • 'The quality of the heat is good but can be too hot and stuffy at times'. • 'Even though there are enough thermostats around we do not feel we have enough control over heating as we do not really know how to use them properly'.	• 'It warms up quickly because it is set at a fixed value throughout winter. It cools down and heats up very quickly.' • 'The quality of heat is absolutely fine.' • Occupants feel they have enough control over heating and room temperatures, apart from that period when it was broken.
Renewables performance	• 'We do not understand how the PV panels perform'. • 'We are not aware of the PV performance and have not received any return from them yet'.	• 'We do not know how the renewable energy systems preform. No return shows up on their bill'.
Heating controls	• Occupants are not comfortable with using the thermostat to control the temperature. • 'We would prefer to have radiators to turn on and off'.	• 'Easy to use and understand.' • Occupants change the thermostats seasonally.
LIGHTING		
Day lighting	• Occupants are satisfied with the daylight in the house. •	• 'Day light is very good. The house has large windows.'
Electrical lighting	• 'Electrical lighting is fine'.	• 'It is effective'.

		• Occupants try to use as less electrical lighting as possible.
Lighting controls	• 'Lighting controls are easy to use'.	• 'Lighting controls are easy to use'.
WATER		
Water system performance	• Occupants find that the system performs well. • 'There is always hot water when it is needed and it is sufficient for our daily needs'. • 'Hot water temperature is good'. • The system is automatic; no user input is required. Occupants are not aware of the solar thermal panels.	• 'Water temperatures are good'. • 'There is an inhibitor in the bath, which is good for the kids'. • Heating up the water is automatic, no occupant input is required. • There is always hot water when it is needed and it is sufficient for occupant's daily needs.
ACOUSTICS		
Noise	• Occupants complain about lots of noise coming from the houses next door. • 'There is occasionally noise from the other rooms in the house'. • 'If the windows are shut there is no noise from outside'.	• 'We can sometimes hear the neighbours going up and down the stairs'. • 'When the windows are closed there is no noise from the outside'.
VENTILATION		
Ventilation patterns	• 'We open windows to ventilate the house'. • 'We leave the kitchen window open when cooking'. • During the summer we open the windows to get rid of excess heat; the hotter it is outside the more windows are opened. • 'The air quality in the house is good'.	• 'We use the MVHR system'. • 'It is easy to ventilate the house'. • 'The air quality is good even with the windows closed'. • 'During summer we keep doors and windows open to keep the temperatures down'. • 'During winter we open the windows only in the bathrooms and do not feel the need to open other windows to get fresh air'.
Ease of use and control of ventilation	• 'We control ventilation by opening windows'. • 'We never operate the MVHR system and are unaware of the boost button'.	• 'We understand how the MVHR performs and know how to use it'. • 'We do not use the control of the MVHR and never felt the need to use the boost'. • Occupants are confused about the purpose of the boost and believe it can also be used for extra hot water.
MVHR performance	• 'Fine. No problems with noise or draughts'.	• It is automatic, no occupant input required • 'Some noise from the MVHR'.
MVHR guidance and training	• Occupants feel that they did not receive sufficient guidance and training and guidance pointing out that 'None of the MVHR controls was shown during induction'	• Occupants feel that they did not receive sufficient guidance and training and guidance • Occupants admit that they 'never touch the system' and that they were advised not to.
MVHR control panel	• 'We did not know where the control panel for the MVHR was.'	• Occupants said that they never use it but find it easily accessible.

Operational issues	• No noise or draughts from the MVHR were reported. • Occupants never had a problem with the MVHR system, but do not know about its maintenance and wouldn't realise if it broke down. • 'We do not know about filter changing'. • 'We never tried to disable it.'	• Occupants complained that there is some noise from the heat pump and the vents. 'At night it can be quite noisy and especially in the bedrooms.' • Occupants complained that the MVHR can cause draughts when on boost mode. • 'The MVHR can create a pleasant effect during summer'. • 'We never tried to disable it'.
MAINTENANCE		
Breakdowns	• 'There have been many times that the heat pump broke down.' Occupants reported that the council is not fully able to sort those problems out as there is a lack of knowledge on low carbon technologies. • 'The hot water tank had an overflow problem and there was boiling hot water coming down from the drain overflow pipe.' Occupants are not fully aware of what the problem was but reported that one of the hot water settings was wrong. It took the council very long to figure out the problem and resolve it. The hot water cupboard was locked and the occupants did not have immediate access to the space. Leakage was spread through the ceiling and into the bathroom.	• According to the occupants there have been several breakdowns and faults. • 'One year ago there was a leak from the heat pump as the overflow was not properly commissioned'. • There was a leak from the boiler when the occupants had first moved in. They reported that hot water settings were not correct and there was not enough hot water. This was problematic in al houses and in half of them the hot water tanks had to be taken out of the cupboards for the technician to gain access to the system and change the settings. After that was done the hot water tank was put back in place but was not connected properly causing a leak. Also, the technician accidentally they had disconnected the solar panels. This was discovered six months later by the occupants. • This year, the heat pump broke down for two months during winter and there was no heating in the living room. The occupants did not report the problem immediately. It took the council a lot of time to repair the problem. • After the pump was fixed it was underperforming but the person who went to the house to take a look could not find any problem. The pump is still underperforming and the occupants are paying high electricity bills.
Help service	• 'We have to call Swindon council but it takes time for the council to sort the problem out'.	• Occupants can call Swindon council but are very displeased with the help service. • According to the occupants the

		responsiveness of the council is very slow and in some occasions the technicians do not show up. • Occupants reported that sometimes the wrong people are sent out to the house or people who lack technical knowledge required for repairing the heat pump and the other low carbon technologies. • 'Standard damages get repaired easily but this is not the case when it comes to solar panels or the heat pump.'
ENERGY MANAGEMENT		
Energy & water consumption	• 'Both water and electricity bills are high'. • Occupants are paying £120 per month for electricity. • Occupants are not particularly careful with water consumption. • 'We do not get any info on PV generation'.	• Occupants are satisfied with water bills, paying only 11£/month. • They are very conscious of their water consumption. • 'Electricity bills are very high.'
FLEXIIBLITY & SPACE		
Space flexibility	• 'Space is fine and it accommodates our needs.'	• 'It is quite flexible. Doors and corridors are quite wide and the rooms are wide and square.'
Space size	• 'Space is fine and it accommodates our needs.'	• 'Room spaces are very generous.'
Storage	• 'Storage space is not satisfactory at all'.	• Occupants are satisfied with storage space. • 'Big space in the attic that we use as storage space'. • 'We make use of the bike-shed, bin cupboard and garden shed to store many things outside'.
Room function	• 'Most rooms are appropriate for their function except the downstairs shower room that cannot be used for shower as the floor level is wrong and the water flows out.' • 'The open plan kitchen is not good.'	• 'Most rooms are appropriate for their function except apart from the shower downstairs that we cannot use as a shower because the floor is not levelled'.
Future needs	• Occupants are not sure if the house would be suitable for their future needs.	• 'It could easily be used by a disabled person with the wide doors and ground floor toilet'. • 'It can be expanded to a three bed if the family expands so we wouldn't have to move out'.
GENERAL		
Best aspects	• House within walking distance from the school.	• Good design and layout. • Good daylight, large windows • Large spaces.

Worst aspects	• The open plan kitchen. • The heat pumps not performing well.	• The high electricity bills.