# Tigh-Na-Cladach affordable housing

**Phase 2 study**
In-use and post-occupancy

This document contains a Building Performance Evaluation report from the £8 million Building Performance Evaluation research programme funded by the Department of Business Innovation and Skills between 2010 and 2015. The report was originally published by InnovateUK and made available for public use via the building data exchange website hosted by InnovateUK until 2019. This website is now hosting the BPE reports as a research archive. Although no support or further information on the reports is available from the host, further information may be available from the original InnovateUK project evaluator using the link below[1].

| | |
|---|---|
| **InnovateUK project number** | 450081 |
| **Project author** | Glasgow School of Art, Mackintosh Environmental Architecture Research Unit (MEARU) |
| **Report date** | 2015 |
| **[1]InnovateUK Evaluator** | N/A |

| No of dwellings | Location | Types | Constructed |
|---|---|---|---|
| Three | Dunoon | Semi-detached | 2010 |

| Areas | Construction form | Space heating targets | Certification levels |
|---|---|---|---|
| Low energy: 110 $m^2$<br>PassivHaus: 95 $m^2$ | Timber frame | See Table 7.3, p.86 | Scottish *Building Regulations* and PassivHaus |

### Background to evaluation

The Tigh-Na-Cladach (Gaelic meaning 'Houses by the Shore') development is located one mile south of the town of Dunoon in the Scottish county of Argyll and Bute. The BPE project studied one PassivHaus home and two low-energy homes. The Tigh-Na-Cladach dwellings performed significantly better than the UK average and approached best practice. The PassivHaus dwelling was the first in Scotland at the time.

| Design energy assessment | In-use energy assessment | Sub-system breakdown |
|---|---|---|
| Yes | Yes (See p.86 for detail) | Yes |

Air-tightness was found to far exceed the *Building Regulations*/design stage targets of 10 $m^3$ ($m^2$.h) for the low energy dwellings. The PassivHaus dwelling was just under the PassivHaus target of 0.6 $m^3$ ($m^2$.h) and slightly over the design target of 0.5 $m^3$ ($m^2$.h). Significant problems were found with mechanical ventilation with heat recovery systems (MVHR) and the air-to-air source heat pumps (AASHP), which had to be corrected and/or replaced. Energy consumption varied significantly across the dwellings, mainly as a function of user behaviour. The heat pump in the PassivHaus dwelling was found to achieve an average COP of 3.49 in heating mode. The COP quoted by the manufacturer was 4.0. In Scottish weather, a supplementary heat source may be required to meet thermal comfort needs.

| Occupant survey type | Survey sample | Structured interview |
|---|---|---|
| BUS domestic | See report | Yes |

As-designed aspects of the affordable low-energy homes were, on the whole, achieved. The health design intended by the architects was considered successful on the basis that there were no negative health issues noted in survey scores or comments. The PassivHaus had a number of problems post-occupancy and these were reflected in BUS responses. (Students and researchers: see additional notes on Pages 10 and 55 relating to BUS survey data interpretation.) Occupant diaries were maintained across all surveyed dwellings.

# Contents

# List of Tables

## List of Figures

# Acronyms

| | |
|---|---|
| **AASHP** | Air to Air Source Heat Pump |
| **ACH** | Air Changes per Hour |
| **ATTMA** | Air Tightness Testing and Measurement Association |
| **BPE** | Building Performance Evaluation |
| **GSA** | Glasgow School of Art |
| **ESRU** | Energy Systems Research Unit (University of Strathclyde) |
| **HA** | Housing Association |
| **HFP** | Heat Flux Plate |
| **LCH** | Low Carbon Homes |
| **MEARU** | Mackintosh Environmental Architecture Research Unit |
| **MVHR** | Mechanical Ventilation and Heat Recovery |
| **NHBC** | National House Building Council |
| **PH** | PassivHaus |
| **PoE** | Post Occupancy Evaluation |
| **SPHC** | Scottish Passive House Centre |
| **STS** | Solar Thermal System |

# 1. Introduction and overview

## 1.1. Tigh-Na-Cladach

The Tigh-Na-Cladach (*Gaelic meaning 'Houses by the Shore'*) development is located one mile south of the town of Dunoon in the Scottish county of Argyll and Bute (Figure 1.2). The land was purchased from Argyll and Bute Council in 2007, and developed into an affordable, low energy housing scheme by Fyne Initiatives Ltd, the commercial subsidiary of the Argyll based Fyne Homes Housing Association. An Aberdeen based G. Deveci, Chartered architect designed it and the contractors were locally based. The Scottish Passive House Centre (SPHC) provided consultation during the construction process and certification for one of the dwellings for the PassivHaus Standard after completion on the site. This Chapter outlines the project; project team; the project context; and summarises the overall findings. Table 1.1 summarises the key facts and features, figures, and findings of study.

**Table 1.1:** Summary of Key Features, Facts, Figures, and Findings.

| | **House Type A (TA1 and TA2)** **Code for Sustainable Homes – Level 4** | | | **House Type B (TB1)** **PassivHaus home** | | |
|---|---|---|---|---|---|---|
| **Treated floor area** | Each 110m² | | | 95m² | | |
| **Construction** | Timber frame | | | Timber frame | | |
| **In-situ U-values in W/(m²K)** | **Element** | **Design** | **Actual** | **Element** | **Design** | **Actual** |
| | Ext. walls | 0.13/0.18 | 0.13 | Ext. walls | 0.09 | 0.10 |
| | Pitched Roof | 0.13 | 0.15 | Pitched Roof | 0.09 | 0.13 |
| **Ventilation** | Window/door/trickle vent opening | | | MVHR with 91% efficiency. | | |
| **Heating** | No mains gas. Electric heaters (In 2014, householders in TA2 changed to under-floor heating in the living/kitchen) | | | No mains gas. An air-to-air heat pump heats hall and kitchen. Heat distributed via MVHR unit | | |
| **Domestic Hot Water** | Electric | | | Solar thermal collectors, 300-l-buffer with electrical immersion heater | | |
| **Air Permeability ($m^3(h/m^2)$ @50Pa** | First test: TA1 = 4.035 and TA2= 4.290 Second test: TA1 = 2.98 and TA2 = 3.36 | | | First test: 0.955 Second test: 0.58 | | |
| **SAP Energy Efficiency Rating** | 76C | | | 80C | | |
| **SAP $CO_2$ Rating** | 71C | | | 84B | | |
| **Number of Occupants** | TA1 = 5 | TA2 = 3 | | 2 | | |
| **Occupancy patterns** | Occupied typically 24hrs. 3 occupants away during the day during term time weekdays; and 2 occupants in weekday and weekend days and nights | Shift workers who alternate day and night so 24hr occupancy weekdays and weekends | | Both occupants away during the day weekdays ; and in day and night during weekends | | |

## Key findings from overall BPE study and process

- Based on the awards it received, Tigh-Na-Cladach was ranked highly in comparison with other domestic building developments in the UK as at 2010 and 2011. Based on the BPE findings on the energy performance presented in Chapter 7, Tigh-Na-Cladach performs significantly better than UK average; and approached best practice.

- There were significant problems in TB1 with the installations of the MVHR, SHW and AASHP, which had to be corrected and/or replaced at the inconvenience and dissatisfaction of the occupants and the developer. Findings from BPE of the before and after the remedial/replacement works showed that all the systems operated far better than originally installed/commissioned in 2011.

- The developer cited these problems; the installers (SPHC) not providing adequate information regarding the remedial works; and the delivery team not taking responsibility; as reasons to not install MVHR and AASHP systems in their current and future projects until there is confidence in them in the market.

- The developer pointed out that it is important to be careful about promising occupants/buyers how well their dwellings will perform unless there is a proven performance through bills/monitoring. There was a clear gap in TB1 between the performance they expected and the delivered performance; and although the remedial works resulted in good performance; the initial dissatisfaction with the systems seems to have resulted in discouraging impact on how they view the overall performance.

- The delivery of the development was considered a success, coming in on time and on budget. Both the architect and contractor felt that the procurement and contractual process had been exceptional. There were very few problems, most of which had been solved in advance. Problems on site were as a result of budget cuts; external groups; and teething-problems with the AASHP and MVHR, which were linked with a learning curve, as the PassivHaus was the first in Scotland at the time. The developer, Fyne Homes, pointed out that the outcome of the Passivhaus did not go as originally thought.

- Except for known reasons in dwellings TA2 and TB1, Air permeability results for the two (three in TA1) tests remained close to stable over time suggesting that the means of achieving air-tightness are robust. The second tests of air pressure towards the end of the BPE project were slightly better than the first tests

- Air-tightness was found to far exceed the building regulations/design stage target of $10m^3/h/m^2$ for dwellings TA1 and TA2. It was just under the PassivHaus target of $0.6m^3/h/m^2$ and slightly over the design target of $0.5m^3/h/m^2$ for TB1.

- The achieved level of air-tightness in TA1 and TA2, under current Technical Standards, would suggest that a whole house mechanical ventilation system would be required (if pressure is less than $5m^3(h/m^2)$ @50Pa) to provide good IAQ and that the current strategy (using background ventilators) is insufficient.

- The general quality of the construction appears to be thermally robust with limited weaknesses identified.

- The wall construction in House Type A was found to achieve an in-situ U-value of $0.13W/m^2K$, which compares well to the design value of $0.13W/m^2K$. House Type B was found to achieve an in-situ U-value of $0.12W/m^2K$, which compares well to the design value of $0.13W/m^2K$. The respective measured values for the roofs were slightly higher (worse) than the design values.

- From the BUS, occupant interviews and other occupant feedback:

1. On the whole, they all liked their homes: The location was favourable –the views in particular. However, the road in-between the dwellings and the sea was considered a negative. The layout on the whole was popular. However, two respondents would prefer not to live in open plan again; and preferred a separate kitchen. A number of occupants with first floor dwellings would prefer garden access, although several enjoyed the terrace access.
2. As designed aspects of affordable, good quality, low-energy homes were on the whole, achieved.
3. The health design intended by the architects could perhaps be considered successful on the basis that there were no negative health impacts noted in the data or comments.
4. The PassivHaus had a number of problems post-occupancy; and these are reflected by the BUS occupant comments. However, caution should perhaps be exercised with feedback, as it may have been influenced by discussions surrounding the problems encountered and subsequent repairs.

- The following problems identified from the data analysis may suggest problems with the BUS survey method rather than the environment and the homes themselves.
  1. Still air was perceived as a problem in the two house types, winter and summer – rating red diamond. It is not clear if this is a method issue; or respondents' misunderstanding of the question.
  2. Natural light in both house types rated poorer than the benchmark and scale midpoint, red diamond, on the basis that they were more towards the 'too much' end of the scale
  3. Noise is perceived as a problem in both house types, on the basis that there is 'too little noise'.

- The HW system currently achieves 36% of its *HW* contribution via solar thermal. A previous study by ESRU in early 2011; one year after the building was opened; concluded that 40% annual contribution from solar irradiance would be a more realistic system target. Switching the control logic can raise the current summer contribution of 43% to approximately 71%.

- The *MVHR* system meets the *PHI* criteria by recovering heat with an average monitored temperature transfer efficiency of 85%; consuming a low level of electricity. It is therefore operating above the *PHPP* outlined minimum of 75%; but slightly below the manufacturer's quoted 92%.

- The testing indicated that the heat pump can achieve an average COP of 3.49 in heating mode – the COP quoted by the manufacturer (Mitsubishi) is 4.0. In very low Scottish weather, a supplementary heat source may be required to meet thermal comfort needs.

- Discrepancies between the actual performances of the dwellings compared with SAP values suggested that SAP is not suitable for making such predictions. The discrepancy in SAP rating for TA1 and TA2 versus TB1 highlights areas of potential further investigation with regards to the SAP methodology use on PassivHaus

- Energy consumption varied significantly across the dwellings; mainly as a function of user behaviour.

- Internal temperatures varied significantly across dwellings and this can also be linked with user behaviour.

- $CO_2$ concentrations in the dwellings were generally within the recommended levels, but can get overly high, particularly so during the heating season and in bedrooms.

- Internal RH% was typically within recommended levels

- Regarding BPE monitoring kit,
  1. Building designers should design in monitoring or anticipation of post occupancy monitoring and/or integration of monitoring kit design into that of the building space and the M&E systems.

2. Kit should be selected to meet the nature of monitoring and flexibility when monitoring is underway.
3. Calibration and accuracy of sensors should be considered early to ensure good performance.
4. Installation and commissioning should be by a qualified person and done as specified and designed.
5. Verify data early to ensure capture, transmission, and storage of valid and accurate data.
6. Consider the impact on the occupants to ensure it is not obtrusive or in inconveniencing locations; and that access for checks and recalibration is easy and of minimal disruption to occupants.
7. Locate sensors to best represent the monitored space, and minimise resident interference.
8. Facilitate alerts to be sent should data sensing or logging fail.
9. Minimise the risk of data loss through signal failure by adequate time lag between local storage and remote transmission.
10. Good rapport and communication with the residents is essential so that access is easy when needed.
11. Engage and consider householders throughout to ensure their continuing active participation.

**Figure 1.1:** General eastwards view of the development - car park to the west and sea front to the east.

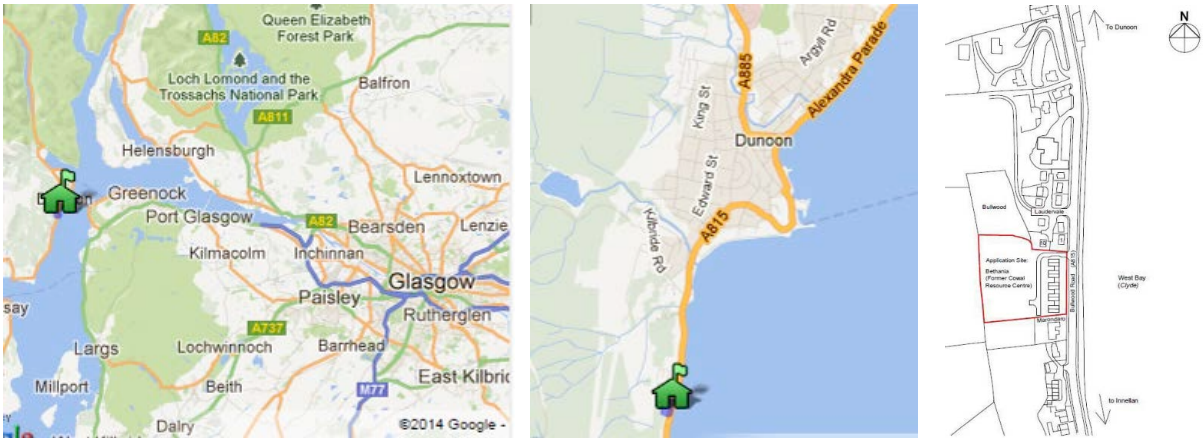



**Figure 1.2:** Location map and site orientation in relation to Clyde Peninsula, Dunoon town: and the neighbourhood.

The contractor went to site in 2009 and the project was completed on 5th April 2010 in one phase, on time and to budget. The Defects liability period ended in April 2011. The client's aims were to develop affordable, good quality and low-energy family houses in a mix of one, two and three bedroom dwellings. The development comprises of 15 dwellings **(Figure 1.3 and Figure 1.4)**. These include one low-energy dwelling which is a meeting place for the local Bullwood community group; thirteen low-energy dwellings; and one PassivHaus Standard dwelling. There are four single storey 1-bedroom units (each 51m²); four single storey 2-bedroom units (each

65m²); the 2-bedroom double storey Passivhaus (104m²); and four double storey 3-bedroom units (each 120m²).

The long site layout **(Figure 1.3)** was significantly influenced by, and evolved in response to topography and the seafront; and is in harmony with neighbouring housing developments along the sea front. The diversity of dwellings (one, two and three bedroom units) in the development, and their overall sizes do, however, not follow in the tradition of large homes in the neighbourhood, since the development targeted the affordable sector. The orientation of the buildings and internal layout is designed to optimise natural light and energy efficiency **(Figure 1.6)**. The design orientation and layout will be discussed further in **Section 2.2 and section 2.4** under **Design intent.**


**Figure 1.3:** Site plan: the selected dwellings for the TSB BPE project are shaded.

**Figure 1.4:** Section through the entire development.

**Figure 1.5:** View towards steep slope to the west of the development. The gable end windows shown are for the Living rooms and kitchens located on the ground floors and bedrooms on the first floors – all facing the sea.

Based on the awards it received, Tigh-Na-Cladach was ranked highly in comparison with other domestic building developments in the UK as at 2010 and 2011. The low-energy homes achieved a Level 4 rating of the UK's Code for Sustainable Homes. The PassivHaus dwelling was the first social 'affordable' home in the UK and the first social housing developer home in Scotland to achieve full official PassivHaus Standard certification by the German PassivHaus Institute. The development has received the following awards:

i. RIBA Award 2011;
ii. Scottish Design Awards 2011 – Architecture Grand Prix and Affordable Housing Award;
iii. Sustainable Design Award;
iv. Finalist at the RIAS Andrew Doolan Award 2010;
v. Commendation at the Saltire Housing Design Awards 2010.

## 1.2. The BPE Project

The BPE project focused on three of the 14 dwellings - two low-energy houses (TA1 and TA2) and one PassivHaus (TB1). All the residents from these dwellings kindly participated in this two-year study. The three dwellings are the ones shaded in **Figure 1.3;** and the monitored rooms in each dwelling are the ones shaded in **Figure 1.6.**

The BPE study included the following objectives:

1. Evaluation of the relationships between design intentions and delivered dwellings; and between predictions and actual performance;
2. Evaluation of the impacts of the procurement process;
3. Monitoring of the indoor environmental performance, external environments, and energy performance;
4. Evaluation of the performance of the fabric, mechanical systems, low and renewable energy technologies;
5. Evaluation of the role of occupant factors:
    a. Surveys on users' experiences, user comfort, and perceptions of the design;

   b. Surveys and observations regarding occupancy, and occupant actions, including: patterns of window opening and MVHR switching by users;
   c. Assessment of impacts of user actions on heating, lighting; MVHR, air quality and energy performance.
6. Further occupant engagement in the form of user diaries and the testing of an improved Quickstart Guide for occupants;
7. Consideration of whether a cultural change is required if the Passivhaus Standard and UK's Zero Energy Standard are to be effective for UK homes in general; and for the affordable sector in particular.

These objectives were met through:

1. Walkthroughs with the delivery team and with occupants (Objectives 1 and 2) ;
2. Evaluation of drawings and evaluation of design and as-built SAPS (Objective 1);
3. Photographic surveys (Objective 1);
4. Occupant feedback through BUS and occupant surveys, interviews and general communication with occupants during visits, email and phone conversations (Objectives 1, 3, 5, 6, 7);
5. Installation of different types of kit to monitor internal and external environments, energy, window opening patterns, particulate matter, air pressure, U-values, and sound levels (Objective 3);
6. Installation of kit to assess the performance of mechanical systems (Objective 4)

House Type A: 3 Bedroom (four dwellings)


| Room | Metric |
|---|---|
| Ground Floor | |
| Kitchen | 3100 x 4500 |
| Living Room / Dining | 3950 x 5200 |
| Bedroom 01 | 3950 x 3300 |
| First Floor | |
| Bedroom 02 | 3950 x 3300 |
| Bedroom 03 | 3950 x 3600 |

House Type B: 2 Bedroom (one dwelling)


| Room | Metric |
|---|---|
| Ground Floor | |
| Kitchen | 3950 x 3300 |
| Living Room / Dining | 3950 x 5200 |
| First Floor | |
| Bedroom 01 | 3950 x 3300 |
| Bedroom 02 | 3950 x 3600 |

**Figure 1.6:** Floor plans with monitored rooms shaded. a) House Type A (TA1 and TA2): Low-Carbon Homes, Code for Sustainable Homes, Level 4; and b) House Type B (TB1): PassivHaus Standard home.

## 1.3. Development in a Wider Context

The wider area can experience severe weather conditions at any time of the year. The mean min. monthly temperature is 3 deg. C in January and mean max. is 15 deg. C in July. RH% is more than 60% most of the year. The average wind speed is 5 m/s, almost even throughout the year, and predominantly SW.

In Scotland, timber frame construction is commonplace, and on this development all the dwellings are timber frame construction; only that it had to be developed to satisfy the Code for Sustainable Homes – Level 4 and PassivHaus standards. There is typically less money available in the affordable housing construction sector in Scotland and this influenced the design features. In turn, the innovative nature of this being the first affordable PassivHaus in the UK with a direct comparison with low energy homes, provides an excellent case study for the development of similar homes across Scotland, and in the wider context of other TSB projects too.

## 1.4. Project Team

| | |
|---|---|
| **Mackintosh Environmental Research Unit (MEARU)** | Based at the Mackintosh School of Architecture in Glasgow, MEARU was the project lead, and undertook testing, surveys, environmental and energy monitoring; analysis, and reporting. |
| **G Deveci, Chartered architect** | The project architect helped with information on the design and design/construction process and intent |
| **Fyne Initiatives Ltd** | Provided Developer information and communication with householders |
| **ESRU, University of Strathclyde** | ESRU worked with MEARU in testing the Solar Thermal System, Air Source Heat Pump, and MVHR system and air quality monitoring |
| **Scottish Passivhaus Centre** (No longer exists at the time of completion of this report). | Provided information on the Passivhaus accreditations process. Worked with MEARU in the First round of Air pressure tests |

**Table 1.2:** The BPE project team.

## 1.5. Key Findings and Conclusions for this section

Based on the awards it received, Tigh-Na-Cladach ranks very highly in comparison with other domestic building developments in the UK. Its procurement went smoothly and the construction was delivered on time and to budget – resulting in a major achievement for a social housing development. The resultant layout and massing was significantly influenced by the local topography. The development provided opportunities to concurrently study and compare the performance of:

1. Three homes on one site with similar architectural design, orientation, topography and climatic conditions.

2. Homes with different specifications for energy and carbon standards - 'Code for Sustainable Homes – Code level 4' versus 'PassivHaus'

3. Two similar homes, constructed to the same energy standard, but differing occupancy numbers/patterns.

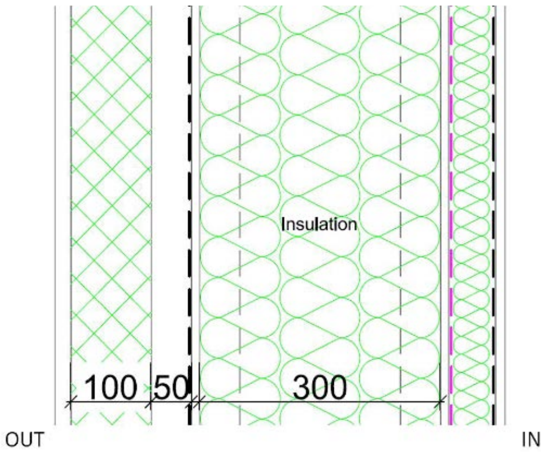
The sections in the following chapter discuss the detailed characteristics of the dwellings.

# 2. About the building: design and construction audit, drawings and SAP calculation review, and delivery team interviews

## 2.1 Design and construction audit

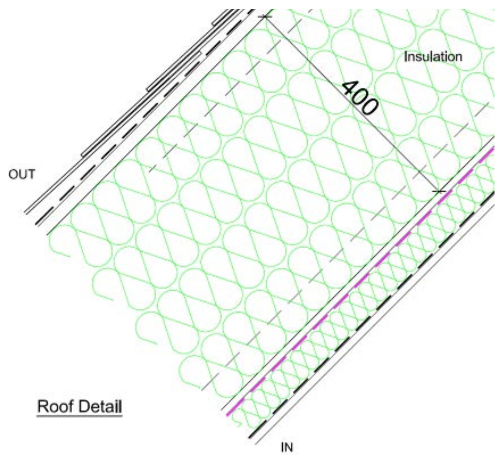
The construction audit of the houses included a review of as-designed and as built drawings; completion of standard characteristics forms; and seeking clarifications from the design and construction teams. The construction details, specifications and U-values for the wall, roof and floor elements are shown in **Figure 2.1, Figure 2.2 and Figure** 2.3. The construction details for both house types only differ in wall and roof insulation thickness. For more information please refer to **Table 2.1:** Similarities and differences between House Types A and B.

The external fabric elements were specified to meet requirements of the Scottish building regulations in operation in 2007. The external and internal walls, roof, floors, and glazing for compliance of the Scottish Building Regulations - Section 6.




External Wall Construction:
12.5mm plasterboard with vapour control layer, screw fixed, tape & filled.
50mm thk o/a Kingspan Thermawall TW55 insulation (thermal conductivity 0.022 W/mK)
Proctor Reflectatherm Internal Air Membrane / VC barrier, taped and sealed.
9mm OSB3 internal sheathing
300mm thk o/a Owens Corning Mineral Wool Insulation, fitted tightly between studs.
JJI 300mm deep o/a timber 'I' Studs at 600mm ctrs.
9mm OSB3 external sheathing
Proctor Reflectashield breather wall membrane, taped and sealed
50mm ventilated cavity and stainless steel wall ties
100mm thk 1500 kg/m3 to be min 7.3 KN/mm2 to BS 6073 concrete blockwork
20mm Sto Render Flex Cote System

**Figure 2.1:** House Type A: external wall detail and construction specification.




Roof Construction:
Roofing Slate (Type TBC), copper fixings
'Tyvek' breather membrane
22x150mm treated kiln dried pine sarking boards to BS 1297.
400mm deep o/a timber 'I' rafters at max 600mm ctrs
400mm thk o/a Owens Corning Mineral Wool Insulation, fitted tightly between rafters
9mm OSB3 Internal sheathing
Proctor Reflectatherm internal Air Membrane / VC barrier, taped and sealed.
50mm thk o/a Kingspan Thermawall TP10 insulation (thermal conductivity 0.022 W/mK)
12.5mm plasterboard with vapour control layer, screw fixed, tape & filled.

**Figure 2.2:** Roof detail and construction specification.

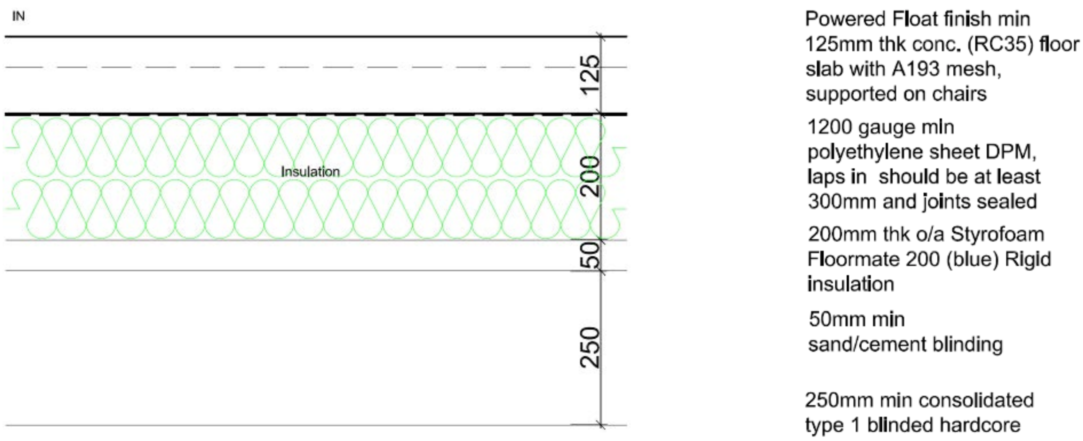



**Figure 2.3:** Ground floor detail and construction specification.

**Figure 2.4:** PassivHaus on the right of image has thicker layer of roof insulation (grey).

**Figure 2.5:** PassivWall closed panel timber system by RTC Timber Systems.

**Figure 2.6:** PassivWall closed panel timber system by RTC Timber Systems.

The dwelling characteristics forms contain details of the 'as designed' SAP information and 'as constructed measurements', including: fabric characteristics; occupancy; room numbers, areas and volumes; energy; ventilation approach; installed mechanical systems and controls. A separate form for each dwelling was completed, and these are in **1**. These comprise the major part of the construction audit. A construction review in **Appendix 2.3** lists the elements that had snagging issues and changes that were made during construction, early occupation, and recently.

## 2.2. Development

As outlined in Chapter 1, the design brief specified the development of low energy affordable homes. This section shows key aspects of the development, in particular the differences between house types A and B.

The architect, G. Deveci, was approached to design the houses due to previous experience in very low energy work with Fyne Homes. The architect embraced passive and low energy design principles, in terms of orientation, materials and consideration of occupant well-being. At the outset of the project, the architect undertook a community consultation. Three options were offered to the community – they chose the one that was built. The architect felt that, as it was a sensitive and important site locally, it was important to ensure the general acceptance of the development by the local community. The design considerations and relationships with its context are as follows:

**The design respects, the landscape setting, and the traditional building patterns of the locality:**

1. A special effort was made to ensure that the architectural form and proportions were in harmony with the essence of Scottish vernacular architecture.

2. The overall design follows the traditional built form of the arrangement of fishing villages. The architect took his inspiration from Brighton Beach Huts with their terraced arrangement along the shoreline. Although white render finish is the most common tradition, there are many examples in coastal areas where contrasting colours, as employed in the project, are used to add a strong sense of place and vitality.

3. Construction: the buildings are of timber framed construction, finished externally in mainly smooth render, coloured in a range of pastel colours so that each home is identifiable, with small areas of untreated larch. StoRend Cote, the chosen render system, is weather resistant and cost effective. It is coated with StoLotusan to prevent moss from growing on the building.

**The immediate context and specific site conditions influenced the design:**

1. The orientation of the gables to face the estuary helps to reduce weather exposure and prevailing winds, and enable windows to be orientated to maximise natural lighting.

2. The massing arrangement creates a two storey 'street of double gables' with a gap between to accommodate south facing one bedroom units with exclusive use of roof gardens.

**Inspirational ideas for sustainable, creative and innovative design:**

1. The scheme demonstrates key characteristics of good contemporary architecture i.e. it is distinctive, which is one of the '6 qualities of successful places' that appear in the Scottish Government 'Designing Places' guide (http://www.scotland.gov.uk/resource/doc/212607/0099824.pdf [Accessed: 30.10.14]).

2. The project innovatively manages to accommodate one, two and three bed units with private garden spaces within the same block form.

The dwellings in the study are described and compared in **Table 2.1**. Photographic surveys of each dwelling are in **Appendix 2.4**.

| **Characteristic** | **House Type A** | **House Type B** |
|---|---|---|
| *Layout and Type* | | |
| **Floor Area** (Based on SAP) | 120m$^2$ | 104m$^2$ |
| **Bedrooms** | 3 | 2 |
| **Type** | Semi-detached | Semi-detached |
| **Orientation** | East - West | East - West |
| **Floor Plan** | 'L' – Shaped, open plan living and kitchen spaces | Rectangular, separate living and kitchen spaces. Entrance porch. |
| **Roof** | Pitched, gable end | Pitched, gable end |
| **Ground floor ceiling heights** | 2.4 – 2.6m | 2.6m |
| **First floor ceiling heights** | Double height, pitched ceiling at 45° | Double height, pitched ceiling at 45° |
| ***Heating*** | | |
| **Heating** | Electric Storage Heaters | No conventional heating system. MVHR, AASHP |
| **Water Heating** | Electric water heating | Solar Thermal System plus electric |
| ***Construction*** | | |
| **Overall System** | Prefabricated Closed Panel Timber Frame System (RTC PassivWall) specifically developed to Passivhaus levels. Prefabricated floor, wall, and roof cassettes which were super pre-insulated with 80% recycled-content glasswool; and draught proofing | Prefabricated Closed Panel Timber Frame System (RTC PassivWall) specifically developed to Passivhaus levels. Prefabricated floor, wall, and roof cassettes which were super pre-insulated with 80% recycled-content glasswool; and draught proofing |
| **Wall Insulation** | 300mm | 350mm |
| **Floor Insulation** | 160mm | 160mm |
| **Roof Insulation** | 300mm | 350mm |
| **Windows and Doors** | Nordan N-Tech 1.0 Triple Glazed 'Internorm' with insulated frames | Nordan N-Tech 1.0 Triple Glazed 'Internorm' with insulated frames |
| **Velux Windows** | Velux Triple Glazed GGL 3065 | Velux Triple Glazed GGL 3065 |
| **Linear thermal transmittance** | Effect of thermal bridges = 0.0800 x total area = 19.35 W/K | Effect of thermal bridges = 0.0800 x total area = 21 .72 W/K |

**Table 2.1:** Similarities and differences between House Types A and B.

**Project strengths and challenges:**

In the briefing, design and construction stages, the project benefited from some strengths, but also experienced some challenges to achieving low carbon targets:

**Strengths:**

(a) From the outset, there was an ambition to provide low energy homes and there were no barriers related to the lack of motivation for very low carbon dwellings. The developer set the brief for low-energy, affordable homes of high quality to demonstrate that dwellings of high standard could be achieved with the tight budgets available to the affordable housing sector.

(b) In the context of skills and knowledge, the architect had long standing experience and knowledge in low carbon housing gained from practice-based research and design of low carbon and low energy housing.

(c) The contractor was a long established building contractor based locally in Dunoon, Argyllshire; and for many decades had worked with private clients of residential homes and the public sector in delivering high quality social housing projects; and on substantial commercial projects.

(d) For TB1, the developer was clear on achieving Passivhaus standard, and sought direct support from the Scottish Passive House Centre with the house systems, particularly MVHR.

(e) The energy efficiency and low running costs were a particular selling point for the properties.

**Challenges:**

(a) Although some of the chosen technologies and products were available in Scotland, others had to be imported. The chosen Prefabricated Closed Panel Timber Frame System (RTC PassivWall) with prefabricated floor, wall, and roof cassettes was from 'RTC Timber' in Elgin, Scotland, quite a distance from the site. A distributor based in Fife supplied both the triple glazed and insulated framed 'Internorm' windows from Austria; and the PassivHaus certified 'Paul thermos 200DC' MVHR from Germany.

(b) The aim for very airtight homes (air tightness below n50=1/h) was a challenge for a timber frame building.

(c) There was no mains gas on the site, and electric heating and DHW had to be put in.

(d) Regarding cost and perceived cost, the challenge was to provide quality, affordable homes. Affordable housing meant there was less money to be spent compared to a standard house, achieving a PassivHaus was therefore unique in the sense of being in the affordable sector.

(e) Unfavourable site for south facing orientation and optimisation of solar thermal energy. The site was also overshadowed by the cliffs to the west.

## 2.3. SAP Assessment

The Governments Standard Assessment Procedure (SAP) is a compliance tool that was originally developed for existing (inefficient) UK housing, but has tended to be used as design tool for new-built very low energy dwellings. Its purpose is to provide assessments of potential dwelling energy performances that are needed to underpin energy and environmental policy initiatives. SAP works by assessing how much energy a dwelling will consume, when delivering a defined level of comfort and service provision. The assessment is based on standardised assumptions for occupancy and behaviour input by a trained user. This enables a like-for-like comparison of dwelling performance. Related factors, such as fuel costs and emissions of carbon dioxide (CO2), can be determined from the assessment.

SAP quantifies a dwelling's performance in terms of: energy use per unit floor area, a fuel-cost-based energy efficiency rating (the SAP Rating) and emissions of CO2 (the Environmental Impact Rating). These indicators of performance are based on estimates of annual energy consumption for the provision of space heating, domestic hot water, lighting and ventilation. Other SAP outputs include estimate of appliance energy use, the potential for overheating in summer and the resultant cooling load. SAP does not count all end energy uses in dwellings.

This and its use as a prediction tool instead of a compliance tool are some of the reasons for the discrepancies between SAP predictions and actual energy use. The SAP calculations reviewed for this BPE study are summarised in **Table 2.2 and 2.3.** The original as designed and as built Standard Assessment Procedure (SAP) sheets are attached in **Appendix 2.5** and Error! Reference source not found..

For energy efficiency rating, both CSH-Level 4 dwellings and Passivhaus score a ‘C’. The PassivHaus achieves a score of ‘80’ out of a hundred, compared to the ‘76’ given to the CSH-Level 4 dwellings. Although SAP predicted that the PassivHaus unit will generally have significantly lower energy consumption, this is not the case in reality. For example, although SAP predicts overall primary energy use in the PassivHaus that is 57% of the use it predicts for the two CSH-Level 4 Homes, the actual measured annual consumptions show clear differences between consumption in the two similar CSH-Level 4 dwellings. They also show that consumption of the PassivHaus unit is pretty close to that of one of the CSH-Level 4 dwellings (TA1). These discrepancies can be largely attributed to the observed occupancy factors: (1) behaviour and operation of energy systems; (2) occupants per dwelling; (3) temperature level preferences; and (4) occupancy patterns. The discrepancies highlight areas of potential further investigation regarding the use of the SAP methodology; and its application on proposed PassivHaus dwellings. There are minimal differences between the as-designed and as-built SAP results as summarised in **Table 2.2 and 2.3.** Detailed analysis and comparisons of the actual energy use within the different dwellings is presented in **Chapter 7**. It is worth noting the discrepancy in SAP area calculation method and the treated floor area calculation method; and to be careful with which area to use in the expression of energy use per $m^2$. SAP includes the staircase area in both ground floor and first floor and calculates 120 $m^2$ for House type A, 104 $m^2$ for House Type B. Without this duplicated area, the actual areas are 110 $m^2$ for House Type A and 95$m^2$ for House Type B.

| Dwelling | TA1 | TA2 | TB1 |
|---|---|---|---|
| Energy Efficiency Rating | 76C | 76C | 80C |
| Environmental Impact, $CO_2$ Rating and band - Kg/ $m^2$/year | 71C | 71C | 84B |
| Primary Energy Use - kWh/$m^2$/year | 196.80 | 196.80 | 111.27 |
| $CO_2$ /year - kg $CO_2$ /year | 3559.31 | 3559.31 | 1744.07 |
| Space Heating Primary - kWh/year | 10099.33 | 10099.33 | 11572.04 |
| Space Heating Secondary - kWh/year | 2524.83 | 2524.83 | N/A |
| Area - $m^2$ | 120 | 120 | 104 |
| Water Heating - kWh/year | 8641.72 | 8641.72 | 3933.49 |

**Table 2.2:** As-Designed SAP calculations of Environmental Impact; Primary and Secondary space and water heating.

| Dwelling | TA1 | TA2 | TB1 |
|---|---|---|---|
| Energy Efficiency Rating | 77C | 77C | 80C |
| Environmental Impact, $CO_2$ Rating and band - Kg/ $m^2$/year | 72C | 72C | 84B |
| Primary Energy Use - kWh/$m^2$/year | 188.27 | 188.69 | 116.08 |
| $CO_2$ /year - kg $CO_2$ /year | 3405.03 | 3412.61 | 1819.47 |
| Space Heating Primary - kWh/year | 8902.68 | 8942.92 | 3693.31 |
| Space Heating Secondary - kWh/year | 2225.67 | 2235.73 | N/A |
| Area - $m^2$ | 120 | 120 | 104 |
| Water Heating - kWh/year | 9113.89 | 9113.89 | 3933.49 |

**Table 2.3:** As-built SAP calculations of Environmental Impact; Primary and Secondary space and water heating.

## 2.4. Construction Process

**Delivery Team interviews**

The architects, contractor and housing association were interviewed separately in the office of each interviewee. The structure of the delivery team interviews allowed individual experiences to be gathered from those involved in the delivery of the project. The main objective of the process was to develop an understanding of whether design changes (if any) had been made to the original design intent and if so at what stage changes had been made, why these had been made, who made the change and to understand the main challenges in delivering the project. As built drawings, operation and maintenance manuals were used as aids. This section shows in detail the design intent; contractual issues and consents; construction; and management. For drawings and layouts please refer to **Chapter 1**.

### Design intent

The following paragraphs provide a brief overview of the original intentions, strategies, and targets regarding energy, architectural design, social and health aspects, construction, and materials. This includes information from the design team, collected in semi-structured interviews post-occupation. Specific reference is made in the following section to the viewpoints of the architect, contractor and PassivHaus specialist.

The brief was developed by Fyne Initiatives Ltd, who had a track record for affordable low energy homes, innovative design and procurement, all targeted at benefitting tenants. The target for the development was to achieve affordable homes of high quality to demonstrate that dwellings of a high standard could be achieved within the tight budgets available for the affordable housing sector. As fuel poverty is one of the biggest issues the association has to deal with, the association tends to focus on keeping energy costs low. They also aimed to provide different sizes of dwellings as described in Section 1.1.

The PassivHaus dwelling was introduced following the appointment of the G Deveci, Chartered architect. The architect's response to local vernacular and seaside homes; and orientation for solar thermal and natural light throughout internal spaces are shown in drawings in **Chapter 1** and described in **Section 2.2**. With the support of the client, the architect considered the health implications of the dwellings. These included where possible within the constraints of budget and availability, the specification of natural materials and finishes with lower off-gassing.

### Procurement and planning process, and contractual relationships

The following paragraphs discuss the parties and processes that were involved, and how they affected the delivered buildings.

Argyll and Bute Council sold the site to Fyne Initiatives, on the basis that the purchaser would provide affordable housing to meet the needs of the local community, as well as leasing the woodland and providing a small workshop that would accommodate activities of the Bullwood Group. This group provides education for local people with special needs as part of managing the woodland.

The contract was a Traditional Contractual Arrangement. An additional informal document was signed in which an informal 'partnering' relationship was established with the Contractor, who was then involved "from day 1". Any issues arising were resolved and agreed between the Client, Architects and Contractor prior to work commencing on site.

Both the architect and contractor deemed the project and working relationship to have been successful. The architect emphasised the excellent work by the contractor, which reduced the need for difficult discussions about quality on site. The contractor deemed the procurement to have been “exemplary” and “couldn’t fault it”. They thought it was a good set-up and everybody involved was reasonable; and the project went ahead to budget and time.

SPHC were brought into the project after the contractual relationship was developed. They were responsible for the delivery of PassivHaus certification and the specification of MVHR and heating systems. When problems arose in-use, they helped to identify and resolve these issues.

The design group said that project relations with local community groups remained cordial throughout. Residents were interested and engaged with the project, in particular those from the Bullwood Group who were allocated a house on the development. This may have been aided by the initial community consultation undertaken by the architects in November 2007 prior to commencing the design of the development.

## Changes

On the whole, all parties involved felt that any significant issues regarding layout, materials and specification had been agreed and resolved prior to work commencing on site. The main problems that arose were post-construction; concentrated in dwelling TB1; and were a result of the M&E systems installed. The following paragraphs discuss the changes that happened on site, when these occurred and their impacts:

**1. Design and Layout**

The architect held that no changes were made on site, as these were all resolved in advance between the main parties. The only unforeseen exception was that there was an alteration in funding allocated to external works, so changes had to be agreed during the process and reductions made. The contractor also considered this to have been the only main issue with the layout on site.

There was a provision, in the original design, for shading of the doors and large windows on the east façade, but this feature was omitted during the construction stage owing to budget constraints. The omission has partly contributed to the summer overheating recorded in the houses during the BPE study as reported in measured data in **Chapter 7**; and occupant interviews and the BUS survey in **Chapter 5**.

The only amendment observed by the contractor was a verge detail, which had not been resolved previously, so something was agreed with the architect and made up.

**2. Materials**

The architect said that no changes were made as all materials for example had been agreed with the National House-Building Council (NHBC) for accreditation. The contractor referred to a few material changes but these were very minimal.

**3. Specification**

Following the 1 year defects period, some internal finishes were provided by occupants, e.g. finish flooring and internal paintwork. The SPHC consultant noted that one householder added a towel rail to increase warmth in house TB1.

**4. Equipment**

The SPHC consultant noted that there were problems with both the AASHP and MVHR, independently of one another, but also impacting on the location of each piece of equipment and ductwork. The heat from the AASHP was not being transferred from the hallway to the rest of the house. This required the adjustment of transfer gaps/undercuts beneath adjoining doors (specified min 10mm), which had not previously been cut. The AASHP was originally planned for the kitchen but the hallway was chosen. The heat build-up in the small hallway resulted in the AASHP thermostat switching it off. The unit needed to be replaced with a more expensive one with a remote thermostat. It was noted by the SPHC consultant that both units had been provided as options, but the cheaper one with fixed thermostat had been selected. This will be discussed further in **Chapter 6**.

There was also a problem with the defrost unit on the AASHP. When it was most needed to work, when the weather was coldest, the defrost unit activated and would not provide heat. In addition, this process created higher than expected electricity demand and subsequently high electricity bills from the use of bathroom towel rails as heat sources. The performance of this system is detailed in **Chapter 6**.

The replacement AASHP was planned for the kitchen but this would have involved considerable disruption so it was placed in the hallway. An extract was added into the hall and the MVHR location was changed to the porch and kept within the insulated envelope. The original location of the MVHR was under the stairs. The relocation resulted in 8m of ductwork from Exhaust and Intake Air Terminals, contributing to significant heat losses. The performance of this system is detailed in **Chapter 6**

There was a separate problem with the solar thermal system, which did not work properly for 8 months. This was a result of the thermostatic control device being installed the wrong way around; an apparently common mistake, which was resolved by the Velux specialist. During the 8 months period, water was being heated by immersion, resulting in high electricity bills.

## Construction Process

A health and safety challenge of significance was that the contractor had to ensure that access was available to the adjacent woodlands to the west for the Bullwood Group, a local charity working with disadvantaged children. This was deemed to be a challenge by both the contractor and the architect. The Bullwood Group had been the previous occupant to the site. As stated in Section 1.1, one dwelling is now the group's offices and meeting room.

The main contractor stated there were some issues with sewage and drainage connections, which were resolved. They also stated the issue with the heating in dwelling TB1, requiring the AASHP to be changed (see previous outline of this problem by SPHC). The electricians were the only sub-contractor who worked with the main contractor except the SPHC and specialist suppliers. All other services were provided by the main contractor, so there were no other problems with everything else in the house.

## Delivered Dwellings

The architect, G. Deveci, was involved in providing information for the standard Housing Association Handover Guide. This included information on the ventilation systems, especially for the PassivHaus. When asked if the building is being used / inhabited as expected, the architect did not consider this to be much of an issue, because the homes are owned and if they are not suitable they will presumably sell and move on.

There were a few problems with the PassivHaus dwelling in particular. At the time, this was the first PassivHaus in Scotland, and it was a learning curve, particularly for the ventilation specialist and installers. The Type A dwellings had no problems in use except stuck door/window locks in TA2. For House Type B, the SPHC found the level of handover involvement on all sides to be of a lesser quality than that in Germany, based on experience in German PassivHaus practice.

## 2.5. Key findings and Conclusions for this section

- The delivery of the development was considered a success, coming in on time and on budget. Both the architect and contractor felt that the procurement and contractual process had been exceptional. There were very few problems, most of which had been solved in advance.
- Problems on site were as a result of budget cuts; external groups; and teething-problems with the AASHP and MVHR, which were linked with a learning curve, as the PassivHaus was the first in Scotland at the time. The architect emphasised the excellent work by the contractor.
- The SPHC had experience working on a range of different PH projects in Europe, therefore it was difficult for them to say how this project had gone. However, given that there were no south-facing windows and the lack of experience on all sides, they felt that everyone did well to progress the project to certification level. The SPHC felt the only thing, which could have been done differently, was that there was more time on site.
- The lack of experience of some specialist aspects resulted in a number of installations not done as per specification. This could have been helped by more time on site by SPHC staff and more engagement with the system design.
- The developer, Fyne Homes, pointed out that the outcome of the Passivhaus did not go as originally thought.

## 2.6. Recommendations:

1. Engagement of PH specialists at the start of design stage. The SPHC has closed down and developers wishing to meet the PassivHaus standard in Scotland have to rely on individuals with expertise in the standard; and other institutions to get certification.
2. Better understanding as to the interaction between AASHP and MVHR in PassivHaus, particularly in relation to: room size; thermostat location; AASHP and MVHR location.
3. More rigorous checks and design procedures, as per German PassivHaus: this will also improve with market experience.
4. Improvements as to commissioning and handover procedures, these were deemed to be not to as high a standard as in Germany.

# 3. Fabric testing

The BPE monitoring mandated non-invasive testing of the building fabric to provide an indication of construction quality and to identify whether specified design targets were met. Each dwelling underwent two air permeability tests to determine where air leakage occurred and to determine how the air permeability of each building performed over an extended period of time. In-situ U-values and thermographic surveys were also undertaken in the three dwellings. These tests are discussed in more detail herein and **Table 3.1** summarises the findings to allow easy comparison of whether the as built dwellings met the design criteria.

| | | **House Type A** | | **House Type B** |
|---|---|---|---|---|
| | | TA1 | TA2 | TB1 |
| Air Permeability ($m^3/(h.m^2)$ @ 50Pa | Target | 10 | 10 | 0.5 (based on SAP sheets) |
| | Initial | 4.035 | 4.290 | 0.955 (One MVHR vent was difficult to reach and therefore not fully sealed) |
| | Final | 2.98 | 3.36 | 0.58 More confident results – MVHR sealed from external inlet and outlet. |
| U-Value Wall ($W/m^2K$) | Design | 0.13 | | 0.13 |
| | Measured | 0.13 | | 0.12 |
| U-Value Roof ($W/m^2K$) | Design | 0.13 | | 0.09 |
| | Measured | 0.15 | | 0.16 |

**Table 3.1:** Comparison of design targets against as-built building fabric.

## 3.1 In-situ U-Value Measurements

The in-situ measurement of U-values was carried out on a sample dwelling from each house type. U-values are incrementally being improved in new revisions of the Building Regulations to improve energy efficiency, therefore, as the dwellings were designed in 2007 the Building Regulation in force at that time have been used to compare the in-situ U-value results with. **Table 3.2** indicates the maximum elemental U-values for construction elements in 2007.

| **Element** | **U-Value ($W/m^2K$)** |
|---|---|
| Wall | 0.30 |
| Floor | 0.25 |
| Roof | 0.20 |
| Windows, doors, roof lights | 2.2 |

**Table 3.2:** Maximum U-values for building elements of the insulation envelope.

### 3.1.1 Methodology

In-situ measurements of U-Values for the construction of roofs and walls of TA1 and TB1 were undertaken between 5th and 25th February 2013. Two measurements were taken in each dwelling; one on an external wall and one on the roof. In dwelling TA1 the apparatus, as described below, was set up in the passage upstairs. The set up in dwelling TB1 was in the master bedroom.

The equipment used for the measurement of each element included:

- Hukseflux TRSYS01 thermal resistance measurement system, measuring two constructions simultaneously. The system comprises two heat flux thermopiles and matched thermocouples for differential surface temperature measurements.

- Tiny tag data loggers to measure ambient internal and external air temperatures.

The methodology for the testing procedures and subsequent analysis are described in detail in **Appendix 3.1**.


**Figure 3.1:** Thermographic imaging before mounting of heat flux sensors to ensure sensors are mounted on a surface representing even thermo physical properties in dwelling TB1.

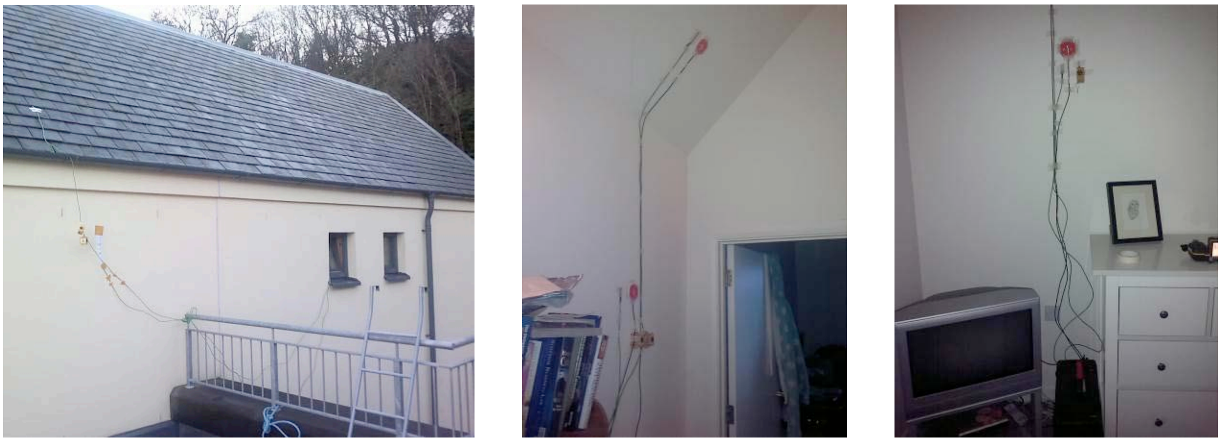


**Figure 3.2:** Air temperature and Heat Flux sensors mounted on internal wall surfaces in dwelling TB1.

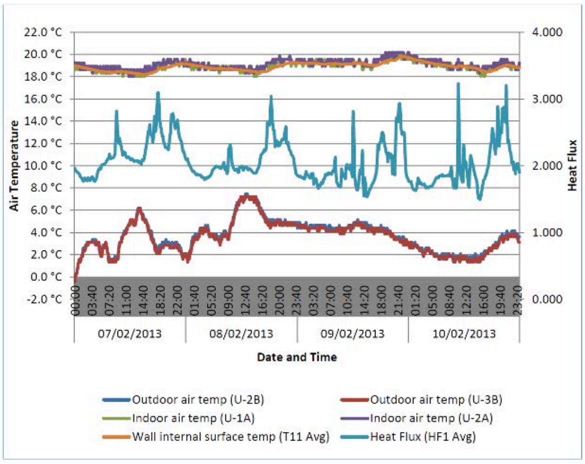



**Figure 3.3:** Temperature and Heat Flux profiles used in U-Value Calculations in dwelling TA1

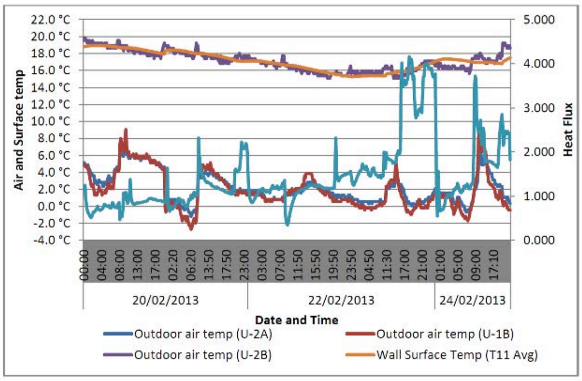



**Figure 3.4:** Temperature and Heat Flux profiles used in U-Value Calculations in dwelling TB1

## 3.1.2 Results

A summary of the Building Regulation maximum back-stop U-values, design U-values and the measured results are recorded in **Table 3.3**.

| | | **Bldg regs. Max. values** | **Design values** | | **Measured values** | |
|---|---|---|---|---|---|---|
| **Element** | **Construction / U-Values** | | TA1 W/(m2K) | TB1 W/(m2K) | TA1 W/(m2K) | TB1 W/(m2K) |
| **Windows** | Triple-glazed, argon filled, low-E, En=0.05, soft coat, Nordan HP. Insulated framed '释Internorm' windows | 2.2 | 0.96 | (0.78) | N/A | N/A |
| **Half-glazed door** | Triple-glazed, argon filled, low-E, En=0.15, hard coat, Velux HP | 2.2 | 1.10 | (1.16) | N/A | N/A |
| **Roof light 70° or less** | Triple-glazed, argon filled, low-E, En=0.05, soft coat, Velux HP | 2.2 | 1.05 | 0.96 | N/A | N/A |
| **Pitched roofs** | Slates, Sarking Boards 30 cm, I-studs + Mineral wool (035), OSB 5cm, PU Insulation (023), & Plasterboard. Insulation is between joists | 0.2 | 0.13 | (0.094) | 0.15 | 0.16 |
| **Flat roofs** | | 0.2 | | 0.19 | N/A | N/A |

| | | | | | | |
|---|---|---|---|---|---|---|
| **External cavity walls** | OSB 30cm, I-studs, Mineral wool (035), OSB 5cm, PU Insulation (023) & Plasterboard | 0.3 | 0.13/0.18 | (0.095) | 0.13 | 0.12 |
| **Ground floors** | 12.5 cm Concrete slab 20 cm XPS Insulation | 0.25 | 0.13 | (0.15) | N/A | N/A |

**Table 3.3:** Comparison of the building regulations, construction and U-Values in W/($m^2$K) of various construction elements - design and measured U-Values (House Type A and House Type B).

### 3.1.3 Discussion

The in-situ U-value testing demonstrated a little variation between U-value targets at design stage and the measured U-value in each house type. Those for house TA1 were very close to the design values while those of TB1 were slightly higher (worse) than the design values. Whilst the latter are slightly higher (worse) than the design estimate, they are well within the building regulations then, current, and proposed tighter values in future; and do not demonstrate significant failure of the construction as built. The design U-value targets were already an improvement over the then current maximum U-values in the Building (Scotland) Regulations and the measured actual values for TA1 achieved slightly higher and for TB1 significantly higher than the regulations backstop values. The relatively high performance of the U-values is confirmed by the thermographic imaging results in the next section; and the environmental and energy results in **Chapter 7**.

## 3.2 Thermography

Infra-red thermographic surveys were undertaken on a sample dwelling for each of the two house types. The surveys were carried out during the winter/spring period of 2013/2014 and again at the time of undertaking the air pressure tests and smoke testing – on 1st March 2013. The aim of the survey was to detect which, if any, areas of the building fabric are at risk of condensation or mould growth; whether the construction was executed as specified. It sought to find out the uniformity of insulation and possible air leakages due to settlement or construction defects, which may cause unwanted heat loss, cold ingress, and low internal surface temperatures.

### 3.2.1 Methodology

The thermographic imaging was undertaken by Futurkomfort Ltd and MEARU on 18.02.2013 using a FLIR ThermaCAM B-360 camera, in accordance with the requirements of TSB monitoring protocol, BPE IP1/06 and BSRIA 39/2011. The surveyors worked systematically around the dwellings capturing images (both infra-red and digital) and taking videos of smoke testing of areas of potential defects and equipment heat gain. A detailed description of the methodology and the internal and external conditions at the time of the survey is provided in **Appendix 3.2.**

### 3.2.2 Results and Discussion

The thermographic images are presented at a scale of between -10 and 8 $^{0}$C for the external images (Figure 3.a and 3.b); and between 13.5 and 22 $^{0}$C for the internal images (Figure 3.c to 3.f). They show suspected cold air ingress (**Figure 3.d**); and leakage of warmer indoor air to the outdoors via window edges. These suggest windows not sealing fully when closed. The results of air pressure tests in the next section suggest that air actually does leak through these gaps, but result in better performance than conventional dwellings. There is also suspected thermal bridging along window edges (**Figure 3. 'a' to 'd'**). The spot temperatures relative to the image temperature range (**Figure 3. 'e' to 'g'**) show that the workmanship

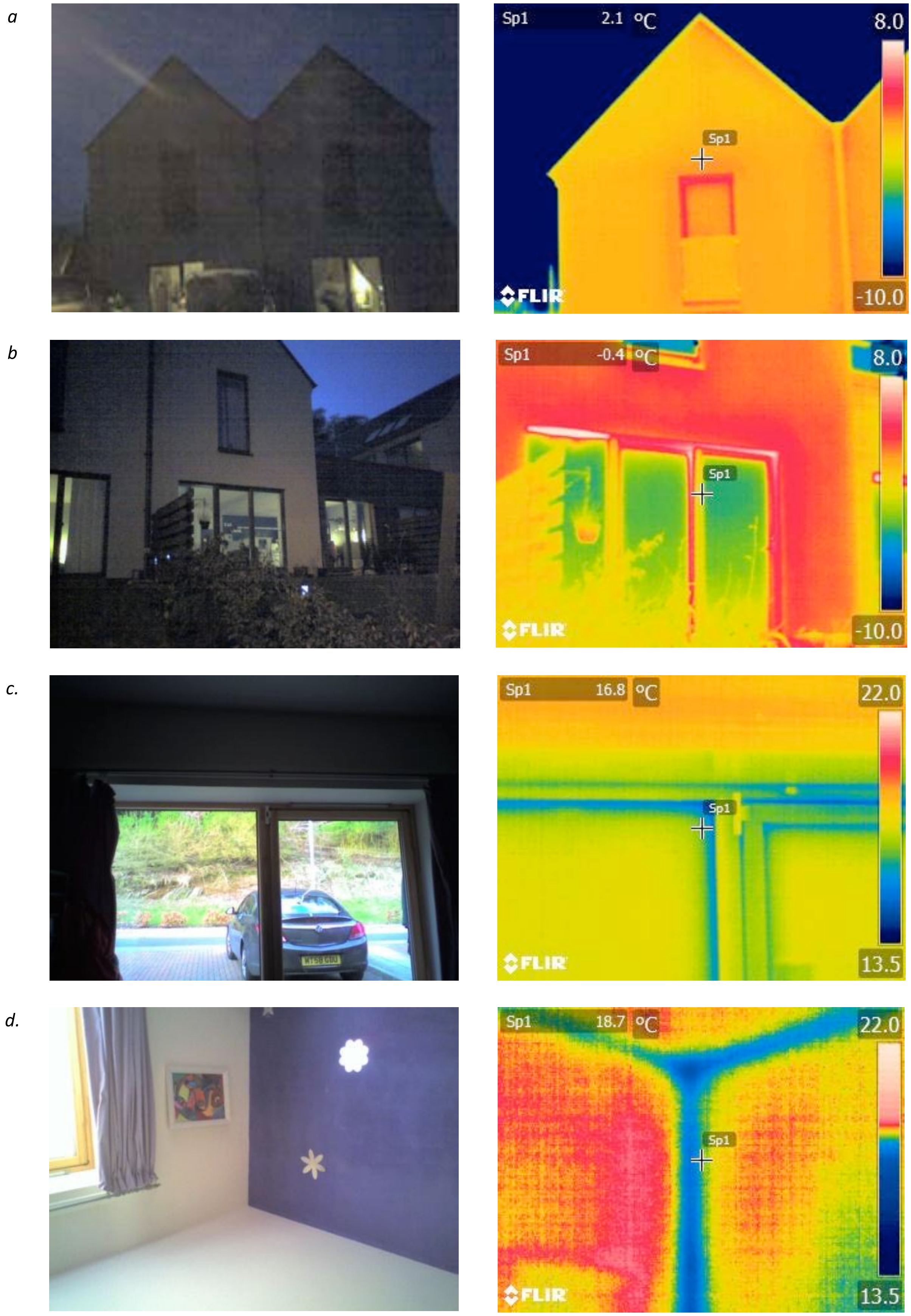
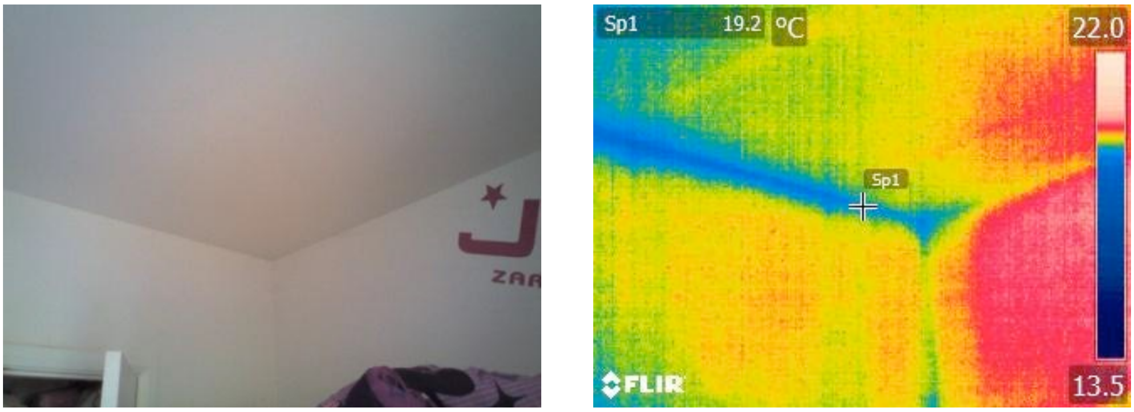
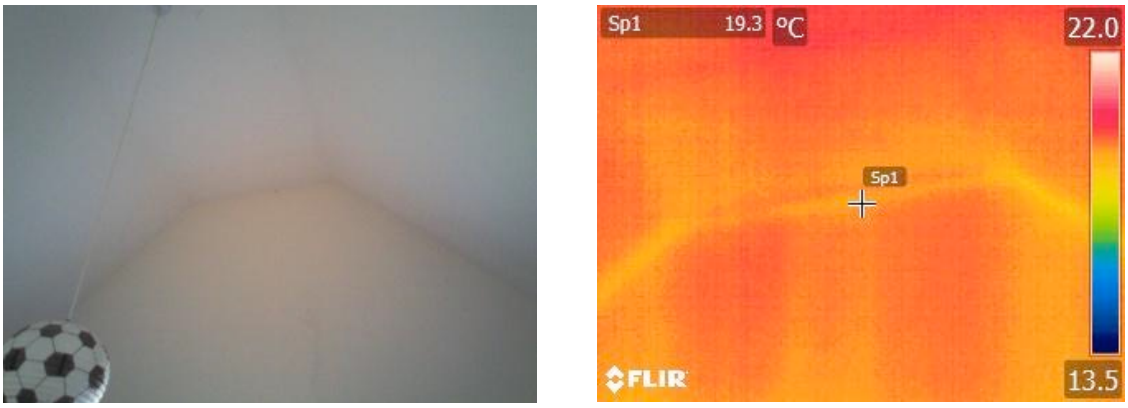



**Figure 3.:** Thermographic Imaging

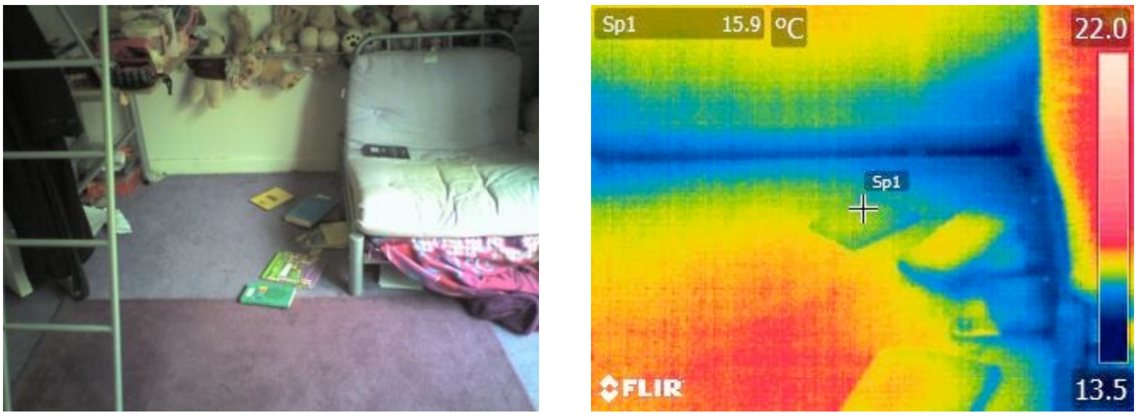
*d.*




*e.*




*f.*




*g.*


**Figure 3.5 continued:** Thermographic Imaging

and insulation effectiveness at wall/wall, wall/floor and wall/roof intersections are quite good compared similar intersections in a conventional house. Although some of the intersections results may suggest weak unsealed intersections, they may also be due to cold air stagnated at these junctions.

Although the images in **Figure 3. 'h' and 'g'** illustrate uneven green and blue thermal patterns, suggesting that cold air ingress is cooling surfaces at the skirting level, and possible relation to the insulation fitted being ineffective, it is possible that the surrounding furniture and curtain produced this thermal image effect.

## 3.3 Air Permeability Testing

Air permeability testing is performed on buildings to determine the extent of uncontrolled air leakage (infiltration) through the gaps and cracks in the building fabric; these affect internal comfort conditions by increasing heat loss and causing draughts (in winter) and increase heat gain (in summer). In Scotland, air permeability testing on dwellings is not mandated through the Building Regulations. In order to achieve an air-tight dwelling, it is imperative to ensure attention to detail in design by inclusion of airtightness targets in specifications; and that the airtightness layer is clearly identified on drawings. Good workmanship is required by the contractor as well as coordination between trades. It is not easy to visually detect infiltration pathways and as such testing is required to ensure internal comfort conditions and control energy demand.

In line with TSB BPE mandatory requirements, air permeability testing was undertaken on all three dwellings at the beginning of the BPE monitoring period on 1st March 2013 by Scottish Passivhaus Centre and MEARU; and repeated towards the end of the project on 14th and 15st August 2014 by Futurkomfort Ltd and MEARU. Additional tests to Dwelling TB1 were undertaken in September 2012 by the SPHC when a new MVHR was refitted; these results are not reported here but are referred to in Section 3.1.3 Discussion.

### 3.3.1 Methodology

The testing was carried out in accordance with ATTMA (Air Tightness Testing and Measurement Association) TS1 (Technical Standard for air permeability testing of dwellings) which is broadly based on BS EN 13829:2001. It involves the creation of a pressure differential between inside and outside, by using a portable variable flow fan temporarily installed in a doorway. Air permeability is expressed in air leakage ($m^3$/hour) in or out of the building, per square meter of building envelope at a reference pressure of 50 Pascal ($m^3/(h.m^2)$@50Pa). In order to detect the location of infiltration pathways a smoke pencil is routinely used, together with thermography, these are shown in **Appendix 3.3**. The fan was placed at the main door for TA1 and TA2 (**Figure 3.3Figure 3.4**); and at the door between the glass door after the entrance porch in TB1 (**Figure 3.5, Figure 3.6**). The entrance porch was therefore excluded from the pressure test for TB1. Each property was pressurised and depressurised and the mean of the measured values taken as the air permeability. The procedures for the test on each dwelling are presented in **Appendix 3.2**.

**Figure 3.3:** Air pressure test door fan in Dwellings TA1 and TA2.

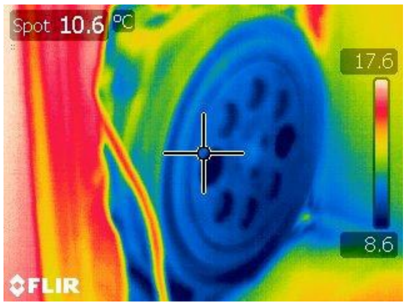



**Figure 3.4:** Air pressure test thermography in Dwellings TA1 and TA2.

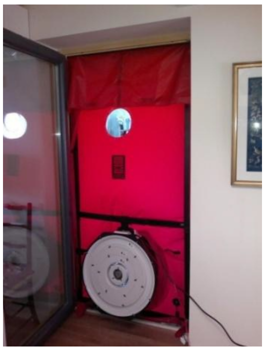


**Figure 3.5:** Air pressure test door fan in TB1.

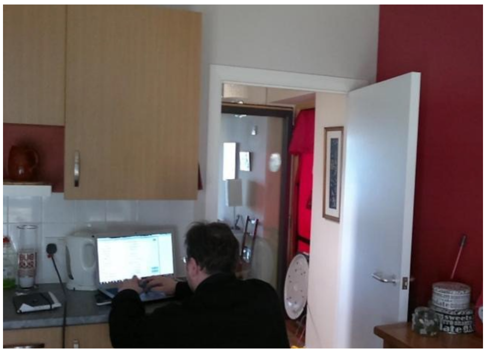


**Figure 3.6:** Air pressure test door laptop link in TB1.

The tests involved the sealing of vents (Fig 3.7) - all kitchen hoods, mechanical vents, trickle vents (TA1 and TA2), and air-to-air source heat pump (TB1). The MVHR air ingress and egress points were also sealed, except two small vents located high at the ceiling of the bedrooms during the tests 1st in March 2013.

**Figure 3.7:** Air vents sealed and mechanical vents switched off before air pressure and air leakage tests.

### 3.3.2 Results and Discussion

The results of the testing on the 1st March 2013 for the positive (pressurisation), negative (depressurisation) and mean air permeability and air change rates for each dwelling are provided in **Table 3.4**. The tests were repeated towards the end of the project on 14th and 15st August 2014, the results are provided in **Table 3.5**. These results are important because they demonstrate that significant levels of airtightness were achieved in House Type A, better than the target air permeability levels. Although the target value was not achieved in House Type B, it had been set very high, and the achieved value far exceeds the 2007 and current building regulations. The following discussion explains the range of results achieved, particularly for Dwelling TB1.

**Table 3.4:** Air Permeability Test 1 results.

| | | Air Permeability ($m^3(h/m^2)$ @50Pa | | | |
|---|---|---|---|---|---|
| Dwelling Ref | Test Date | Target Air Permeability | Negative Air Permeability | Positive Air Permeability | Mean Air Permeability |
| TA1 | 01.03.13 | 10.0 | 4.31 | 3.76 | 4.04 |
| TA2 | 01.03.13 | 10.0 | 4.44 | 4.14 | 4.29 |
| TB1 | 01.03.13 | 0.5 | 1.15 | 0.76 | 0.96 |

**Table 3.5:** Air Permeability Test 2 results.

| | | Air Permeability ($m^3(h/m^2)$ @50Pa | | | | (ACH) |
|---|---|---|---|---|---|---|
| Dwelling Ref | Test Date | Target Air Permeability | Negative Air Permeability | Positive Air Permeability | Mean Air Permeability | Mean air changes per hour |
| TA1 | 14.08.14 | 10.0 | 3.07 | 2.89 | 2.98 | 2.98 |
| TA2 | 20.08.14 | 10.0 | 3.41 | 3.32 | 3.36 | 2.36 |
| TB1 | 14.08.14 | 0.5 | 0.59 | 0.57 | 0.58 | 0.56 |

A full report of the results is appended in **Appendix 3.2**. For TB1, past results from a previous test done in September 2012 when a replacement MVHR was fitted indicated approximately 0.6 $m^3(h/m^2)$ ACH. Therefore, the first test result for the BPE project was a significant increase. This was due to two small vents located high up on the ceiling of the bedroom, which could not be shut off. During the testing done in September 2012 when a new MVHR was being refitted, everything was blanked off at the MVHR but it was not possible to dismantle it for the first TSB test. For the second test of the BPE project, however, all vents were sealed, and the results are very close to the original September 2012 test – and within the PassivHaus standard requirement.

The slightly higher figures for Dwelling TA2 compared with Dwelling TA1 can be attributed to some mechanical problems with the door locks that prevented the windows from being closed tightly. The figures for Dwelling TB1 would be expected to be a bit lower. The values from TA1 and TA2 are close to what one would expect with a timber frame dwelling.

No air permeability testing was carried out at completion for TA1 and TA2, as it was not required under the regulations at the time. For TB1, a test was done at completion for the PassivHaus accreditation. Unlike the English Part L document, the Scottish Building Regulations in force at the time of initial design of the dwellings did not mandate air permeability testing of dwellings. At this time, air permeability testing was required on a sample number of dwellings in a development if the target specified at Building Warrant stage was less than $10m^3/(h.m^2)$ @50Pa. Testing was not considered necessary for dwellings designed and constructed to the Accredited Construction Details (Scotland) and a value of $10m^3/(h.m^2)$@50Pa could be inserted within the SAP (Standard Assessment Procedure) calculation. In the case of TA1 and TA2, their respective SAP calculation sheets declared air permeability targets of $10m^3/(h.m^2)$@50Pa, thus assuming the intention for the dwellings to be designed and constructed to Accredited Construction Details (Scotland). This negated the requirement for post construction air permeability testing.

The current (2013) Scottish Building Regulation Technical Standards recognise this issue of dwellings being constructed to high level of air tightness but at the time of construction, no provision was made in terms of requirements to test air tightness or for ventilation provision allied to this. Under the current regulations (2013) section 3.14.10 states *"where infiltration rates of less than $5m^3/h/m^2$ @ 50Pa are intended, then such a [mechanical ventilation] system should be used."* Both dwellings TA1 and TA2 had infiltration rates less than $5m^3/(h.m^2)$ @50Pa; the level at which mechanical ventilation measures should be installed to avoid issues with internal air quality and condensation. However, there appear to be no moisture related issues in the two dwellings.

The results are significant, in that they demonstrate that the dwellings have achieved far better than the building regulations requirement. However, for TA1 and TA2, the good results by present standards, would suggest the need for MVHR if the risk of poor air quality is to be minimised in future, particularly if future tenants have more indoor clothes drying habits or generate more moisture than the current tenants. While the slight variation between the first and second results could be attributed to faulty door locks in TA2 and the two vents in TB1, in TA1 it may suggest that some settlement may have happened; or the testing methodology and accuracy of the two different fans used during the two tests may be slightly different. Although the results may reveal settlement that could have happened between the two BPE tests, only one test is required for compliance with ATTMA TS1.

**Challenges met**

The challenges associated with the air permeability testing included:

- The occupants have varied occupancy patterns; some are shift workers with working patterns varying each week. This created a logistical challenge for organisation of access to test dwelling TA2 as there was a person asleep most of the time. The second test of this dwelling had to be done on a different date a week after those of TA1 and TB1.

- Tracing of air leakage pathways were difficult where furniture placement at room perimeters created physical obstacles. The furniture also restricted the evaluation of hidden air flow pathways within the walls using thermography.

- ATTMA Technical Standard is not explicit in defining the pressurisation method for air permeability testing, highlighting the need to revise the document to allow like for like comparison of any air permeability test. As a result of learning about inconsistent testing approaches by different air permeability testers, MEARU developed a specification to ensure future tests commissioned were comparable. This specification stipulates the testing to be under both negative and positive pressurisation with final results expressed as a mean of these two values.

## 3.4 Conclusions and key findings for this section

The key findings are as follows:

- Air permeability rate was found to be 4.04 and 4.29 ($m^3/h/m^2$) for TA1 and TA2 respectively (House Type A) and 0.96 ($m^3/h/m^2$) for TB1 (House Type B) in the first BPE test. They were 2.98 and 3.36 ($m^3/h/m^2$) for House Type A and 0.58 ($m^3/h/m^2$) respectively in the second BPE test. The good results suggest that winter heat loss and summer heat gain through infiltration is minimised.

- Except for known reasons in dwellings TA2 and TB1, Air permeability results for the two/three tests remained close to stable over time suggesting that the means of achieving air-tightness are robust.

- Air-tightness was found to far exceed the building regulations/design stage target of $10m^3/h/m^2$ for dwellings TA1 and TA2, and just under the PassivHaus target of $0.6m^3/h/m^2$ and slightly over the design target of $0.5m^3/h/m^2$ for TB1.

- The achieved level of air-tightness in TA1 and TA2, under current Technical Standards, would suggest that a whole house mechanical ventilation system would be required to provide good IAQ and that the current strategy (using background ventilators) is insufficient. The result of slightly under 5 ($m^3/h/m^2$) suggests that MV may be required, particularly in TA1 where the higher occupancy of five occupants could get inadequate ventilation when windows, doors and vents are closed, although the $CO_2$ monitoring in presented in Chapter 7 does not suggest that this is happening.

- The general quality of the construction appears to be thermally robust with limited weaknesses identified.

- The wall construction in House Type A was found to achieve an in-situ U-value of $0.13W/m^2K$, this compares well to the design value of $0.13W/m^2K$. House Type B was found to achieve an in-situ U-value of $0.12W/m^2K$, this compares well to the design value of $0.13W/m^2K$. The respective measured values for the roofs were slightly higher (worse) than the design values. The good U-value and air permeability performances imply that internal heat containment is good. This could, however, become a problem in hot summer days, especially when external air temperature is higher than the required internal comfort range; and given that the thermal mass in the dwellings is minimal.

While the in-situ fabric testing revealed the dwellings were generally constructed to a better standard than the then current Building (Scotland) Regulations, it should be noted the Building Regulations are progressively being updated to reduce heat loss through the thermal envelope. The target wall U-Values for all the dwellings is already below (much better) than the current (2013) Building Regulation backstop value of $0.25W/m^2K$. Backstop air permeability targets have also improved since the construction of these dwellings. The results show that all the dwellings achieved much better than the current backstop value of $7m^3/ (h.m^2)$@50Pa. All of the fabric tests show that the dwellings' were therefore very future proof.

Finally, for air permeability testing, we would recommend a revision to the ATTMA standard for valid testing results to be through a mean of tests conducted under negative and positive pressures. This would reduce ambiguity in comparing results. One key lesson in the fabric performance is that targeting higher than the minimum regulations requirements does not need to cost significantly more; and is a good approach to future proofing new developments against ever tightening regulations.

# 4. Key findings from the design and delivery team walkthrough

## 4.1 Introduction

The sources of information for this chapter are: design drawings; the initial building walkthrough at the start of the monitoring project; and semi-structured interviews conducted with the design team; as partly discussed in chapter 2; and shown in Appendix. The design information is compared with observations made on the walkthroughs. The purpose of this chapter is to demonstrate the differences between design and 'as-built', and any differences this may have made to the dwellings and what could be learnt for future projects. A number of walkthroughs happened in the course of the BPE project. One involved the design team, MEARU representative, and occupants. MEARU also made further visits for independent walkthroughs with the occupants and to confirm specific issues. All these included discussions and documentation.

## 4.2 Comparison of designed vs. delivered

Commencing the evaluation of the development with a walkthrough involving the architects and occupants provided essential insight at the start of the project. The whole walkthrough process was useful in providing an in-depth understanding of the design and in-use issues of the development to the MEARU and TSB officials. The following section compares the project and the two house types, as designed and delivered.

### 4.2.1 The Project

From the architects perspective the original concept of the homes and aims were delivered, except for omission of shading devices and ambition to achieve PassivHaus standard for one of the dwellings, which came post planning. Please refer to Chapter Two for further detail relating to construction and comments from different members of the project delivery team.

As discussed in **Chapter 2** there was an unofficial agreement between the architect and the contractor. This resulted in most changes being resolved prior to the development going on site. In particular this would have had a significant impact on issues which could have been significant in the building outcome.

The project delivery team felt that the development had been a success. Where there were problems, these mostly related to TB1, the PassivHaus, and equipment installed in this dwelling. A particular accomplishment for the team was the achievement of affordable, low-energy homes and the PassivHaus home.

With regards to house type TB1, at the walkthrough, the BPE project team discussed the implications of SPHC ceasing trading. Subsequently, MEARU arranged for a former member of staff from SPHC to remain with the project as part of their new start-up company, Futurkomfort. Therefore the expert knowledge for the PassivHaus side of the project was not compromised.

The following is a list of general issues identified:

- There was little variation between the designs and as-built House Type A; there were some changes to installed equipment with House Type B.
- Cross ventilation helped; and the decision to remove the solar shading to the west had a significant impact on the temperatures above the comfortable range experienced (see figure 4.1 and chapter 7); and overall aesthetics of the buildings.

- In the case of TA2 and TB1 the occupants were very interested in how their new homes worked and appeared to engage well with them to optimise energy savings.
- Low utility costs in comparison to previous homes were noted by the occupants to TA2 and TB1.

### 4.2.2 House Type A

From the architects' perspective, the dwellings original aims to provide the following were achieved: a sense of space; natural light; the optimal use of natural light and air; and a healthy specification using lower off-gassing finishes, and natural materials.

The following is a list of issues discussed:
On the whole the design team felt that very few changes had been made to House Type A from design to completion for a number of reasons:

- The timber construction was of a fairly standard type with which the contractor was experienced.
- The communication between the design team from design inception.
- Good quality work by the contractor.

**Dwelling TA1:**

- The occupants pointed out issues with over-heating (similar to that in dwelling TA2 as shown in Figure 4.1), in particular in the summer in westerly rooms facing seawards: the kitchen, living room and bedroom. Opening the window and cross ventilation in the kitchen helped to reduce this. The temperatures above the comfortable range was also a problem in dwellings TA2 and TB1.

- The lower bedroom was the coldest bedroom; this was due to no heating being installed on the basis that it would be warmed passively by the living room and kitchen heating installations.

- On the initial walkthrough, 28th September 2012, the heating had not yet been switched on for the autumn. It should be noted that the occupants were very keen to reduce their heating requirements, as evidenced by the temperature and energy profiles in Chapter 7. They particularly liked this aspect of their current home. They hardly switched on the Duo electric heater in the passage upstairs even during the heating season.

- The occupants felt that their previous house was not as good as their current one. Their power bills in their former home averaged £120 per month in 2009. This is based on a family of 5 in which the parents are at home most of the time.

- The absence of instant hot water was a problem for the occupants.

**Dwelling TA2:**

- There were issues with over-heating (see Figure 4.1), in particular on sunny afternoons in westerly rooms facing seawards: the kitchen, living room and the main upstairs bedroom. This resulted in the main upstairs bedroom window being open most of the time.

- Temperatures above the comfortable range as defined in CISBE Design Guide A (2006) were experienced in the main bedroom upstairs was partly from the waste heat from the boiler in the adjacent cupboard.

- The occupants, who included two children at the time (a teenage girl moved out later); found it an issue not having a utility room. These homes are, on the whole, family homes in an area which is on the outskirts of a town, near to a rural area and the seaside. This would have been a practicality which could have made a significant difference to the way in which a home is used and the comfort of it.

- Issues with acoustics: in particular impact noise between the first floor slabs was noted as a problem.

- There was a draft to the living room doors facing the seaside, subsequently this was confirmed during the thermographic survey (see chapter 3), and was identified as being a problem with the locks, this was subsequently resolved. There was mention of the possibility that the doors had been left outside during construction. This had exposed them to a lot of moisture, which could be linked with the locking problem. Post construction, neither the contractor nor supplier would take responsibility, but the issue was resolved.

- The control for the boiler had been replaced during the snagging period of defects liability period.

- The occupants had installed an instant water heater at the shower. The main reason they cited was that they had one in their previous house.

- The occupants felt that the user manual was not easy to read, and the BPE team felt this needed to be reviewed.

- It should be noted that the occupants wanted their home to be warmer than an average temperature. Consequently the heating was switched on in September, which it was not in the case of dwelling TA1.

- The occupants of TA2 were curious to know how their energy use compared with that of the adjacent PassivHaus (TB1).

### 4.2.3 House Type B

As with House Type A, from the architects' perspective, the dwelling was originally designed to provide: a sense of space; natural light; the optimal use of natural light and air; and a healthy specification using lower off-gassing finishes, and natural materials.

The following is a list of the issues discussed:

- Although it was considered that this house type had also been a success, there were a number of teething problems, in particular with the technical installations.

- The main householder had a clear understanding of, and was interested in PassivHaus. They were generally happy with their home. It is occupied by two people; an adult and school age child.

- As with House Type A, there were issues with summer over-heating to the west, seawards aspect rooms. Windows remained opened to reduce temperatures above the comfortable range but with midges, this became a challenge in the upstairs bedroom at night.

- Location of equipment installed to meet PassivHaus not anticipated in the design. It is worth noting that the SPHC were not involved in design stages of the contract, and their limited experience in the Scottish context, all may have effected placement of key equipment in and related problems.

- The location of the MVHR had changed (please refer to **Chapters 2 and 6** for details).

- The MVHR has a summer bypass and the occupant was aware of how to operate it.

- In early days, the house felt colder than comfort expectations.

- They expected the £71 per month electricity bill would most likely go down. NB. Due to immersion costs in the first 8 months of occupancy, as a consequence of the Solar Thermal System not working properly, electricity costs were likely to be considerably lower per annum. This is an issue which was investigated further, as described in **Chapters 6 and 7**.

- The occupants of the PassivHaus (TB1) had added a towel rail to the second bathroom. A walkthrough by MEARU at a later date revealed that this towel rail was being used to heat up the house. MEARU felt that this needed further investigation. The energy impact of the towel rail was analysed at a later date (see Chapter 7).

- The occupants particularly love the high ceilings upstairs. However, they would have liked more light to the 1st floor at the rear of the building through a Velux window. This met with the original design intent for spaces, but limited the light, for which the dwellings had been orientated.

- Solar hot water plus backup water heating were not working in harmony and subsequently, a new control had been installed

- The Architect pointed out that the window and door frames had insulation.

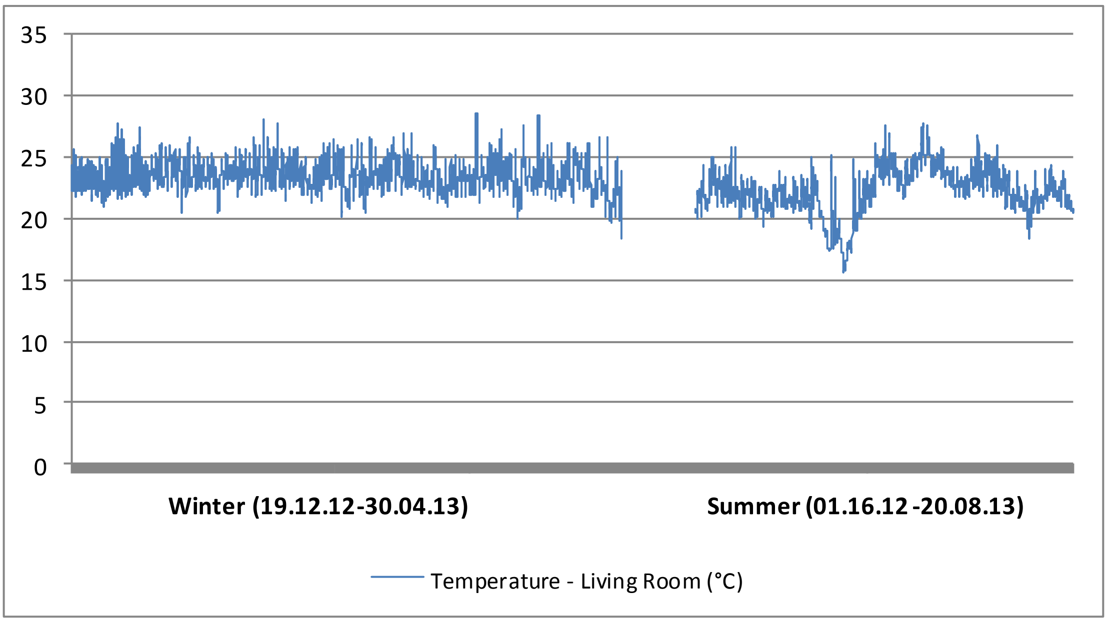



**Figure 4.1:** Winter and Summer indoor air temperature in dwelling TA2 – living room

## 4.3 Key findings and Conclusions for this Section

On the whole, the development met the design team's aspirations for the project. The occupants liked the lower energy bills to previous homes. There were a few gaps between design intent and as-built, which were of great significance. The main one was omission of shading, which contributed to the over-heating problem.

The problems encountered with the PassivHaus (TB1) highlighted the need, as identified by the SPHC, for better communication, training and hand-over. They also suggest a significant need for communication with occupants of new house types about their experiences, particularly types to which the contractor, architect, client and occupants may not be entirely familiar. As the PassivHaus standard and new products become more wide spread, this will prove to be more important, with a wider range of people who are not receiving regular contact with the design teams and specialists post-handover. There is also need for keeping installed equipment as simple to use as possible for the occupants operation.

The removal of the solar shading was made for cost saving purposes, however, the direct westerly aspect of the main living accommodation and glazing area has contributed to a significant summer temperatures above the comfortable range problem which will potentially have long-term consequences for the occupants and their modes of habitation of the homes. The lesson here for the future is to avoid changes post design stage, if such changes have potential for long term impact on performance. Other than the shading, most of everything else was agreed prior to construction, reducing significant changes on site, and subsequently as-built variations from design. This is something from which other projects could learn.

Overheating in low energy homes is increasingly becoming an issue. At the design stage, architects should develop adaptive designs that temper high temperatures by shading, ventilation and/or thermal mass. Although the obvious link with temperatures above the comfortable range is the omitted shading, further investigations should be undertaken into other causes and effects of these temperature rises. The relationship between solar shading, high insulation, and airtightness needs to be considered. It is important to establish whether the problem can be mitigated for this project. The addition of solar shading at a higher cost than what was originally saved, or planting of deciduous vegetation, at minimal cost, may help solve this problem.

The occupants' installations of additional systems suggest that a need to allow for flexibility for occupants to adapt homes to their specific needs without undermining the low energy design intentions.

It is significant that all occupants mentioned that they liked the homes and energy bills. This concurred with the reporting on interviews and questionnaires in **Chapter 5**, and will help to substantiate this and pinpoint specific aspects of the homes which they liked.

Considerations should be made as to the impacts on thermal-comfort and perception of not having heating in each room (thermostat and control). The addition of a utility space for other properties of this nature would serve well as an intermediate space. The heating and space needs of prospective tenant demographics in relation to that place need to be better understood. This was something that the BPE Team aimed to investigate further; the findings are reported in **Chapter 7**.

The walkthrough revealed the need for clarity of occupant guides as pointed out by one the TA2 occupant during the walkthrough. The 'Quick start Guides' developed by MEARU (see Section 5.22 next chapter) are expected to help to change occupant user behaviours to better match those of the house, and vice-versa. This will be discussed further in **Chapter 5**.

# 5. Occupant surveys using standardised housing questionnaire (BUS) and other occupant evaluation

This section discusses occupant surveys and other occupant evaluations conducted during the monitoring period. The TSB mandatory elements of the occupant handover process are designed to understand the level of information provided to the occupants when they moved into their homes, and the outcomes of the BUS evaluation undertaken across the entire development, not just the selected three dwellings for the TSB BPE study. The occupants were also invited to keep diaries for one week in the February 2014 and one week in the June/July 2014. As stated in chapter 5 and sections 5.1.1 and 5.1.2 below, a number of problems were identified and changes to the dwellings made before, and during the BPE monitoring timeline. It is worth noting that these may have influenced the occupant interviews, BUS, diaries, etc.

## 5.1 Occupant Handover Process

Semi-structured interviews were developed to discuss the handover process with the occupants. These aimed to understand the level of advice and support each household had received when moving into their home and to understand issues that the occupants were worried about. In particular, they were questioned over their ability to operate and control the heating and hot water systems to provide comfortable living and whether the heating was affordable. The questionnaire prompted discussion, in particular about heating, cooling and storage. The final questions were to establish whether there were any instances of asthma or health problems considered to be associated with the living environment. The questionnaire responses are summarised below and full questionnaires uploaded to **4**.

The housing association handed over the dwellings to the tenants with tenant information packs containing user manuals for the buildings operation (See **Appendix 5.2**). The tenants confirmed on their moving in, they received a booklet and a quick run through of the systems and controls. The occupants to TA1 found the User Manual difficult to understand, however the occupants to TA2 and TB1 appeared to be at ease with their new home and enjoying it. To address the difficult in understanding the original manual, MEARU prepared a simplified 'quick start' guide for the tenants in the three BPE dwellings, at a much later date in 2013. **Section 5.2.2** contains more information on the guides, **Figure 5.1** shows sample pages of the guide and **Appendix 5.1** contains a complete example guide.

### 5.1.1. House Type A

There were very few technical issues identified at or after handover in house type A. The reporting procedure for the new tenants for technical issues was through Fyne homes housing association, who would then arrange for fixing. Maintenance and repairs during the defects liability period were also through the Association and fixed by the contractor. The BPE team contacted both the contractor and window supplier regarding the difficult window/door locks, but they both did not seem keen to take responsibility, and the matter was left to the tenants to pursue through the housing association. On the whole, the occupants like their homes, in particular: the location and aspect, naturally lit rooms, the view and their energy bills.

### 5.1.2 House Type B

The technical issues identified after handover in house type B were related to do with the following not working properly, and remedial measures were proposed as follows:

| Item | Remedial tasks |
|---|---|
| Mechanical Ventilation with Heat Recovery (MVHR) - | Install new MVHR unit at high level above the glass door in the porch |
| Air Source Heat Pump | Install new air source heat pump |
| Controls for the Solar hot water system | Install a new control |
| Door bell | Reposition or replace existing front door bell so that it can be heard inside the house |
| Heat distribution through doors | 20mm to be removed from the bottom of the doors so that air can travel underneath |
| Requirement for a second towel rail | Install a new towel radiator in the down stairs bathroom |

The reporting procedure for the new tenants for technical issues was through Fyne Homes Housing Association, who would then arrange for fixing. Maintenance and repairs during the defects liability period were also through the Association and fixed by the contractor and the suppliers of systems installed through the Scottish Passive House Centre. The works for the above listed items were specified by The Scottish Passive House Centre. The occupants complained about feeling cold during winter. After the above remedial works they also complained of high energy bills and mistakenly thought it was the MVHR consuming high energy. Details of their energy consumption are presented in **Chapter 7**. Since the remedial tasks were completed, on the whole, the occupants have liked their homes. Other items identified after handover included issues of maintenance, high ceilings, and storage.

### 5.1.3 Other house types

The other house types on the development are not included in the BPE except for the BUS survey. The issues identified in these are highlighted in the BUS survey in the next section.

## 5.2 Occupant Interviews

MEARU developed semi-structured interviews from the TSB Guidance documentation. Semi-structured interviews with occupants were undertaken on 1st March 2013. The occupant of TB1 was unavailable, and had temporarily withdrawn from the BPE, citing disappointment with the remedial works of the mechanical systems, but later resumed participation after persuasion. However, the same questions had been asked as part of a pilot study on 14th March 2011. All occupants consented to participate in the interviews and did not have to complete a consent form since they had accepted to participate in all aspects of the BPE project. The transcriptions of these are in **4**. The specific objectives that MEARU set out for the interviews with the occupants, combined with the responses, were as follows:

*1. Note where the dwelling was being used as intended and where it was not; what they like/dislike about the home; what is easy or awkward; what they worry about.*

**TA1:** Occupants stated that their previous house was not as good and were happy with their current home. When asked what they liked about the house: the space is good; the light and views; warm and good storage. The summer nights were found to be too hot at the front of the house. In previous meetings and the BUS questionnaire, high internal summer temperature was something which they disliked about the home. Their main complaint related to the garden: more space needed for clothes drying; garden sloping too much to be useful; no privacy or safety to road for small children (fence had to be installed). Clothes were washed outside if the weather was good; but space for outdoor drying is inadequate. When the weather was poor, wet clothes were hung on the drier in the living room or in the boiler cupboard.

**TA2:** Felt that the home was much better than their last house. Things which worked well were the: Big windows and views; open plan and modern size of rooms; location; warm; own parking; good storage. Things which the occupants did not like were that there was no utility room and that the garden was a bit poor. Their internal laundry drying happened in the boiler cupboard at the upstairs landing. Sometimes the clothes are dried externally if the weather is good. They have a tumble drier but almost never used. The occupants felt that they knew how to use the building efficiently. They thought that they could probably be more efficient by switching off lights more and using the low electricity tariff for washing, etc. They also installed instant electric showers. The electricity bill was £118 per month, which they felt to be 'OK'.

**TB1:** The occupant said she loved the house but felt it could be warmer in extreme winter weather; may have to consider extra heating in certain rooms i.e. living room; and that temperature is topped up by the air preheater (AASHP) so depends if it is switched on or off. They stated that when temperature drops outside it can be difficult to keep rooms at a constant comfortable temperature. In terms of overall satisfaction, there was no comparison with the 100 years old traditional stone cottage she lived in before, adding that TB1 doesn't leak, no draughts and power doesn't cut out all the time. The main door entrance was seen as an excellent feature.

**Summary:** All occupants interviewed liked their homes and felt them to be an improvement on their previous homes. The garden was an issue for both TA1 and TA2 occupants. Clothes drying and a lack utility space was an issue, and this could be improved upon. Although both TA1 and TA2 occupants felt that their electricity bills were good and that they were using the homes well, the energy performance data (see **Chapter 7**) suggests evidence to the contrary in TA2.

*2. Which aspects provide occupant satisfaction and which do not meet their needs or result in frustration and / or compensating behaviour on the part of occupants. Are there any misunderstandings occupants have about the operation of their home?*

**TA1:** At the time of the first interview (28.09.12) the occupants had not yet switched on the heating system (in contrast to dwelling TA2); and anticipated switching it on in October. They found the building to be comfortable, but disliked the periods of overheating at the front of the house. When it was too hot they opened the windows and large sliding doors in the living room. *"They're often open in summer when it can be a bit too warm most of the time."* As the house is next to a busy road, noise has been an issue when the windows are open *"We've gotten used to the noise and have no choice otherwise it would be unbearably hot."*

If there are smells or moisture, they open the window by the kitchen. *"We never use the extract vent, not convinced it works but in any event, have never used it."* The occupants felt that they knew how to use the building efficiently. *"Bills all in (all heating and elec) are about £100/month so pretty good, and have come down since first moved in",* so believe that they are improving and learning how best to use things. They were not sure that they had clear expectations of the energy consumption of the dwelling. Given the 'hype' they thought the building might have been cheaper, but it is fine for them: it is cheaper and a lot warmer than the last place, so it is 'OK'.

**TA2:** In TA2, the householders indicated that the bedroom on the ground floor is without heating and is the coldest room in the house. The occupants had noticed a draft at the front door.

The electric boiler in this house was switched on most of the time and contributed to significant heat gains to the first floor space; resulting in overheating in summer and autumn; and causing frequent window opening. The householders had switched on their heating system around the 14th September 2012. To control the heating of the house, they found the storage heaters to be simple. They used the upstairs and downstairs hallway heaters most, the living room one much less. They do not use the bathroom towel rail heaters and doors are kept open. To deal with smells and moisture they do not use the extract vents, only windows are opened.

**TB1:** The householders wished that the house could be warmer. Figure 7.31 in Chapter 7 shows significant periods when the house was in the 'cold' temperature range. Periods of overheating are also indicated in the data and reported by the occupant. The occupant also stated that there was, as yet no cooker hood so kitchen smells can linger.

**Summary:** Occupants of all the houses stated that summer overheating happened in the living rooms on the ground floors; and bedrooms on the first floor that face the seaside. As a result, the windows on that side remained open most of the time. They all indicated that windows remain closed at night and most of the time in winter, early spring and late autumn; and that during summer, late spring, and early autumn; windows remain opened, particularly those at the upper bedrooms facing the sea. Section 7.4 discussed overheating and cold periods and the reasons for this in the context of other environmental data.

*3. 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.*

**TA1:** The occupants considered there to be no issues relating to the dwellings operation. They found the control of the heating of the house to be easy, they used the two storage heaters, one in the Living Room and downstairs hall, and they do not use the upstairs heater. They adjusted the programmer by turning it on and off at the thermostatically controlled level. They had problems operating the sliding doors at first, which resulted in a draft during the autumn and winter. The neighbours had a problem with this too. The occupant felt that this was a problem with the Fyne Homes user manual being in different separate parts; therefore they had missed the information.

**TA2:** The occupants made no comments specific to this section.

**TB1:** The occupant also pointed that some people could be nervous of operation based on technical manuals.

**Summary:** Except for TB1 where there was mention of nervousness, occupants felt there were no issues with the control of their homes. However, their problems with overheating and cold rooms, discussed in Section 5.3, suggest that there may be issues with user understanding and behaviour in the dwellings. See Section 7.4 for an analysis of the relationships between overheating and window opening.

*4. Find out if the developer / manufacturers produced user manuals help or hinder the correct use of the dwelling*

**TA1:** The occupant found the user manuals from Fyne Homes to be difficult to use, as it consisted of lots of different manuals for different things. This resulted in them missing information on how to use items such as the sliding doors (see above), which resulted in drafts and energy loss. They viewed the building prior to moving in; however, they felt that a tour of the equipment would have been of more use.

**TA2:** When asked if they had been given any manuals or information on how to work the dwelling, the occupant said that when they moved in they had been shown around by the builders and given a handbook. However, this was all a bit of rush as they were moving in at the same time.

**TB1:** The occupant pointed that when selling this kind of house, an owner's pack in plain English explaining functions of heat exchanger and water heating system would be a good idea.

**Summary:**

Problems with user guides were resolved through introduction of 'Quick-Start' Guides by MEARU, see section 5.2.2. These problems suggest a need for the Housing Association to review its policy for introducing occupants to their homes and accompanying guidance.

5. *Have there been any issues relating to maintenance, reliability and breakdowns of systems within the dwelling? Do breakdowns affect building use and operation? Does the occupant have easy access to a help service? Does the occupant log issues in a record book or similar?*

**TA1:** The dwelling had problems early on with the water heating: the electric box started smoking and there were faults with the system which have since been resolved.

There were ongoing problems with the windows, which were very stiff and hard to adjust, a result of a disagreement between the window manufacturers and contractor. Due to the windows being left outside too long prior to installation, there were subsequent problems with the windows. This resulted in the window manufacturers citing blame to the contractors, whereas the contractors insisted that it was a problem with the windows themselves. Throughout the duration of the dispute the occupants were left with no solution for stiff windows. The heaters would occasionally not switch on, but the occupant deemed this to be 'OK'. When asked about how the occupant dealt with problems, and whether they had a help service, they stated that during the year of defects Fyne Homes were good, resolving most things sorted pretty quickly, for free and on a helpline. After the defects period the helpline is no longer free, so people tend to go directly to tradesmen and resolve problems themselves.

**TA2:** When asked if the occupant is aware of any issues relating to water consumption, there was a fault with the expansion tank with noises / air lock. There was also a problem with the cistern flushing; if "no.2" is pressed then it carries on flushing continuously, so the occupant had to advise people only to flush the small button. As with TA1, the occupant also referred to the free Fyne Homes helpline in the first year of occupancy. After the first year they still had to phone Fyne Homes if there was a problem, but had to sort things out themselves, despite: 'Fyne Homes having a stake in the dwelling.'

**TB1:** Following the errors in installations of mechanical systems and subsequent remedial works, the occupant stated that the house felt warmer than previously. She also stated that she had developed an interest and better understanding of how a Passivhaus should work and were generally happy with their home.

**Summary:** On the whole issues that were identified were dealt with. However, the fee for the Fyne Homes Helpline was deterring occupants from seeking help with maintenance following the first year of occupancy. By using builders who do not know the homes and their systems, other problems may subsequently arise.

*6. Does the occupant have any particular issues with lighting within the dwelling (both artificial lighting and natural day lighting)?*

**TA1:** The occupants made no comments specific to this section.

**TA2:** The occupant stated that the main lighting issue was with the windows.

**TB1:** The occupant stated that at the back of the house, upstairs bedroom has very poor natural light.

**Summary:** The BUS survey (**Section 5.3**) identified issues that the occupants had with the there being too much natural light. But this was not discussed or an issue at the time of the occupant interviews in March 2013.

*7. From the occupiers point of view what improvements could be made to the dwelling to make it more user friendly and comfortable to live in. Cover what the teams would do differently in future (or wanted to do differently but could not) and why.*

**TA1:** The occupant felt that a tour of the equipment would have been useful. The heater manufacturer came a year after moving in, which was useful, but they already knew how to use the heaters by then. The hot summer nights were a problem, and being able to cool the front rooms of the house down would be beneficial. The garden was too small, exposed and steep, not good for families and clothes drying. Fyne Homes added a fence, but more consideration in the garden provision, safety and privacy would have been helpful.

**TA2:** An electric instant hot water shower was fitted by the occupants. As with TA1, they felt that it would have been better to have the house tour a couple of days later once they had settled in and got their bearings a bit. Moving in day was too busy for this. The felt that a utility room would be nice and a dedicated drying cupboard, but otherwise the house was fine. They did not like the lack of a utility room, and felt that the garden was poor.

**TB1:** The back of the house, upstairs bedroom has very poor natural light. Velux windows installed as per hallway would have been a welcome feature to improve daylight at the back of the bedrooms. She could consider extra heating in certain rooms i.e. living room. She stated that storage space is limited, heat exchanger takes space in lower hall cupboard; in the main bathroom, there is no space for towel + toiletries storage; the small bedroom doesn't require such a large cupboard; and in the kitchen units' height, appliances don't fit. As per other developments, consulting buyers on final finishes would be welcome detail. From original design she had seen, she thought a canopy would be built on front, and this would have been good for shelter.

**Summary:** Much of the responses to these questions were covered previously. The main points were that a tour of the building and equipment once they had moved in would have been useful. A utility room, dedicated drying room, and improvements to gardens were also important to the occupants, and more storage would be useful to TB1.

### 5.2.1 User Manual

The original Owner's Handbook (**Appendix 5.2**) issued to the occupants contained the key aspects of the project as prepared by the architect. It outlined the operation of key aspects including services, fixtures and fittings. There was no other information on heating and ventilation, and no information on the heating controls or the energy saving potential through specific aspects of the house. It also had the manufacturer's information on the components of the heating and ventilation systems appended to it. For TB1, the handbook contained the manufactures installation and maintenance information of the MVHR, solar hot water system, and air-to-air source heat pump. The householders of TA2 stated that some of the information contained in the handbook was difficult to understand.

As part of the remedial works in TB1, there was a specific requirement to provide the client with a comprehensive and easy to use operations and maintenance guide for the MVHR unit; and all equipment associated with it, including the use of the new air source heat pump.

### 5.2.2 Quick Start Guides

MEARU developed Quick Start Guides for each household and delivered these to site. A MEARU researcher met with the occupants to discuss their potential role in the BPE study, but also to help them fully understand their homes and services. MEARU and Scottish Building Standards Division have taken these to consultation for inclusion in Scottish Building Standards, Section 7. An example guide can be found in **Appendix 5.3**. The guides were developed with graphics and simplified text to make them easy to understand. Each guide was explained to the main householder by the MEARU researcher who delivered it, and householders asked questions regarding any technical systems and their operation if they did not understand. They reported that the guides and explanation visits were useful in helping them understand better. It was not clear or possible to establish, from the energy and environmental monitoring, whether the guides had a significant impact on householder behaviour because of the many factors that influenced the energy and environmental performance.

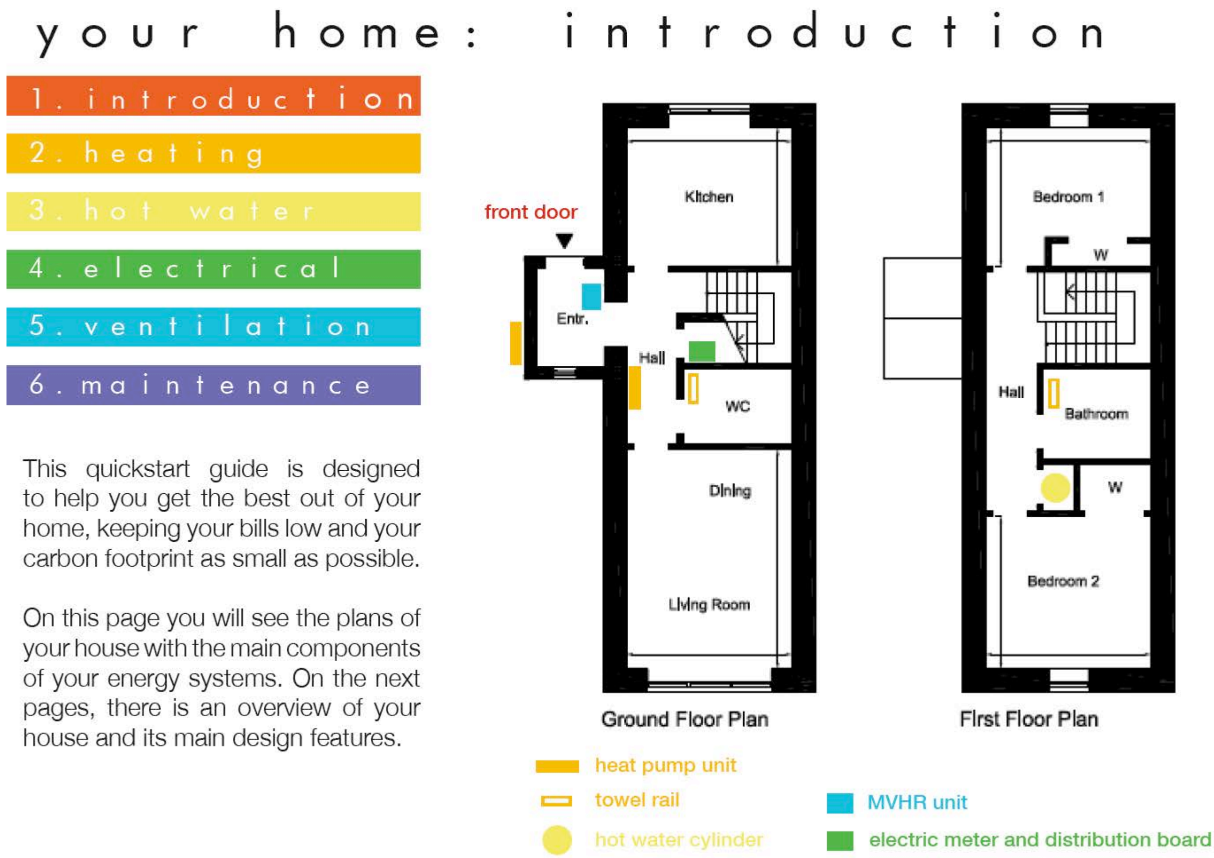
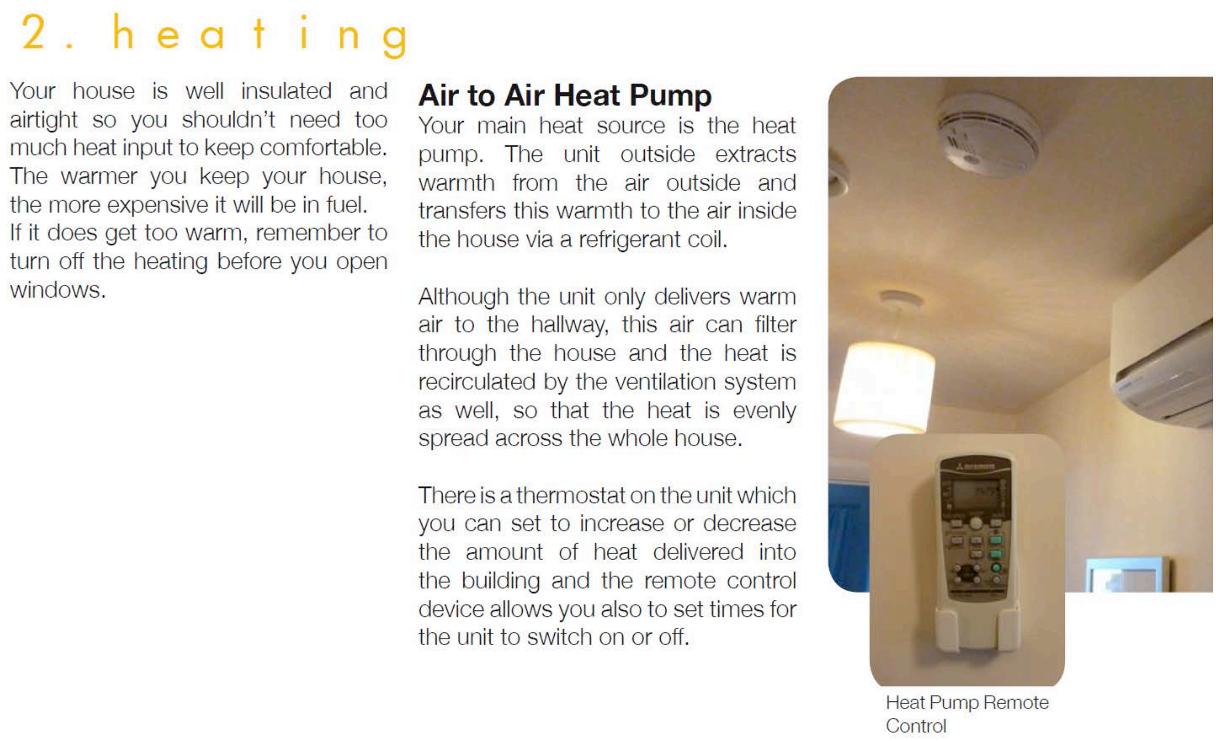



**Figure 5.1:** Example pages from a Quickstart Guide given to occupants.


2. heating

Your house is well insulated and airtight so you shouldn't need too much heat input to keep comfortable. The warmer you keep your house, the more expensive it will be in fuel.
If it does get too warm, remember to turn off the heating before you open windows.

**Air to Air Heat Pump**

Your main heat source is the heat pump. The unit outside extracts warmth from the air outside and transfers this warmth to the air inside the house via a refrigerant coil.

Although the unit only delivers warm air to the hallway, this air can filter through the house and the heat is recirculated by the ventilation system as well, so that the heat is evenly spread across the whole house.

There is a thermostat on the unit which you can set to increase or decrease the amount of heat delivered into the building and the remote control device allows you also to set times for the unit to switch on or off.

Heat Pump Remote Control

**Figure 5.2:** Example pages from a Quickstart Guide given to occupants.

## 5.3 Building Use Study (BUS)

BUS is an established method of evaluating occupant satisfaction and for benchmarking buildings against a large database of details for similar buildings across a development. This survey formed a mandatory requirement of the TSB BPE study and it took place over a two day period, 6th and 7th March 2014. This time of year was specifically selected as it was considered to be more neutral in terms of climate (being spring), which would potentially reduce the probability for weather influencing respondents' comments. One week before the planned survey, a letter was posted to each address in the development to request participation in a doorstep survey. Each survey was conducted in the home of the respondents where the researchers completed the questionnaire by transcribing comments made by the respondent. The introductory letter, BUS information sheet and sample completed questionnaire can be viewed in **Appendix 5.4**.

After the survey, the responses were entered into the standard BUS spreadsheet template and emailed to Arup for analysis. This allowed the results for this development to be benchmarked against other BUS responses; these were presented in two reports. One report sets out the quantitative data and the second report itemises the occupants' responses to the survey questions (these reports can be viewed in **Appendix 5.5**). As part of the analysis, Arup provide a web link to a standard report, located at:
http://portal.busmethodology.org.uk/Upload/Analysis/hqygkcxt.45c/index.html [Last Accessed 23.09.2014].

A full evaluation of the BUS results is provided in **Appendix 5.6**, the quantitative and qualitative results are summarised separately herein.

### 5.3.1 Quantitative BUS Survey Results

The final response rate was 50% i.e. 7 dwellings responded out of the fourteen dwellings to which invitation letters to participate and BUS questionnaires were delivered. For such a small sample of 14 dwellings, a higher response rate would have improved the findings. A MEARU researcher delivered the questionnaire in person, and talked to those who were at home about the purpose of the survey and that it involved a UK-wide selection of housing developments. A person from the housing association was conducted to help in engaging the occupants but was not very helpful. Three householders were not at home during both the days of the delivery and conducting the surveys but the paperwork was left at their letter boxes; two promised to do it at their own time since they did not have time, but never returned them; and one said that she had too much going on in her life at the time to participate. The 14th dwelling is used by a local community group as their offices, and it was closed during both visits.

**Occupant background data**

Table 5.1 shows the results of the BUS survey background questions. This depicts results for both House Type A and House Type B, by percentage and number of responses, providing an overview of the respondents who participated in the survey.

| | | House Type A | House Type B |
|---|---|---|---|
| **Question** | **Value** | **No. responses** | **No. responses** |
| **Age** | 1. Under 30 | 1 | 0 |
| | 2. 30 or over | 5 | 1 |
| **Sex** | 1. Male | 4 | 0 |
| | 2. Female | 2 | 1 |
| **Time lived here** | 1. Less than one year | 0 | 0 |
| | 2. One year or more | 6 | 6 |
| **Other people 18 years or over** | 1no. | 5 | 0 |
| **Other people under 18** | 1no. | 1 | 1 |
| | 3no. | 1 | 0 |
| **Are you normally at home…?** | 1. Most of the time | 2 | 0 |
| | 2. Evenings and weekends only | 2 | 1 |
| | 3. Other | 1 | 0 |
| **Dwelling Type** | 2. Semi-detached house | 6 | 1 |
| **Occupancy Type** | 1. Tenancy | 0 | 0 |
| | 2. Owner Occupier | 5 | 1 |
| | 3. Other | 0 | 0 |
| **Has living here changed your lifestyle?** | 1. Yes | 6 | 0 |
| | 2. No | 0 | 1 |

**Table 5.1:** Responses to BUS background questions from House Type A and House Type B occupants.

**BUS Survey Variables**

A range of questions were asked which required the respondents to answer based on a performance scale of 1-7. The questions were designed to evaluate the dwelling design, needs of the occupants, comfort, indoor air quality, control, noise, lighting, health, lifestyle and utilities.

The results were grouped in the following categories:

- Data set scoring better than Benchmark and scale midpoint (Green Square);
- Data set scoring between the Benchmark and the scale midpoint (Amber Circle) ;
- Data set scoring poorer than Benchmark and scale midpoint (Red Diamond).

The summary of BUS variables for **House Type A** (presented in Table 5.2), and for **House Type B** (presented in **Table 5.3**), indicates that the majority of the variables for both House Types were ranked higher than average benchmark (green squares).

The quantitative results from the questionnaires need to be carefully considered in the context of the individual feedback comments. This is particularly with reference to noise, light (natural lighting), space and design. For example, many participants praised design aspects for both house types, but they ranked with an orange circle (indicating that it was average). They also like the glazing for its views and the natural light, however, in both house types, this ranked with a red diamond (indicating that it is worse).

The absence of draughts in the dwellings during winter should be considered a good result (indicated by a red diamond) for both house types in terms of airtight dwellings. The lack of draughts is in keeping with the relatively good result from the airtightness tests conducted on the three BPE study dwellings (see **Chapter 3**). However, the summer equivalent of this variable also scores lower than the benchmark in House Type A and poorer by the benchmark in House Type B.

The following analysis is predominantly based on the quantitative analysis of the BUS data variable groups outlined in **Table 5.2** and **Table 5.3**. This is also compared and contrasted with the BUS survey comments and occupant walkthroughs, in particular when there is deemed to be a contrast between the two data sets. The analysis particularly focuses on variables which: contradict between quantitative and qualitative data; or have a result contrary to the design intent or other findings. For further details, see BUS survey data tables (**Appendix 5.5**); BUS survey comments **Section 5.2.2** (**Appendix 5.5** and **Appendix 5.6**); occupant walkthroughs (See **Chapter 4**); comparison between design intent and occupant feedback (See **Section 5.5**).

**Seasonal air: Summer and winter**

The air in summer rated better than the benchmark and scale midpoint (Green Square) in three out of the five summer air categories: dry/humid; fresh/stuffy; overall. The air was perceived to be marginally drier on average (score: 3.8), considerably fresher (score: 3.2) than the mean (score: 4.01). The air in summer overall was deemed more towards the satisfactory end of the scale (Score: 5.4). The air in summer: odourless/smelly and still/draughty variables rated between the benchmark and the scale midpoint (Orange circle) scored 4.2 and 3.6 respectively. Whilst 80% of occupants scored 3 and 4 for odour, one occupant scored 7 'smelly'. In the comments section one occupant did not feel able to cook fish because of the open plan, because the smell went throughout the house. Other comments suggested that extraction of smells could be a problem: *"Ventilation for cooking and bathroom is not fit for purpose"; "Kitchen smells can linger"*. The statistical feedback on air in summer, on the face of it, would appear to be successful with the design intent to have a cross-ventilation for summer cooling, and user comfort. However, in contrast, these statistics do not reflect the summer temperatures above the comfortable range which had been of considerable concern to occupants on the walkthrough and in BUS survey comments: *"Greenhouse effect in summer"; "House can get too hot in summer".*

The air in winter rated less well than summer air overall with four out of five variables scoring between the benchmark and the scale midpoint (Orange Circle). Whereas one, still/draughty scored poorer than both the benchmark and the scale midpoint (Red Diamond). This is significant when compared to the results for the summer, and will require review in comparison with House Type B data.

The air in winter overall (Score: 4) was considered unsatisfactory (score: 1) by 33% of participants, but the remaining four scored one each, 4-7. The extreme response of these homes and the related patterns of use, which could have caused this dissatisfaction are important to understand. One outcome of particular significance, which may be a reflection of the methodology rather than the homes, was the rating for Air in winter: still/draughty. This rated a 'red diamond' (score 2.66) in the 26th percentile on the basis that the air was too still, this was also an issue for House Type B. In the comments, for heating comfort, most occupants found the heating to be very good, but a few found their downstairs bedroom to be cold. One made particular reference to preferring a change in radiator.

**Seasonal temperature: Summer and winter**

The summer temperature did not reflect as poorly as previous comments may have indicated, however, it was not excellent. All summer variables rated between the benchmark and midpoint: hot/cold scoring: 3.4; overall: 4.8 although 1no. respondent scored 7, very comfortable; stable/varies scored: 4. The winter temperature variables were all above the benchmark and mid-point, indicating good thermal comfort in winter. However, in the comments, two occupants found the back, downstairs bedroom to be cold.

**The residence overall**

The design variable remained within the midpoint benchmark (Score: 5.66) with an 88th percentile. On the whole, occupants were very positive in their feedback about design, however, the benchmark was high, and one occupant scored the design with a 3. In the comments, one occupant thought that the *"[interior is] too modern/clinical for me"*, while another felt that: *"Everything is first class"*. Other comments about the design were in different sections, in particular the on 'the residence overall', these particularly relate to the appearance from the outside which scored: 6.16 in the 99th percentile. The feedback about layout was split, four respondents scoring 7, one occupant scored it 3, with an overall score of 6. Most comments about the open plan layout and scale of rooms were positive, however, two did not like having an open plan kitchen, this also related to previous comments about lingering cooking smells.

Storage received mixed comments, scoring 4.5. Two occupants felt there was not enough, scoring 1 and 2, whereas one was in the middle and three scored 6 and 7. Storage was a particular problem in comments and from occupant walkthroughs. Some comments differentiate between internal and external storage, while others do not.

#### 5.3.1.1 House Type A

| Green Squares | Amber Circles | Red Diamonds |
|---|---|---|
| Issues scoring better than the benchmark and scale midpoint | Issues scoring between the benchmark and the scale midpoint | Issues scoring poorer than benchmark and scale midpoint |

| | | |
|---|---|---|
| • Air In Summer: dry/humid<br>• Air In Summer: fresh/stuffy<br>• Air In Summer: overall<br>• Control over cooling<br>• Control over lighting<br>• Control over ventilation<br>• Comfort: overall<br>• Health (perceived)<br>• Appearance from the outside<br>• Layout<br>• Location<br>• Space<br>• Lighting: artificial light<br>• Lighting: overall<br>• Needs<br>• Noise: noise from outside<br>• Noise: overall<br>• Temperature in winter: hot/cold<br>• Temperature in winter: overall<br>• Temperature in winter: stable/varies<br>• Utilities costs for electricity<br>• Utilities costs for heating | • Air In Summer: odourless/smelly<br>• Air In Summer: still/draughty<br>• Air in winter: dry/humid<br>• Air in winter: fresh/stuffy<br>• Air in winter: odourless/smelly<br>• Air in winter: overall<br>• Control over heating<br>• Control over noise<br>• Design<br>• Storage<br>• Noise: noise from other people<br>• Temperature in summer: hot/cold<br>• Temperature in summer: overall<br>• Temperature in summer: stable/varies | • Air in winter: still/draughty<br>• Lighting: natural light<br>• Noise: Noise from neighbours |

**Table 5.2:** Summary of results and BUS benchmarks for **House Type A.**

**Occupant needs**

Occupant needs scored highly, in the 99th percentile with a score of 6, all occupants scored 5 or 7. This demonstrates that the housing meets occupant's needs and also satisfies some of the design intent through creating good homes with the occupant's wellbeing in mind.

Overall comfort scored particularly highly (Score: 6.5) above the benchmark in the 99th percentile. Perceived health scored highly (green square, score: 5.83), there were only two comments, which were: *"Cheers you in the summer"* and *"Peaceful".* These comments are important, as they are concurrent with the design intent of occupant well-being and happiness. However, the category of health may have been misleading or misunderstood to some respondents.

It is worth noting that Control over cooling, lighting and ventilation are rated a green square; whereas control over heating and noise are rated an orange circle.

Control over cooling scored very well, in the 99th percentile with 80% of occupants rating 7, 'full control', scoring 6.8 overall. This is significant, given the feedback that there was a significant problem with summer overheating. Control over heating (orange circle, score: 4.8) varies between dwellings. Two respondents rate it 1 and 2: no control; whereas three respondents rate it as 7: full control. Given the feedback about there being good control, this requires further investigation, again, it may relate to the difficult of some occupants with using the storage heaters. Control over ventilation ranked well, (green square, score: 5.6), this was also reflected in the comment: *"Opening windows and trickle vents no problem".* However, this contradicted other comments about summer overheating.

Control over lighting (green square, score: 6.4) 80% of respondents scored 7, while only 20% scored 4. All comments relating to glazing were positive; the main criticism of lighting control was that: there were too many; a different type may be preferable. Control over noise was an issue, (orange circle, score: 4.5, 82nd percentile), three participants scored 1, 2 and 3, whereas the remaining 3 scored 7, full control.

**Lighting and noise**

With regard to the lighting variables, most of the occupants commented positively towards natural light and praised the large windows and the view. This feedback satisfied the design intent for the use of natural light, however, the BUS data contradicted this, rating lower than the benchmark and midpoint (Red Diamond, score: 5.16) by there being too much natural light. This could reflect on the method used, but this should also be compared with data in later chapters as to the role that the glazing and lack of solar shading played in the summer temperatures above the comfortable range of the properties. Artificial light and lighting overall scored 4 and 6.33 respectively, both better than the benchmark.

Noise from neighbours, on the face of the data, would suggest that this is a problem due to scoring poorer than the benchmark and scale midpoint. However, this is on the basis that one is 'too little' while 7 is 'too much', therefore, because 50% of occupants scored 1, and the remaining scored between 4 and 6. This essentially becomes a negative point. This would indicate further that there are misgivings in the BUS survey used, which need to be addressed – refer to conclusions. In contrast, noise from outside and overall, were satisfactory, contrary to several comments about problems with noise from neighbours above and external noise. Noise from other people scored within the benchmark and midpoint: 4.4. In the comments, one occupant found external noise and vertical sound transfer to be a problem, whereas others did not. It would appear that horizontal sound transfer was not an issue.

**Utilities Costs**

Costs for electricity and heating both scored better than the benchmark and scale midpoint. Where 1 was 'much lower' than the occupant's previous accommodation, for electricity: 33% scored 1, 50% scored 3 with an overall score of: 2.16; for gas: 33% equally for 1, 2 and 3 with an overall score of: 2. This result was corroborated by only positive feedback from occupants on utilities costs. This met the design intent of affordable homes during occupancy, as well as reducing the building's environmental impact.

For House Type B, more data was rated as being below both benchmark and scale midpoint (Red Diamond) than between these points (Orange Circle), this was the reverse in House Type A. It should be noted that there are three possible explanations for this outcome:

- The answers to most of the scales with number 1, 4 or 7. While there were a few responses in-between, considerably more data was placed outside the range and in either the extremely positive (Green Square)or negative (Red Diamond) ends of the data set, very few were in the medium range (Orange Circle)
- Differences in design may indicate that factors which may be positive as a result of PassivHaus design may be significantly outside occupant expectations or the current benchmarks – suggesting that these should be reviewed.

**Seasonal air: Summer and Winter**

On the whole, the results for summer air variables were very good - scoring four out of five rating above the benchmark. However, the still/draughty variable was poorer than both the benchmark and midscale point (Red Diamond). The score for this was '1: Still'. This has essentially become a negative point, far preferable to a draughty building. The winter air variable results were similar, with still air also rating Red Diamond. This should be a point for review with regards to the BUS system used.

### 5.3.1.2 House Type B

| Green Squares | Amber Circles | Red Diamonds |
|---|---|---|
| Issues scoring better than the benchmark and scale midpoint | Issues scoring between the benchmark and the scale midpoint | Issues scoring poorer than benchmark and scale midpoint |
| • Air in summer: dry/humid<br>• Air in summer: fresh/stuffy<br>• Air in summer: odourless/smelly<br>• Air in summer: overall<br>• Air in winter: dry/humid<br>• Air in winter: fresh/stuffy<br>• Air in winter: odourless/smelly<br>• Control over cooling<br>• Control over lighting<br>• Control over noise<br>• Control over ventilation<br>• Comfort: overall<br>• Appearance from the outside<br>• Layout<br>• Storage<br>• Lighting: artificial light<br>• Lighting: overall<br>• Needs<br>• Noise: overall<br>• Temperature in summer: hot/cold<br>• Temperature in summer: overall<br>• Utilities costs for electricity<br>• Utilities costs for heating | • Air in winter: overall<br>• Design<br>• Health (perceived)<br>• Location<br>• Space<br>• Temperature in winter: overall | • Air in summer: still/draughty<br>• Air in winter: still/draughty<br>• Control over heating<br>• Lighting: natural light<br>• Noise: noise from neighbours<br>• Noise: noise from outside<br>• Noise: from other people<br>• Temperature in summer: stable/varies<br>• Temperature in winter: hot/cold<br>• Temperature in winter: stable/varies |

**Table 5.3:** Summary of results and BUS benchmarks for **House Type B.**

**Seasonal temperature: Summer and Winter**

The summer temperature variables for hot/cold and overall (green square, score: 4 and 7) did not indicate a problem with temperatures above the comfortable range previously identified. However, the stability of summer temperature was deemed to vary too much during the day, rating red diamond (score: 6). No reference was made in the comments to summer temperature and cooling, but this had been in previous occupant interviews/walkthrough.

The winter temperature variables require further data investigation. These reflected the comments that there were problems with the heating and control of this during the winter. It was deemed too cold (score: 6) with an overall score of 4, and too variable (score: 5). It is only the overall score is rated orange circle, while the others are red diamond.

**The residence overall**

Appearance from the outside and layout rated very highly, both scoring 7. Space rated within the midpoint and benchmark, scoring: 5, this was referred in the comment: *"Living room space is big enough for guests and kids to play. Kitchen size good enough to have a table"*, yet the second bedroom was described as *"smallish"*. Design rated on the mid-range of the scale, scoring 5, although these aesthetics and layout were rated highly, reference was made in the comments to the height of the upstairs room and consequently difficult to maintain. The location was within the midrange and benchmark, scoring: 6, in the 69th percentile.

Storage rated well (green square, score: 6), however, reference was made in the comments to the need for further outdoor storage.

**Occupant needs**

Overall, 'control' scored well – better than the benchmark and scale midpoint on most variables. However, control over heating rated poorer than both (Red Diamond), this was also referred to in the comments, and that heating can become uncomfortable in the winter. This was cited as the only reason for discomfort, the overall comfort variable scored well (Green square, Score: 6).

Health rated on the midrange of the scale (Score: 4), there was no perceived effect in the comments.

**Lighting and noise**

The artificial light and overall variables rated well (green square, score: 6). However, the natural light variable scored poorer than both the benchmark and scale midpoint, red diamond score: 5, towards the 'too much' end of the scale. However, the following comment contradicts this rating: *"Bedroom at the back is dark - other rooms are ok".* As with House Type A, the natural light rating could be an issue for review, as the design intent allowed for a lot of natural light within the building.

The noise variables, specifically noise from neighbours and outside, as with House Type A, rated poorer than the benchmark and scale midpoint (red diamond, score: 1 and score: 2) on the basis that there was 'too little' noise. This raises an issue as to the method applied in the BUS survey, and will be discussed in **Section 5.4**. Overall, noise was deemed to be 'satisfactory' (score: 7), whereas noise from other people rated red diamond (score: 5), towards the 'too much' end of the scale. The results of these variables are contradictory; there are no references to noise in the comments that could clarify this.

**Utilities Costs**

The outcome of the utilities costs variables is excellent, both electricity and gas rating considerably better than the benchmark and midpoint, scoring 1: much lower than their previous accommodation. The comments echo this, relating energy costs to the technologies installed: *"I'm more aware of heating water by electric because I have solar so I monitor more and control both solar and electric depending on sun condition".* This reflects well on the design intent for an affordable PassivHaus system which keeps the running costs low for the occupants, as well has reducing environmental impact through energy consumption.

### 5.3.2 Individual Feedback Comments

The BUS questionnaire was divided into sections with variables as sub-sections. **Appendix 5.5** lists a selection of the comments most frequently made during the survey. There were areas in which the occupants considered the project to be successful in aligning with the design intent. For example the development location with it's to the Clyde estuary and a 'beautiful view' ranked highly (TA: 81$^{th}$ Percentile; TB: 69$^{th}$ Percentile), this was highlighted by frequent comments relating to ability to the view and location.

The greatest numbers of positive comments with no negative counterpoints were for the four Utilities Costs variables. The utilities costs for both heating and electricity were in the 9$^{th}$ percentile for TA1; 10$^{th}$ percentile for TB1. **Appendix 5.6** summarises respondent's comments to each of the BUS variables, for both House Types A and B; highlighting what works well and what does not.

### 5.3.3 BUS Limitations

It is worth noting that there are a number of discrepancies between the BUS survey and the monitored findings from the project. It was apparent in undertaking the BUS survey that there were some limitations to its use in a domestic environment and these are discussed below.

**Sample Size**. There are some limitations of the BUS methodology in domestic dwellings, which suggest that further development is needed to provide a useful tool. The BUS was developed primarily as a tool for non-domestic buildings, such as offices and schools and therefore relies on a reasonably large and homogenous sample size. This sample can also be relatively easily accessed through a workplace, where occupants may be employees. In this project however the sample size is smaller (a total of 7 dwellings), and it was necessary to go 'door-to-door' to elicit surveys. This is time consuming (and therefore expensive) and has limited success rates, in this case 7 out of 14 dwellings. The other related issue is that there are three different house types in this development, with different situations (e.g. mid and end terrace, upper and lower flats). Therefore occupants may thus have very different experiences. The BUS tool may be of more use in domestic assessment if more granularity can be examined, but the current licensing arrangement precludes this.

**Semantic Differentials**. As with other parts of the survey, it would seem that the semantics used are not well suited to domestic surveys and served to cause confusion and, in this instance, provide negative outcomes when this may not have been the perception of the respondents. For example, qualities such as 'still' or 'dry' air may have pejorative resonance with occupants of an office building. For housing tenants, these qualities are the opposites of 'draughty' and 'damp', which in the context of social housing in Scotland, are all too familiar concepts, so describing a building as still and dry may be considered an excellent thing. Similarly, for some occupants 'fresh' has an association with temperature ('its a bit fresh today'). Some items may be confused with other elements, for example 'cooling' and 'ventilation'.

**Prior Experience**. This point also relates to occupants prior experience. In other interviews and discussions with occupants, frequent reference is made to occupants' prior housing experience. It is possible that responses are therefore conditioned to a certain extent by the nature of the prior experience, in which new houses will be seen as very positive. A more longitudinal approach to satisfaction may therefore be more appropriate.

**Useability of the data**. The final issue is how use the Housing Association can make use of the data. The BUS survey was designed for larger buildings with corporate clients and user groups with a greater understanding of statistical analysis. Notwithstanding any methodological issues, the nature of the data and its presentation were of limited use to the Housing Association.

## 5.4 Occupant diaries

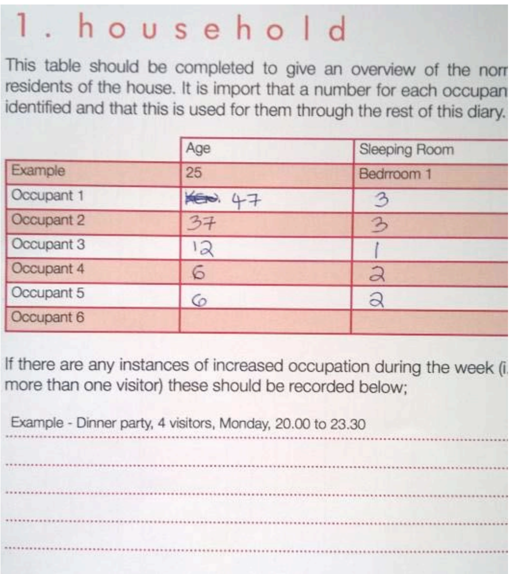
Although not part of the BPE project the research team undertook occupant diaries across all MEARU TSB projects over 24 hours a day over one winter week, Monday 3rd – Sunday 9th February 2014; and one summer week June 30th to July 6th 2014. The aim of the diaries was to gather fine grain data on occupancy and activity patterns in the dwellings, and to analyse these against the environmental and energy performance data. A standard form was developed in-house by MEARU and issued across all projects with guidance for occupants. The building and room use of individual occupants was mapped throughout the week with specific reference to bedrooms, bathroom, cooking and laundry.

The detailed data from the occupant diaries showed the daily routine for each occupant, by room and when at home over 7 days. For a sample occupancy diary see **Appendix 5.7**. This information included:

- *Household Occupant:* by number, age and bedroom.
- *House Occupancy:* a detailed 24 hour occupancy schedule.
- *Bedroom Occupancy:* when they got up and went to bed; whether the bedroom door was open or closed;
- *Bathing:* use of the bath or shower;
- *Cooking:* Cooking duration and meal description;
- *Laundry:* Detail of laundry washing and drying;
- A summary of comfort and air quality for each occupant.

Across the MEARU TSB projects, the return rate for the winter diaries was 100%, while summer diary return rate was poor, at 25%. The winter diaries were specifically handed to an occupant in each household, the completion was explained to the occupant and a stamped addressed envelope (SAE) was provided to return to MEARU on completion. In addition, the occupants were given a financial incentive to complete these which would be handed to them once their diary was returned. In contrast, the summer diaries were posted to the occupants with a SAE and detail of the same financial incentive. Two (25%) diaries were returned. Having spoken to occupants on the telephone to remind them to return the diaries we were advised either they didn't receive a diary, didn't have time to complete it or keeping track of occupants in a dwelling proved too difficult.

The data procured from the occupant diaries was reported in conjunction with measurements of the environmental conditions recorded throughout the week. A sample diary is shown below.



1. household

This table should be completed to give an overview of the norr
residents of the house. It is import that a number for each occupan
identified and that this is used for them through the rest of this diary.

| | Age | Sleeping Room |
|---|---|---|
| Example | 25 | Bedroom 1 |
| Occupant 1 | ~~Ken~~ 47 | 3 |
| Occupant 2 | 37 | 3 |
| Occupant 3 | 12 | 1 |
| Occupant 4 | 6 | 2 |
| Occupant 5 | 6 | 2 |
| Occupant 6 | | |

If there are any instances of increased occupation during the week (i.
more than one visitor) these should be recorded below;

Example - Dinner party, 4 visitors, Monday, 20.00 to 23.30

**Figure 5.3:** General sample Occupant Diary: occupants and visitors were all noted throughout the week.

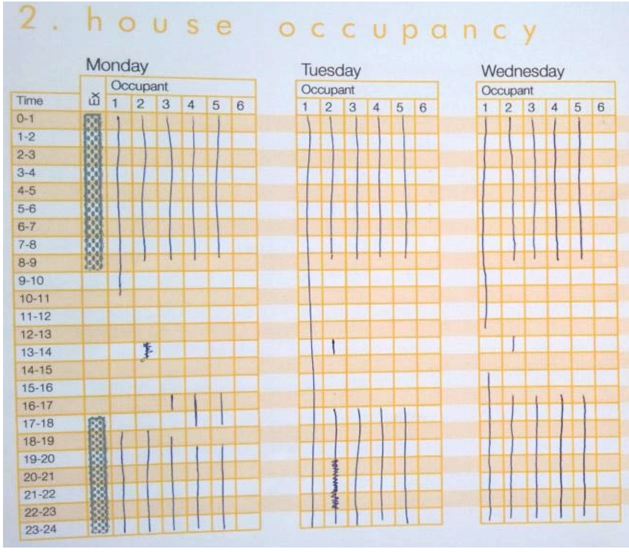



**Figure 5.4:** General sample Occupant Diary: occupancy frequency and levels allows comparison and granular analysis with quantitative data collected during this period.

The key finding from the diaries was occupancy information granularity which was not possible to collect using all the other occupant surveys. In TA1, there was a consistency of the occupancy pattern of the children as described during the interviews. The parents' pattern was however, not one of being continuously at home, as believed by the MEARU researchers after the interviews. In TA2, although after the interviews MEARU researchers believe was that the two shift workers alternated between day and night; and that there would be someone always at home, the diaries revealed that this was not always the case – occupancy it was actually different each day of the diaries completion week. Occupancy in TB1 was very consistent and in harmony with the information provided during the interviews. The information collected regarding use of the baths or showers, cooking durations and times, and laundry; showed very different usage patterns across the three dwellings; and are evidence that some of the assumptions and predictions of unregulated energy using tools such as DomEARM can be incorrect.

## 5.5 Discussion

For a summary of design intent versus occupant feedback for the different BUS topics and variables, see **Appendix 5.6**. In these the occupant comments are summarised and concurrent between house types unless stated otherwise. A significant percentage of the responses in the BUS by occupants of the three BPE dwellings were similar to those they gave in the occupant diaries and the occupant semi-structured interviews. Information for design intent is taken from several sources: design team interviews, the project architect's reports on the project and Fyne Initiatives Ltd.'s records. Detailed information regarding the design intent column in the table can be found in **Chapter 2** of this report. As **Table 5.5** shows, the design intent has largely been met in this project. Of particular note from the occupants feedback was the location of the dwellings and low utilities bills. Comparison between the qualitative and quantitative data of both house types suggests that there are some issues to be reviewed: further data analysis of indoor air variables; and review of the BUS survey method and change which could be made to this.

**Issues for further investigation**

- A comparison is needed between winter air and temperature variables in both house types against BPE data. The variability of temperatures and comfort issues, against a rating which is poorer than both the benchmark and scale midpoint requires further investigation, in particular whether there are adequate air changes
- Noise transfer between properties.

| BUS Variable | Design Intent | As-built: Occupant perception: Comments and rating |
|---|---|---|
| **The Residence Overall** | | |
| Location | • Site sold by Argyll & Bute council on condition affordable homes would be built;<br>• Selected by Fyne Homes for proximity to Dunoon;<br>• Community consultation | • Close to town, beautiful location with good views;<br>• The only downside is the road between the homes and the beach. |
| Space | • Light, double height spaces in bedrooms;<br>• Light and airy;<br>• Sense of space. | • Spacious rooms were noted by a number of occupants;<br>• TB1 – small second bedroom was a negative;<br>• Not enough space in gardens, front and back. |
| Layout | • Orientated to view and optimum passive performance.<br>• Open-plan; organisation of main rooms to view and to maximise heat transfer/reduce need for space heating | • Most felt that the layout worked well for them;<br>• For some the open plan layout was favourable, for others they did not like the open plan layout. |
| Storage | • No mention of design intent | • Some - sufficient indoor storage; others insufficient storage;<br>• Others - not enough outside storage. |
| Appearance | • Reflective of local vernacular: common local form;<br>• Relationship and cultural / visual links with beach huts. | • Liked how homes looked / how they looked 'different';<br>• Negative comments on interior appearance, e.g. Kitchen, modern décor, difficulty maintaining the look. |
| **Occupant needs** | • Affordability (purchase and run);<br>• Accessible. | • For most, convenient<br>• some raise issue with large windows versus furniture location |
| **Comfort** | | |
| Heating | • High level of insulation throughout and high levels of airtightness (better than building regulations) – improve thermal comfort.<br>• Energy efficient electric heaters and heating control. | • Most were positive about heating and the limited use of that.<br>• Some referred to cold in the unheated downstairs bedrooms.<br>• Some would prefer alternative to electric storage heaters.<br>• TB1 – AASHP insufficient – and this feedback was after remedial works on AASHP, doors and MVHR |
| Cooling | • Cross-ventilation (enabled by layout and glazing);<br>• Operable roof lights. | • Extractor fan not efficient;<br>• Can get too hot in summer - greenhouse effect;<br>• TB1 – no problem - Velux windows are openable. |
| Overall | • Kitchen and bathroom extraction vents – reduction of additional humidity.<br>• High performance glazing fitted with trickle vents. | • Well built, well insulated, attractive, good value<br>• One ceiling fan in lounge which helps cooling in summer and blows heat down in winter;<br>• Lack of accuracy and control of storage heaters. |
| **Noise** | • No mention of design intent | • No problems with horizontal acoustic transfer;<br>• problems with noise;<br>• Specific problems with: vertical acoustic transmission; road and external noise. |
| **Lighting** | | |
| Lighting overall | • Adequate natural and artificial light | • Perfect for one, another found the back room to be a 'bit dark'. |
| Natural Light | • High levels of glazing: to allow for natural light; reduction in artificial lighting and related costs; ventilation; aesthetics; views;<br>• High performance glazing fitted with trickle vents. | • House is very light due to huge windows. House faces sun rise so sun streams in in the morning / letting light in and making most of views;<br>• Plenty of light and lots of glazing. |
| Artificial Light | • Energy efficient. | • A few respondents did not like the amount or location and type of lights. |

| BUS Variable | Design Intent | As-built: Occupant perception: Comments and rating |
|---|---|---|
| **Health (perceived)** | • 'Healthy materials': low VOC and natural materials used where possible in construction;<br>• 'breathing wall' systems;<br>• Ventilation – to counter airtightness? | • Two respondents found their homes to be: 'Cheers you in the summer' and 'Peaceful' while another felt that there was no effect. |
| **Personal control** | • Heating control;<br>• Ventilation: Trickle vents, extract fans etc.<br>• TB1 only: AASHP remote control;<br>• TB1 only: Hot water programmer in kitchen.<br>• TB1 – MVHR control panel in the hall. | • Opening and controlling windows and trickle vents is not a problem;<br>• Heating control and bathroom and kitchen ventilation is considered not easy to control;<br>• Control over loud road noise. |
| **Design overall** | • Main roof pitch N/S orientation: better for solar thermal and natural light through internal spaces. | • Good quality design, outside looks really good.<br>• Too modern and clinical for one occupant;<br>• TB1 – Height of upstairs ceilings – too high to maintain / decorate with ease.<br>• TB1 - *Vent too high for MVHR would have been a better design if vented to a wall.* |
| **Environ-mental Design Features** | • Orientation;<br>• Passive design features;<br>• High levels of insulation and airtightness;<br>• Energy efficient design;<br>• TB only: MVHR / AASHP / ST. Circulation of air throughout house, warm and fresh air intake. | • Most comments related to the energy saving measures, in particular: energy saving bulbs, insulation, off-peak water heater;<br>• One feedback referred to the storage heaters and questioning their efficiency. |
| **Anything else** | • Maintenance<br>• Use of local and Scottish materials where possible;<br>• Inclusion of Bullwood Group in development. | • Well built;<br>Negatives :<br>• Have a west facing wall and moss (fungus) infestation on exterior outside wall<br>• Render should not be failing or cracking only after three years<br>• Difficult maintenance of building exterior<br>• Kitchen smells can linger |
| **Lifestyle** | | |
| Work | | • Work close by and more flexible working hours |
| Leisure | • Garden;<br>• Beach access;<br>• Community: connection to site and wider community. | • Community spirit;<br>• Access to beach and woods; |
| Diet | | • More home cooking;<br>• Lingering cooking smells were a negative. |
| Travel | • Location: Public transport and road access. | • Can walk into town |
| Other | | • Made life better. It is a fantastic house, I have lived in about 15 houses over 70 years and this is the best we have ever bought. The view is worth a million dollars<br>• My bank account |
| **Utilities costs** | | |
| Heating/ cooling | • High level of insulation and airtightness throughout (better than building regs) – reduce operating costs.<br>• TB1 only: AASHP and MVHR. | • Significant heating savings;<br>• Using heating less;<br>• Warmer than their previous house. |
| Lighting | • Low energy fixtures and bulbs | • The house always feels light and airy<br>Using less due to natural light |
| Appliances | • Low energy appliances | • More home cooking |
| Water Other | • *TB1 only: Solar Water Heating* | • *'I'm more aware of heating water by electric because I have solar so I monitor more and control both solar and electric depending on sun condition'. This should be seen as a positive.* |

**Table 5.5:** Summary of design intent versus occupant feedback**.**

## 5.6 Conclusions and key findings for this section

On the whole, the occupants liked their new homes, in particular the location and low utilities bills. There were problems in terms of a mismatch between data and what occupants were prepared to discuss. For example, many of the comments were negative for certain areas, in particular, design and layout, but the data results were inverse to this. The introduction of occupant diaries in February 2014 provides a reference point between behaviour and monitored internal data, but it is difficult to deduce the actual role of occupant behaviour from looking at the monitored energy and environmental data because of the multiplicity of variables involved.

During the occupant walkthrough (see **Section 5.2**) the occupants were particularly keen to point out problems with overheating in the summer. However, in both BUS data comments, this would appear to not be as significant a problem which we know it to be from the monitored data and prior occupant feedback. Further analysis of overheating is made in Section 7.4, Environmental monitoring summary. This compares monitored data with CIBSE (2006) comfort guidance (See **Table 7.5**) to determine periods of overheating, comfort and cold temperatures. There was very little evidence of periods of overheating diurnally. There are periods in the 'warm' and 'hot' regions of the CIBSE guidance in both living areas and bedrooms. These mostly occur in heating periods, suggesting that the summer overheating periods, except in the kitchen on TB1 are mitigated by window opening. The temperature range of TB1 demonstrates significant periods of 'cool' to 'cold temperatures in the Living Room and Bedrooms between the autumn and spring. These issues and the implications of these will be discussed further in **Section 7.4**.

**Key points**

- On the whole, occupants liked their new homes;
- The location was favourable, the views in particular. However, the road in-between the dwellings and the sea was considered a negative;
- The layout on the whole was popular, however, two respondents would prefer not to live in open plan again, and preferred a separate kitchen;
- A number of occupants with first level dwellings would prefer garden access, although several enjoyed the terrace access
- As designed aspects of affordable, good quality, low-energy homes were on the whole, achieved.
- The health design intended by the architects could perhaps be considered successful on the basis that there were no negative health impacts noted in the data or comments.

**Learning points**

- The occupants of TA1, TA2 and TB1 were present during the initial site visit for the BPE project on 28.09.12 held between the Architect, two TSB representatives and MEARU and initial feedback sought from occupants about their dwellings. Although there is no consistence between issues raised and the BUS occupant comments, this is not advisable for future projects – this could be sought in the absence of the architect. Occupants appeared freer to talk during the semi-structured interviews with occupants that were undertaken on 1st March 2013 in the absence of the TSB officers and the architect.
- TB1, the PassivHaus had a number of problems post-occupancy, these are reflected by the BUS occupant comments. However, caution should perhaps be exercised with feedback for this property, as it may have been influenced by discussions surrounding the problems encountered and subsequent repairs.

- The sample is small, particularly for House Type B (only one property and one occupant over 18 years). Therefore data and subsequent comparison may be affected. For future developments where comparisons are required, at least 2 of each house types are recommended.

**BUS Survey**

The following problems identified from the data analysis may suggest problems with the BUS survey method rather than the homes themselves; this will require further verification of data in later chapters.

- House type A: summer and winter air: When compared with temperature and air quality data from the BUS survey period, these findings suggest that further consideration is paid to the relationship between the building envelope and ventilation diurnally. The construction, airtightness and ventilation strategies would suggest a design intent which would reflect good air quality both in summer and winter, as well as good user comments in the feedback.

- Still air was perceived as a problem in both house types, winter and summer, rating red diamond. Is this a method issue; respondents' misunderstanding of the question; or is further investigation into airtightness and air changes needed?

- Natural light in both house types rated poorer than the benchmark and scale midpoint, red diamond, on the basis that they were more towards the 'too much' end of the scale. This is contradictory to the design intention of trying to maximise natural light into the homes

- On the BUS scale, noise is perceived as a problem in both house types, on the basis that there is 'too little noise'. For example: TA: Noise from neighbours, scoring red diamond: 3 for 50% of occupants rating 'too little noise'. TB noise from neighbours rated red diamond: 1 for 100% of occupants rating 'too little noise'.

# 6. Installation and commissioning checks of services and systems, services performance checks and evaluation

## 6.1 Introduction

This Chapter assesses the operational performance of individual mechanical systems in the dwellings – focussing on the three systems in dwelling TB1: a solar thermal hot water (*STHW*) system; a mechanical ventilation heat recovery (*MVHR*) system; and an air source heat pump (A*ASHP*) system. Every system has either been fully replaced or the control systems altered.

Telemetry monitoring and on-site testing; and non-invasive monitoring of the equipment was carried out by MEARU and ESRU; in conjunction with interviews with the main occupant. The report outlines how the building is operating better now than when it was originally constructed and commissioned. From the analysis, recommendations to further improve the *STHW*, *MVHR* and *AASHP*'s operational performance have been outlined. A detailed examination of in-use performance in contrast to design and manufacturer's predictions is provided.

## 6.2 Methodology

A strategy of non-invasive monitoring was developed in order to reduce the impact to the occupants and minimise the monitoring costs.

### 6.2.1 Equipment

*Eltek* telemetry monitoring equipment was used to obtain the required data from the passive house. This system used a series of transmitters to record measurements from the mechanical systems and built environment and send them to a data receiver located within the house. This data was then stored for the project time period and obtained using a direct serial link with a laptop when the recording ended. A basic schematic of the process is shown below for clarity.

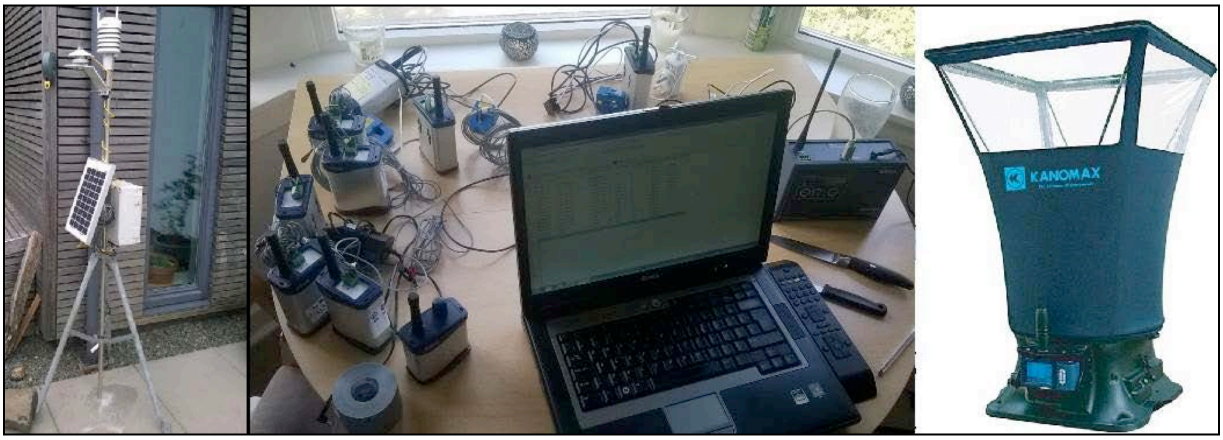



**Figure 6.1:** Dunoon Equipment used

### 6.2.2 Data Logging

This equipment was set-up as follows;

***STHW* System:**

| Location | Measurement | Unit |
|---|---|---|
| Outdoor Weather Station | External Temperature | °C |
| Outdoor Weather Station | External Solar Irradiation Level | $W/m^2$ |
| *STHW* Store | Top of the Tank Temperature | °C |
| *STHW* Store | Cold Water Tank Feed Temperature | °C |
| *STHW* Store | Hot Water Tank Supply Temperature | °C |
| *STHW* Store | Solar System Water Flow Temperature | °C |
| *STHW* Store | Solar System Water Return Temperature | °C |
| Main Circuit Board | Solar Panel Controls and Pump Electrical Consumption | A |
| Main Circuit Board | Immersion Heater Electrical Consumption | A |

**Table 6.1:** *STHW* Monitoring Set-up

***MVHR* System:**

| Location | Measurement | Unit |
|---|---|---|
| Outdoor Weather Station | External Temperature | °C |
| *MVHR* Unit | Supply to Grilles Temperature | °C |
| *MVHR* Unit | Extract from Grilles Temperature | °C |
| *MVHR* Unit | Exhaust Temperature | °C |
| *MVHR* Unit | Fresh Air Intake Temperature | °C |
| Living Room | Space Temperature | °C |
| Kitchen | Space Temperature | °C |
| Downstairs Hallway | Space Temperature | °C |
| Master Bedroom | Space Temperature | °C |
| Bedroom 2 | Space Temperature | °C |
| Main Circuit Board | *MVHR* Electrical Consumption | A |

**Table 6.2:** *MVHR* Monitoring Set-up

The anemometer was also used in order to obtain the operation volume flow rates of the *MVHR* unit. Both supply and extract rates of each room were measured instantaneously under test conditions.

***AASHP* System:**

| Location | Measurement | Unit |
|---|---|---|
| Outdoor Weather Station | External Temperature | °C |
| *AASHP* Unit | Supply Temperature x 2 | °C |
| Living Room | Space Temperature | °C |
| Kitchen | Space Temperature | °C |
| Downstairs Hallway | Space Temperature | °C |

| | | |
|---|---|---|
| Master Bedroom | Space Temperature | °C |
| Bedroom 2 | Space Temperature | °C |
| *MVHR* Unit | Supply to Grilles Temperature | °C |
| *MVHR* Unit | Extract from Grilles Temperature | °C |
| Main Circuit Board | *AASHP* Electrical Consumption | A |

**Table 6.3:** *AASHP* Monitoring Set-up

In addition to this, to meet the *AASHP* objectives the anemometer was to be used to measure the unit's volume flow rate of supply air under test conditions. Also, it must be noted that two *AASHP* supply temperatures were taken for accuracy as the manufacturer's guide indicated the impact the guide vanes have on heat distribution into the space. Hence, a mean temperature was used for purposes of accuracy. A data logging interval of 5 minutes was set up in synchrony across all the equipment.

The monitoring of both the STHW and AASHP was done for days selected to represent the typical weather in the West of Scotland during the different seasons – a summer week (25th to 29th June); and earlier, a winter week and a mid-season week (26th March to 1st April). For the purpose of finding out field efficiencies of the two systems and Coefficients of Performance; in comparison with manufacturer's specs and claims, the representative weather suffices. Previous research comparing results on the basis of efficiency and solar fraction has shown that good correspondence exists between long-term results and short term testing, at least for systems with stable controllers.

However, monitoring for an entire year would have improved the confidence in the results in the context of occupant linked variables. A one year period would have enabled MEARU to pick inconsistencies in usage; variations in the operation of the controls of the systems; variations in space heating; and variations in hot water demand. For the latter, the demand is quite consistent since the house is occupied by two people with a very consistent occupancy pattern, except for the occasional days when they have visitors. Financial limitations and a risk of leaving the expensive weather station outside for an entire year meant that monitoring was done for only representative days.

## 6.3 STHW System Analysis

The *Passive House Planning Package* (*PHPP*) for this specific home stated that 55% of the annual *HW* contribution would be met by the solar thermal system operation; and the remaining 45% by the supplementary electrically driven immersion heater. The objectives for the *STHW* system evaluation were as follows;

1. To analyse the current operational performance by comparing periods of high and low solar irradiance levels.
2. To assess the relationship between the immersion heater and solar thermal pump controls.
3. To analyse and discuss all aspects of current performance and determine if the 55% design prediction is realistic on-site.

The *STHW* system consists of a 200 litres thermal store, rooftop solar thermal collectors, electric immersion heater and accompanying pipework, pumps and controls. All components have been manufactured by *Velux*. There is 4.6m$^2$ of solar thermal rooftop panelling, with 6 x 0.9m$^2$ *Velux M08* collectors. The installation on the roof structure that is almost perfectly south facing enables the collectors to obtain the maximum levels of solar irradiance. Figure 6.2 shows the panel installation and orientation.

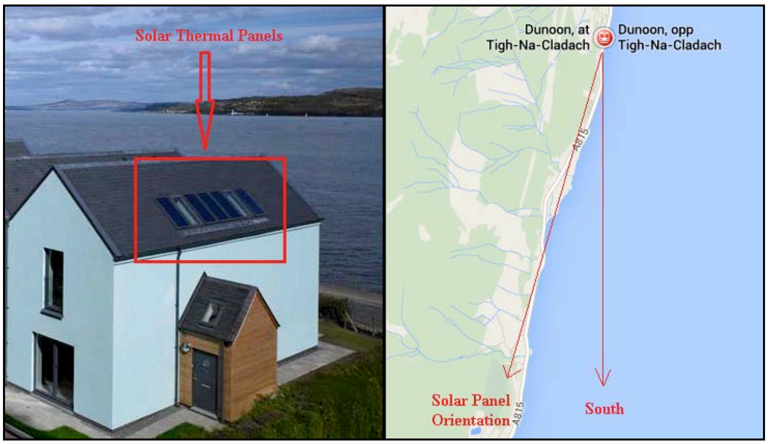



**Figure 6.2:** Solar Panel Installation and orientation

The *STHW* system operates on a solar heating circuit positioned in the lower half of the tank. This is supplemented by an electrically driven immersion heater in the top half of the tank. The immersion heater is time controlled by the occupant. At present, this is timed to operate from 07:00 am until the top of the tank temperature rises to approximately 57°C (based on the data collected from this study). The solar thermal control is programmed to operate based on the conditions experienced by one temperature sensor near the base of the tank and two temperature sensors placed on the solar thermal rooftop panelling. The control logic is set so that the solar pumps operate when the difference between the bottom of the tank and the solar panel temperature is greater than 6K. This value is recommended by the supplier based on trial data. There are two independently operating solar pumps, each one driving the circuit to different sections of panelling. If the controller reads that only one grouping of panels is 6K hotter than the bottom of the tank temperature then only that pump is operational. During the early months when the system did not work well the *Energy Systems Research Unit* (*ESRU*) at University of Strathclyde did some diagnostic tests and their recommendations led to the present control and immersion timings being put in place. As pointed out in previous chapters, when interviewed, the main occupant indicated that she was not entirely happy with the system's operation. She pointed out that she had to become more aware of her consumption levels and patterns.

The system's operation on a day of low external solar irradiance was compared with the operation of a day of high operation. Here, the *STHW* pump and supplementary immersion heater operation were compared, with respect to operation and controls. Consecutive days of low and high solar irradiance were then grouped together and analysed. The percentage of supply being met by solar irradiance could then be compared with the design prediction of 97% in June for this specific PassivHaus. Throughout the analysis, user experience and comfort has been taken into account and discussed.

## Day of Low external Solar Radiation

The installed weather station indicated a mean solar irradiance level of 62.2W/m$^2$ with a daily high of 142.9W/m$^2$. The key data logging temperature variables relating to the operation of the *STHW* system have been plotted in Figure 6.3 for this day.

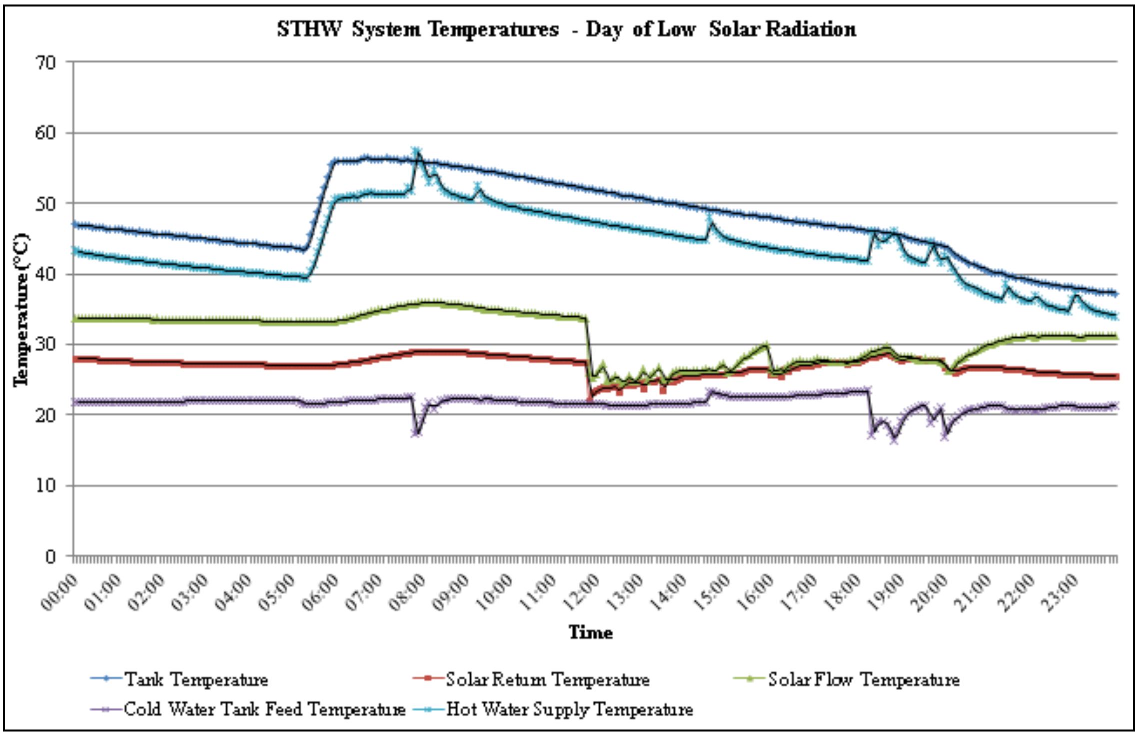



**Figure 6.3:** *STHW* Temperatures on Day of Low Solar Irradiance

At 00:00, the top of the tank temperature is 47.0°C. The tank continues to lose energy until the timed immersion heater comes on. This operates for 60 minutes until the tank temperature is raised from 43.3°C to its daily high of 56.35°C. The top of the tank temperature drops 4K, from 56°C to 52°C in 3hrs 20mins in the morning when no equipment is operational, i.e. static heat losses. Yet in comparison, the top of the tank losses 4K, from 47°C to 43°C, when the solar pump is in operation in 3hrs 5mins even though there is a reduced thermal driving force. For these 24 hours, 0% of the *HW* supply is met by solar irradiance as the tank temperature never once increases once the solar thermal pump becomes operational. Heat losses are just amplified. Here $Sol_{Flow}$ > $Sol_{Return}$ temperature always. The solar heating coil is located higher up the tank where temperatures are higher. Even for the 20mins during the day when solar irradiance is at an average high of 123W/$m^2$ the tank temperature drops by 0.1K. The ΔK between the solar flow and solar return ranges from 3.95K to 0.1K at its daily 'best'.

Another note to be taken from the above graph is that there is a high *HW* demand in the evening time. This clearly impacts on the top of the tank temperature as cold feed water enters the tank. However, the hot water supply temperature to the utilities is still adequate at 35°C. A hot shower typically requires water up to 41°C depending on the consumer but discharge temperatures of 35 - 46°C are cited as the acceptable range within UK domestic properties.

The below graph shows the operation of the *STHW* pump and supplementary electric heater on this day;

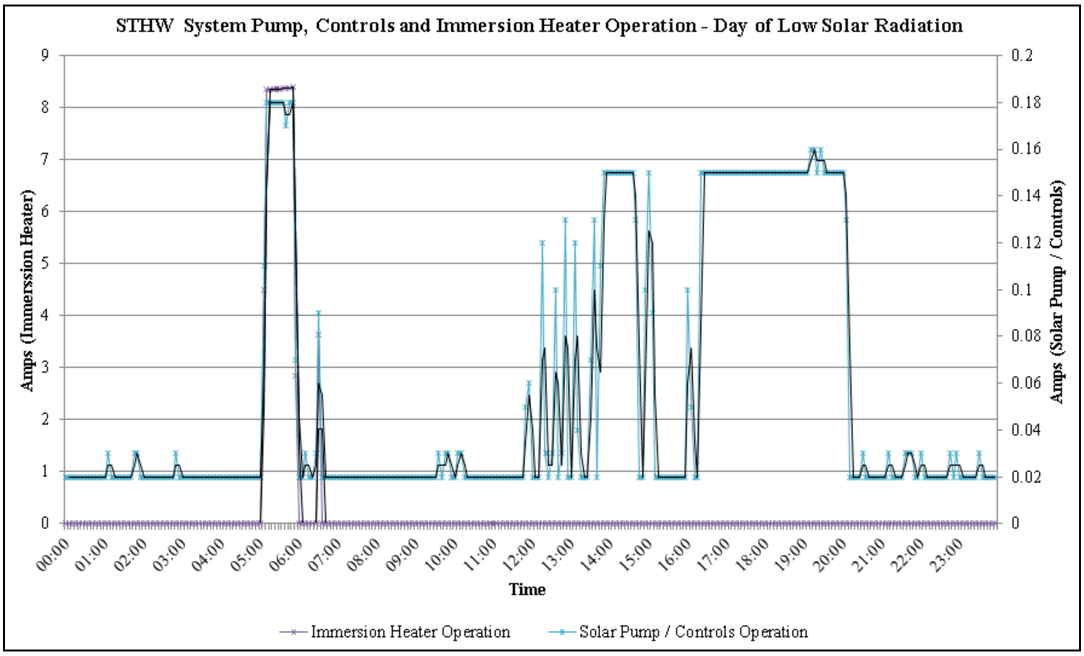



**Figure 6.4:** *STHW* Controls on day of Low Solar Irradiance

It is clear from the graph that the immersion heater is required for 60mins while the solar pump operates intermittently for a combined total of almost 6hrs throughout the day. The external environmental conditions have been shown below so controls can be discussed clearly;

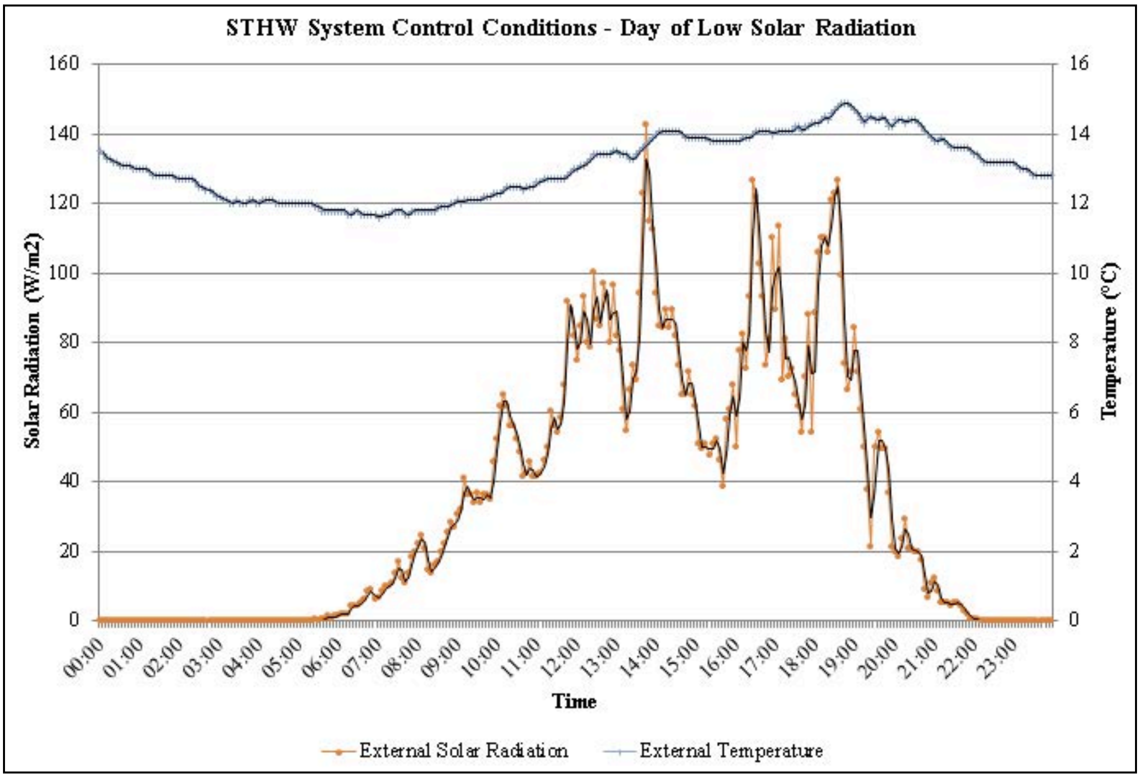



**Figure 6.5:** *Environmental Conditions* on day of Low Solar Irradiance

The control logic ensures that the pump is constantly on between 16:20 and 20:05. Here, the solar circuit temperature is above the solar panel temperature as the solar radiation levels remain low, if varied. Energy is potentially being wasted.

## Day of High external Solar Radiation

The installed weather station indicated a mean solar irradiance level of 333.9W/m$^2$ with a daily high of 1188.0W/m$^2$. This is extremely high for summer conditions in Scotland. Figure 6.5 shows the key data logging variables relating to the operation of the *STHW* system.

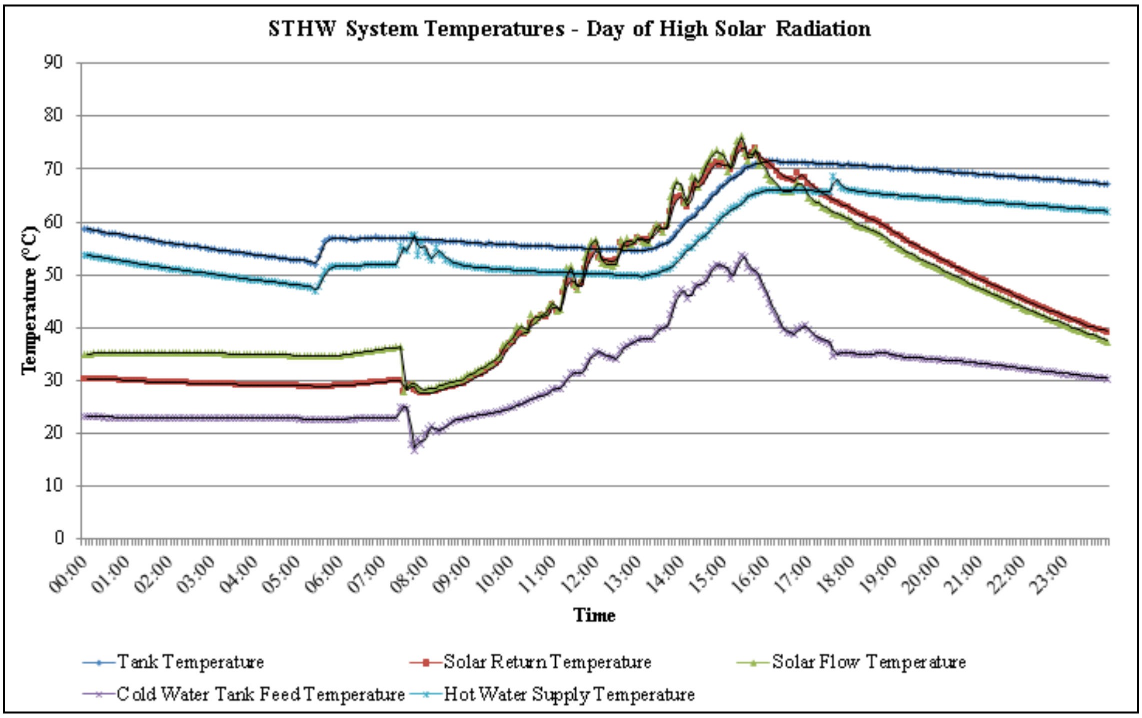



**Figure 6.6:** *STHW* Temperatures on Day of High Solar Irradiance

From the graph, we see that the top of the tank temperature is already at a high of 58.7°C at 00:00. This is due to the good solar conditions and *STHW* operation of the previous day, whereby the mean solar radiation levels stood at 337.7W/m$^2$, almost identical to the 24 hours under examination. This has a substantial bearing on the day's system operation. Here, the tank is sitting at a much higher temperature when the immersion heater is set to come on in the morning. It is at 52.0°C instead of the 43.3°C when the day of low solar irradiance was followed by a day the previous days equally poor levels and operation. This enabled the tank to reach its top of the tank set-point temperature of 57°C in less time (50mins), resulting in an energy saving.

The solar pump becomes operational just after 07:30, coincidentally when a large volume of fresh cold feed water enters the tank. This is probably due to the occupant having an early morning shower. This results in a net cooling of the tank, over a time lag as natural circulation occurs within the water storage vessel.

At 07:30, the solar return temperature begins its operation at 28.45°C. This rises to a weekly peak of 73.45°C at 15:20 due to the ideal solar conditions and pump operation. This operation is an indication of the system working exactly how it is designed and results in the highest witnessed solar return temperatures into the tank. This results in the top of the tank temperature rising to a high of 71.45°C.

It should also be noted from the graph that the *HW* demand was high on this day. That can be seen by the level of fluctuation of the cold water feed temperature into the storage vessel. This has a substantial impact on lowering the tank temperature. Yet, it should also be noted how high the feed water temperature is, above 40°C at times. This is the highest witnessed throughout the monitoring process and helps reduced the heating load. It may be considered surprisingly high.

The control mechanism once again ensures that the solar thermal pump is operational up until 01:50 the following morning. This is despite the solar radiation levels dropping to below 20W/m$^2$ after 19:00 and to 0W/m$^2$ after 22:00. It has little positive effect past 16:00. A resultant net energy loss has been witnessed past this time. The system operation is shown in Figure 6.6; and the corresponding external environmental conditions in Figure 6.7.

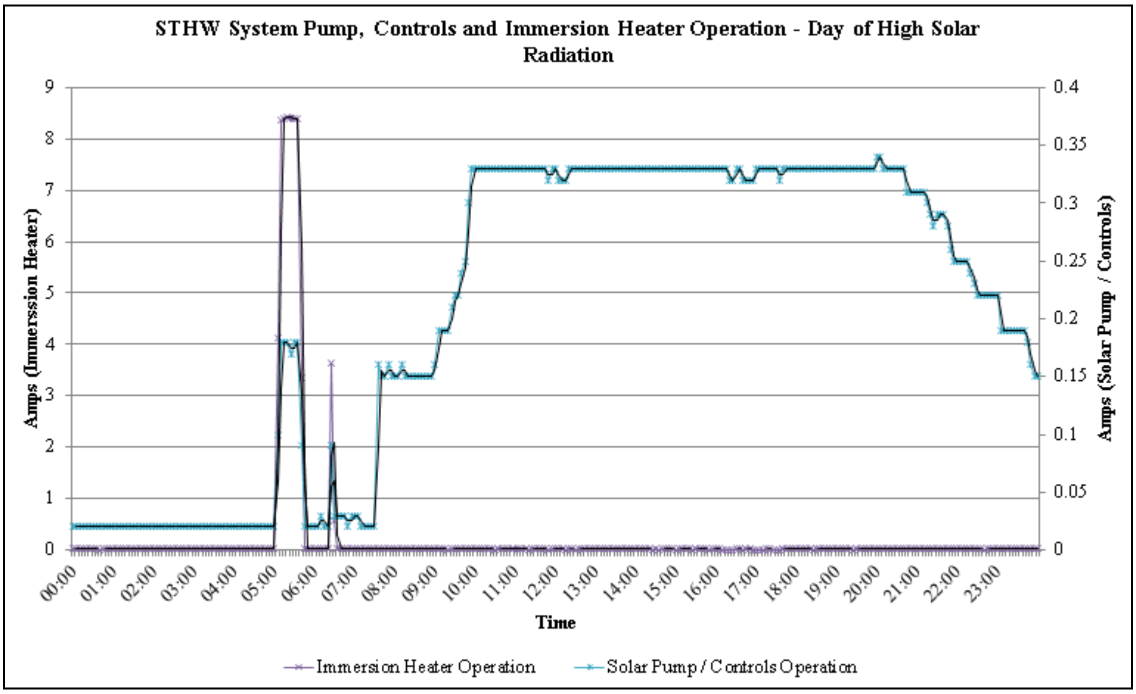



**Figure 6.7:** *STHW* Controls on day of high solar Irradiance

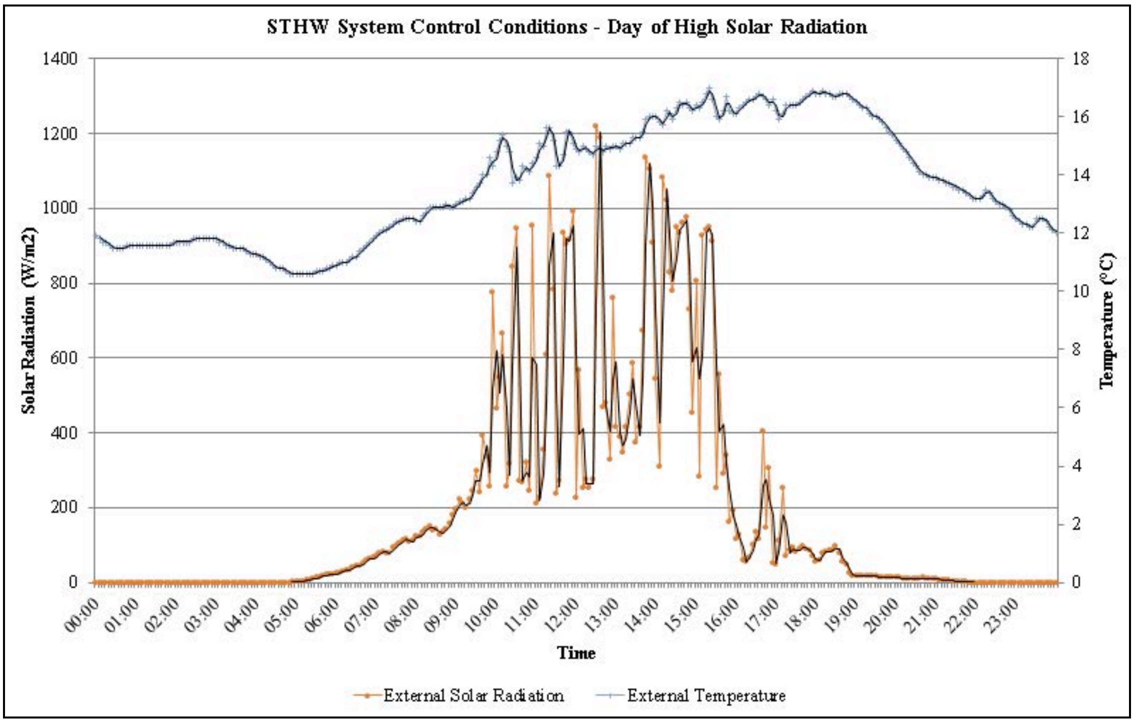



**Figure 6.8:** *Environmental Conditions* on day of High Solar Irradiance

Due to these conditions, it is clear from the graph that the solar flow and return temperatures drop drastically as operation continues into the evening/night. The top of the tank temperature and hot water supply temperature also gradually lowers. This could be attributed to the *STHW* operation; and also static heat losses over time due to the high thermal driving force.

Realistically, should a more intelligent control system have been in place, solar thermal should have been able to meet 100% of this day's *HW* contribution given the high radiation levels. The *HW* supply temperature sits at 48.1°C prior to the supplementary immersion heater beginning its operation and coincidentally prior to the occupant taking a shower. This is more than adequate for all domestic *HW* utilities. This would have resulted in a reduction of operational costs and primary energy usage by over 50%, even with the inefficiently controlled solar pump operation. Ideally, the controls would have resulted in the immersion heater being deemed dispensable and the *STHW* system being in operation between 09:00 and 17:00 when external solar radiation levels would have produced a net gain in thermal energy within the storage tank.

## Comparison of Consecutive Days of Low and High Radiation Levels

System operational performance is impacted by the previous day's external environmental conditions. The top of the tank temperature at the beginning of every day (00:00) has a direct bearing on the costs and energy consumption. Analysing consecutive days of low external solar irradiance gives a clearer picture of the systems operation, as these results will aide in drawing more concrete conclusion about the system and resulting energy consumption and controls. The same theory is applied to consecutive days of high external solar irradiance. In the sample dates, two days of consecutively low levels of solar irradiance occurred on the 25th and 26th of June2014. Extremely high mean solar irradiance was witnessed for three days on the 28th, 29th and 30th of June 2014. The required variables logged for discussion have been tabulated below;

| **Date:** | **25th** | **26th** | **27th** | **28th** | **29th** | **30th** |
|---|---|---|---|---|---|---|
| Tank Temperature prior to Immersion Heating: | 43.6 | 34.4 | 37.7 | 49.2 | 52 | 63.9 |
| Tank Temperature after Immersion Heating: | 56.35 | 56.2 | N/A | 57.1 | 57.1 | 63.9 |
| Mean daytime Solar Irradiance (08:00 – 21:00): | 62.2 | 170.5 | N/A | 337.7 | 333.9 | 381.5 |

**Table 6.8:** Solar Irradiance and Tank Temperatures

Examining the consecutive days of low solar irradiance, it is clear that immersion heating is mandatory due to the top of the tank temperatures on the following days prior to supplementary heating. Even for the three days of high solar radiation, two out of three of the days require supplementary electric heating to raise the top of the tank to the set-point temperature of 57°C. Although guidelines outline that *HW* utility supply temperatures should be up to 41°C, from analysing the logged data it is clear that there is no way that solar thermal alone can maintain this temperature.

For the two consecutive days of low irradiance, over 75% of the electrical consumption is consumed by the supplementary immersion heater. Even during the ideal conditions of consecutive days of high solar irradiance the immersion heater consumes 47% of the total system's electricity. One fundamental flaw is operating the solar thermal pump when the solar return temperature is below the solar flow temperature. Both connections are level on the tank so it is clear that the pump should not be operational when this condition is being met. This happens with surprising frequency. Even for the 3 days of high solar radiation, the solar circuit is having either a zero or negative impact on the overall tank temperature for over 8% of its operational time due to the return temperature being lower than the flow temperature. Thankfully, when analysing consecutive day's operation, it has been found that the average daily running costs are reduced when solar conditions are superior.

## Further Findings from the Analysis

In order to further analyse the week period as a whole, the following table has been developed;

| Date | Average Solar Irradiance (08:00-21:00) (W/m$^2$) | Average Static Tank Losses per Hour (ΔK/hr.) | Average Tank temperature Change during ST Pump Operation (Δ/hr.) | Net Tank Temperature Change during ST Pump Operation (ΔK/hr.) | Immersion Heater (ΔK) |
|---|---|---|---|---|---|
| 25th | 62.20 | -0.55 | -1.05 | -0.50 | 13.0 |
| 26th | 170.50 | -1.15 | -0.51 | 0.64 | 21.8 |
| 27th | 283.10 | -0.43 | -0.29 | 0.14 | 18.7 |
| 28th | 337.70 | -1.26 | 0.44 | 1.70 | 8.0 |
| 29th | 333.90 | -0.63 | 0.59 | 1.22 | 5.1 |
| 30th | 381.50 | -0.71 | 0.77 | 1.48 | 0.0 |
| 1st | 502.90 | -0.58 | -0.56 | 0.02 | 0.0 |
| 2nd | 114.90 | -0.48 | -0.51 | -0.03 | 4.4 |
| **Average** | 273.34 | -0.72 | -0.14 | 0.58 | 8.9 |

**Table 6.9:** Tank Energy Gains and Losses due to Solar Thermal; and Tank Temperature Gains due to Immersion Heater

Here, the average hourly temperature drop at the top of the tank has been calculated for the period of each individual day whereby the immersion heater and solar pumps are not in operation. This gives an average static loss per day, arising from the tank temperature itself and also the *HW* demand as *HW* supply is draw from the tank and cold water is fed in to supplement this. This varies greatly and is a good indicator of the thermal store's energy losses per hour. Then, the average temperature change per hour due to the operation of the solar thermal circuits has been calculated. From this value, the static losses have been offset to give a guide as to the net temperature change per hour within the tank due to solar irradiance. This gives a good indicator as to what net energy gains the solar thermal circuits are achieving over each days operation. In addition, the right column shows the temperature increases in the tank due the operation of the immersion heater.

Under the current controls and environmental conditions, the immersion heater raises the tank temperature an average of 8.9K per day. Meanwhile the solar thermal circuits raise it by an average of 6.6K a day. This has been calculated using the average temperature increase and the average pump running time. In terms on energy, this analysis gives an approximate estimate that only 43% of the *HW* supply is being met by solar irradiation.

## Control Recommendations

Although the control system of the *STHW* system was sometime after it's commissioning, it could still be more efficient. Should the homeowner want to avoid investing in new and costly controls, a number of steps may be suggested. One solution may be to reduce the top of the tank set point temperature to ≈ 43°C and operate the system as currently doing so. It is clear from the monitored data that the occupant's peak *HW* demand occurs directly after the immersion heating operation. Therefore, 57°C is unnecessarily higher than the required 41°C for a hot shower and other utilities. Should the occupant require a large *HW* demand or external conditions are substantially lower than average, manual boosting of the thermal store may be undertaken. The problem with lowering the set point temperature would introduce some risk of legionella, but this could also be addressed through programmed or manual booting.

Furthermore, a logical control setting using the current control equipment would be to reduce the immersion set point temperature to 46°C (maximum recommended requirement for domestic *HW* utilities) and to alter the solar thermal pump to be set on a timer whilst using the current temperature sensor logic. The operation would remain the same but could only operate during times of potentially high solar irradiance.

From overall analysis, the system currently achieves 36% of its *HW* contribution via solar thermal. A previous study by ESRU of the system's operation in early 2011; one year after the building was opened concluded that 40% annual contribution from solar irradiance would be a more realistic system target. They based this on a literary review and similar monitoring as the one described above. The conclusions reached on solar system operation for this current study could have slightly underestimated the performance of the solar system since it doesn't recognise solar inputs when the top temp doesn't change, but recognises that there are solar inputs that heat the colder water at the bottom of the tank without affecting the top temp.

*ESRU* outlined how the system was controlled with one obvious flaw being that at times the water flowing to the panels was slightly warmer than the return water to the tank, indicating a net heat loss. This occurred when the tank stratification was such that the temperature difference of 6K between the bottom of the tank and the panel used to trigger the solar pump was not great enough.

Initially, *ESRU* discovered that the supplementary immersion heater was set to automatically operate 3 times per day, regardless of solar irradiance levels. This intermittent operation throughout the day was in order to maintain the tank at a very high temperature. The controls were reset to operate the electric heater twice a day in order to achieve an upper tank temperature of 60°C. *ESRU* indicated that no supplier could provide better system controls at a price deemed worthy.

## 6.4 The MVHR System

The objectives for assessing the systems operational performance were as follows:

1. To compare the system's thermal performance with that of the *PHPP* building design and manufacturer's quoted data.
2. To analyse the risk of the overheating within the passive house during summer operation.
3. To investigate the *MVHR*'s ability to aide in meeting the space heating and cooling demands; and supply each room with the adequate level of fresh air.

As well as ensuring an adequate fresh air supply into the building for occupants, the *MVHR* compliments the main source of space heating and cooling in meeting thermal demands through two steps. Firstly, the *MVHR* recovers heat from the extract ducting system by heating or cooling the fresh air supply delivered to the building. Secondly, the *MVHR* circulates the heat around the building as required. Different levels of supply for different rooms are determined in the design phase and the system is commissioned accordingly. The *MVHR*'s main function besides ventilation is to assist with meeting the winter space heating loads. However, it also ensures the building does not over heat in summer.

A *PAUL: Focus 200 MVHR* has been installed in dwelling TB1, and is officially validated as a suitable passive house component by the *PHI*. This is located along the south facing exterior wall, within the roof space. It has been rated to recover 91% of exhaust heat. The cited electrical demand is extremely low at 0.31Wh/m$^3$. This rated criterion is far better than the *PHI* requirements of ≥75% heat recovery and ≤0.45Wh/m$^3$. According to the manufacturer's data, the *MVHR* is capable of achieving a ventilation supply temperature of ≥16.5° when the external temperature drops to -10°C. These results ensure it is an ideal selection for a building located in Scotland. The system is fully functional at extremely low temperatures as it is equipped with frost protection for external temperatures as low as -15°C. The *MVHR* is designed to deliver a volume flow rate ranging from 116 - 155m$^3$/h. The *PHPP* predicted this to be a good match based on the building's occupancy levels, air change rate and volume.

The main occupant has expressed her happiness with the ventilation units operation in the past. She has been very satisfied with the level of thermal comfort in the summer time. However, she has expressed concerns about thermal comfort during winter. These issues are detailed in the responses in the BUS survey in the previous chapter.

Thermal performance of the MVHR was investigated through the examination of the system's temperature transfer efficiency via the logging of the temperatures recorded in the supply, extract and fresh air ducts. The operation for different weather conditions was tested. Potential summer overheating risks were studied using the collected data. The effectiveness of the heat distribution was also evaluated. Furthermore, an examination of the volume flow rates delivered to each room were tested and fresh air requirements and blockage due to ageing filter usage were determined.

### 6.4.2 Thermal Comfort during Summer Operation

According to the *PHI* criteria, '*thermal comfort must be met for all living areas during winter as well as in summer, with not more than 10 % of the hours in a given year over 25 °C.*' This is in conjunction with *CIBSE* guidelines which states that domestic internal environments should range between 21 - 25°C with relative humidity in the range of 30 – 70%. The summer test period has been analysed for overheating potential (Table 6.10).

| Room: | Living room | Bed 2 | Master | Kitchen | Hall | House Average | Units |
|---|---|---|---|---|---|---|---|
| Frequency above 22°C: | 25.76 | 20.33 | 81.06 | 54.94 | 31.01 | 42.62 | % |
| Frequency above 25°C: | 2.42 | 0.00 | 7.05 | 0.00 | 0.00 | 1.89 | % |
| Average Temperature: | 20.26 | 21.64 | 22.94 | 22.20 | 21.63 | 21.73 | °C |

**Table 6.10:** Room Space Temperatures

Overall, it is clear that the *MVHR* ensures that the passive house meets the *PHPP* and *CIBSE* design criteria for thermal comfort. Temperatures above the comfortable range are experienced, but within the limits deemed acceptable. The living room experiences temperatures above the comfortable range in the morning when solar irradiance is high. This is due to the room's orientation and high glazing percentage. However, this room is typically unoccupied apart from late in the evenings so this is not an issue. The master bedroom is by far the hottest space and suffers temperatures above the comfortable range on a day of high solar irradiance between 15:00 – 00:00 hrs. This is due to a number of factors including the west facing glazing, low *MVHR* supply volume flow rate (discussed later). The local midges problem also prevents manually controlled natural ventilation at night!

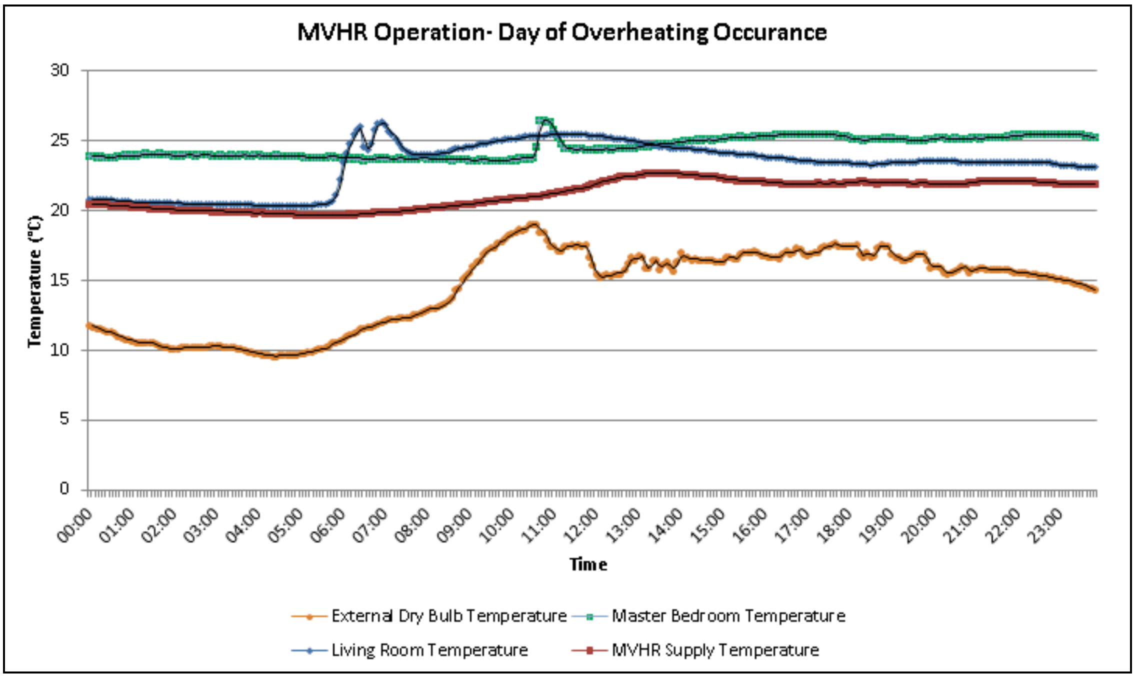



**Figure 6.9:** *MVHR* and Space Temperatures on Day of Frequent temperatures above the comfortable range

On this day, the master bedroom experiences temperatures above the comfortable range for 37% of the time, with an average temperature of 24.55°C. This must be considered high. The living room experiences temperatures above the comfortable range for 15% of the time, with an average temperature of 23.27°C. Although this is not a major concern due to the relatively low frequency over the test period, this could have easily been eradicated with the implementation of an *MVHR* summer by-pass. From the data, this is not in use for this summer's operation. Additional control and equipment to operate summer by-pass operation should be considered an unnecessary cost and control complication, and the monitoring backs that up.

Overall, the 1.89% house average overheating for the test period is below the 2.8% *PHPP* summer prediction. The *MVHR* is operating well with respect to internal temperature. From the performed occupant's BUS survey, the *MVHR* feedback has been extremely positive. A score of 7/7 was given for level of control, with the occupant claiming to have full ventilation control and '*very happy*' with the system's operation. The internal environment was described as '*still, fresh and odourless with no relative humidity issues*.' The summer temperature was judged to be perfect during both day and night.

### 6.4.3 Performance in mid-season Conditions

As stated, the *MVHR* is of vital importance during winter operation. Its heat recovery is critical in maintaining an ambient living space. However, much can be taken from analysing the system's performance during a 24 hours period of data. The following figure shows the MVHR supply temperature and corresponding external air temperature.

It is critical to note that the supply temperature to the rooms remains relatively constant, even at the lower external temperatures. This is due to the very high temperature transfer efficiency of the device. This has been guaranteed by the manufacturer and is holding up under intensely scrutinised monitoring, and maintaining an ideal internal ambient temperature.

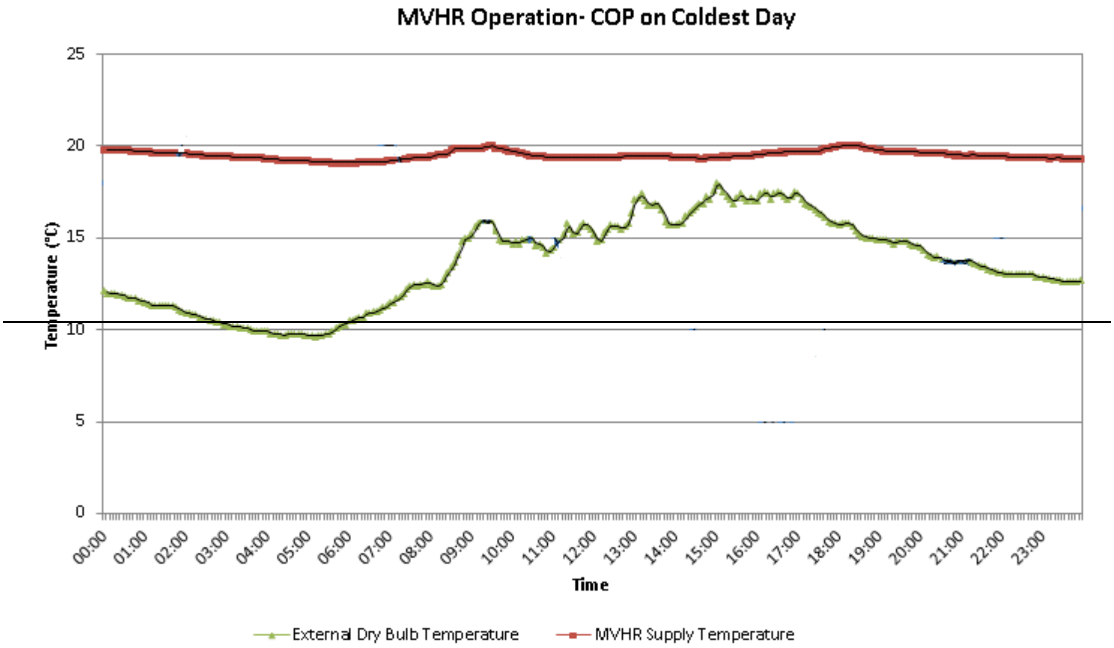



**Figure 6.10:** *MVHR* and External Temperatures on Coldest Day

## 6.4.4 Commissioning/Maintenance issues:

A basic system performance test was undertaken on site. A hooded anemometer was used to measure the volume flow rates of all supply and extract ducts within the passive house under '*normal*' (Fan Setting 2) and '*boost*' (Fan Setting 3) operation. The system was also tested with clean filters and with a 50% cardboard occlusion to simulate dirty filter operation as shown in the below tables:

**Extract:**

| | Clean Filter | | | 50% Occlusion | | |
|---|---|---|---|---|---|---|
| | Setting 2 | Setting 3 | Variation | Setting 2 | Setting 3 | Variation |
| Room | (l/s) | (l/s) | (%) | (l/s) | (l/s) | (%) |
| Kitchen: | 8.00 | 13.40 | 0.60 | 7.20 | 13.60 | 0.53 |
| Hallway: | 3.30 | 5.40 | 0.61 | 3.10 | 5.30 | 0.58 |
| Downstairs WC: | 4.70 | 6.40 | 0.73 | 3.10 | 5.30 | 0.58 |
| Bathroom: | 5.50 | 9.30 | 0.59 | 5.60 | 8.70 | 0.64 |
| Total: | 21.50 | 34.50 | 0.62 | 19.00 | 32.90 | 0.58 |
| Total ($m^3$/hr.): | 77.40 | 124.20 | 0.62 | 68.40 | 118.44 | 0.58 |
| Design Flow Rate ($m^3$/hr.): | 85.00 | 131.00 | 0.65 | 85.00 | 131.00 | 0.65 |
| % Leakage/Losses: | 8.94 | 5.19 | | 19.53 | 9.59 | |

**Supply:**

| | Clean Filter | | | 50% Occlusion | | |
|---|---|---|---|---|---|---|
| | Setting 2 | Setting 3 | Variation | Setting 2 | Setting 3 | Variation |
| Room | (l/s) | (l/s) | (%) | (l/s) | (l/s) | (%) |
| Living Room: | 4.50 | 5.60 | 0.80 | 4.50 | 6.10 | 0.74 |
| Master Bedroom: | 8.10 | 12.50 | 0.65 | 7.50 | 12.30 | 0.61 |
| Bedroom 2: | 8.10 | 11.60 | 0.70 | 7.30 | 11.30 | 0.65 |
| Total: | 20.70 | 29.70 | 0.70 | 19.30 | 29.70 | 0.65 |
| Total ($m^3$/hr.): | 74.52 | 106.92 | 0.70 | 69.48 | 106.92 | 0.65 |
| Design Flow Rate ($m^3$/hr.): | 85.00 | 131.00 | 0.65 | 85.00 | 131.00 | 0.65 |
| % Leakage/Losses: | 12.33 | 18.39 | | 18.26 | 18.39 | |
| Supply: Extract | 0.96 | 0.86 | | 1.02 | 0.90 | |

**Table 6.11**: MVHR Volume Flow Rate Test Results

The supply: extract ratio is very important in ensuring a high level of heat transfer in the *MVHR*'s heat exchanger and maintain the thermal efficiency above the *PHI* requirement of 75%. The 0.96 calculated here during normal operation is very good. This improves as the filters become blocked. The 0.86 under boost conditions is quite a drop off. This is alarming as the *MVHR*'s performance gains greater importance under this setting in winter operation. There will be a greater level of heat transfer as the ratio decreases but the volume flow rate of hot air supplied to the rooms will be significantly lower. Overall, the losses witnessed are to be expected due to duct leakage and a drop in fan performance over time. These losses stand at 9% for the extract and 12% for supply under normal operation. Upon system inspection, the standard of installation must be deemed of very high quality since the *MVHR* unit replacement and system upgrades have been made.

Under monitored summer conditions, the system operation must be deemed successful. However, under winter operation when the fan operates in '*Boost*' mode, the system becomes more unbalanced, favouring depressurisation. This could result in higher running costs and additional wear on the fan units. The supply volume low rate is over 18% lower than the manufacturer's catalogue. This has a large bearing on heating distribution in winter and reducing the load on the *HP*. Performance drops even further as static pressure rises within the ductwork under occlusion testing. The importance of clean filters has been stressed to the occupant, especially in winter.

*CIBSE* recommends a minimum of 8l/s of fresh air per person in domestic dwellings. In the test results, the total delivery of 20.7l/s under '*normal*' *MVHR* operation and 19.3l/s when the filters become clogged is more than required for the current two occupants; but could be unsatisfactory for a house designed for 3 to 4 inhabitants, if it was fully occupied. A minimum fresh air supply of 32l/s would be expected. The fresh air supply to the living room is inadequate for even one person. This has a bearing on thermal comfort and health, and calls for appropriate change of filters.

### 6.4.5 MVHR System Conclusions

1) The *PHI* criteria regarding the *MVHR*'s operating efficiency is being met successfully, with an average temperature transfer efficiency of 85%.
2) The *MVHR* is providing a high level of thermal comfort and is preventing over-heating in the summer effectively.
3) The system's operation should be considered cost effective and user friendly.
4) Under unchanged filters, the *MVHR* would be supplying insufficient and unhealthy levels of fresh air to the home if it had more than two occupants.

## 6.5 AASHP Analysis

The dwelling was designed to meet its space heating demand via internal gains and an air-source heat pump. It is manufactured by *Mitsubishi* and has a quoted *COP* of 4.0 in heating mode. It has a rated capacity of 4.0kW for heating and 3.5kW for cooling. It has been certified as an 'A' ranked energy efficient product. The heat pump is operated manually and on a timer set by the occupant. It is not used by the occupant as a space cooling device, mainly due to the building climatic location. Its sole purpose it to meet the winter space heating demand.

Following the first winters operation, the heat pump was replaced with the current model. The unit was largely undersized to meet the peak heating load. Even since the replacement, the homeowner has described conditions in very cold days of winter as '*too cold, with noticeable variations in temperature throughout the day and night*.' She stresses that a single *AASHP* is not sufficient for the house and that supplementary heating via the use of the fireplace is often necessary. It is also pointed out that the system is expensive to run and that heat does not distribute around the house evenly. This later issue has been significantly resolved since internal door undercuts were increased.

The A*ASHP*'s main function within the PassivHaus dwelling is to meet the winter condition's space heating loads. It also incorporates a cooling function in summer but this is rarely required due to the operation of the *MVHR* system and manually assisted natural ventilation. The testing was carried out in order to meet the following objectives;

1. To determine the operational performance of the *AASHP* in heating and cooling operation and compare this with the manufacturer's data and *PHPP* design criteria.
2. To analyse the heat distribution and load matching ability of the system in conjunction with the operation of the *MVHR* system during both winter and summer environmental conditions.

The operation *of the AASHP* was tested; and distribution of heat around the home scrutinised. Another test was performed for the *AASHP* operating in cooling mode in tandem with the functioning *MVHR*. The installation of the monitoring equipment and testing had to be non-invasive. Although not a definitive testing procedure, it is felt that some valuable conclusions can be drawn from the test data obtained.

### 6.5.1 Heating Operation Testing

*ESRU*'s monitoring of the first *AASHP* highlighted the issue of the required defrost operation during extreme winter conditions. This occurred when the outdoor unit drop below 6°C for prolonged periods of time, negatively impacting the systems *COP* and reducing the energy delivered to the home as heating operation ceased during these periods. The manufacturer was contacted regarding this issue yet could not provide any insight or data relating to the affected performance. After some time since the *ESRU* monitoring and report, the *AASHP* was replaced by a larger and upgraded model due to the reported inadequate winter operation. The *PHPP* design tools had resulted in an undersized original installation. The second model performs better but is still inadequate during very cold weather.

### 6.5.2 Cooling Operation Testing

The same methodology has been applied to the summer operation test method and analysis. Here the *AASHP* maximum design *COP* is outlined as 1.02 by the manufacturers' catalogue. This has been attained under test conditions of a 35°C source temperature and an internal temperature set point of 27°C. Realistically, these conditions would never be met in Scotland. This *AASHP* has not been primarily designed for cooling operation. However, it is important to test the actual performance against the manufacturer's literature.

The homeowner could only perform the test when the source temperature averaged 16°C and the internal temperature was 22.3°C. This is typical for Scotland. This was at mid-day when solar irradiance and the external temperature were at their daily maximums. The internal temperature set-point was reduced to its absolute minimum in order to simulate the maximum available cooling load to ensure that the *AASHP* would operate at its maximum output for the specific fan speed setting. The monitored data is presented in the following graph for the test period:

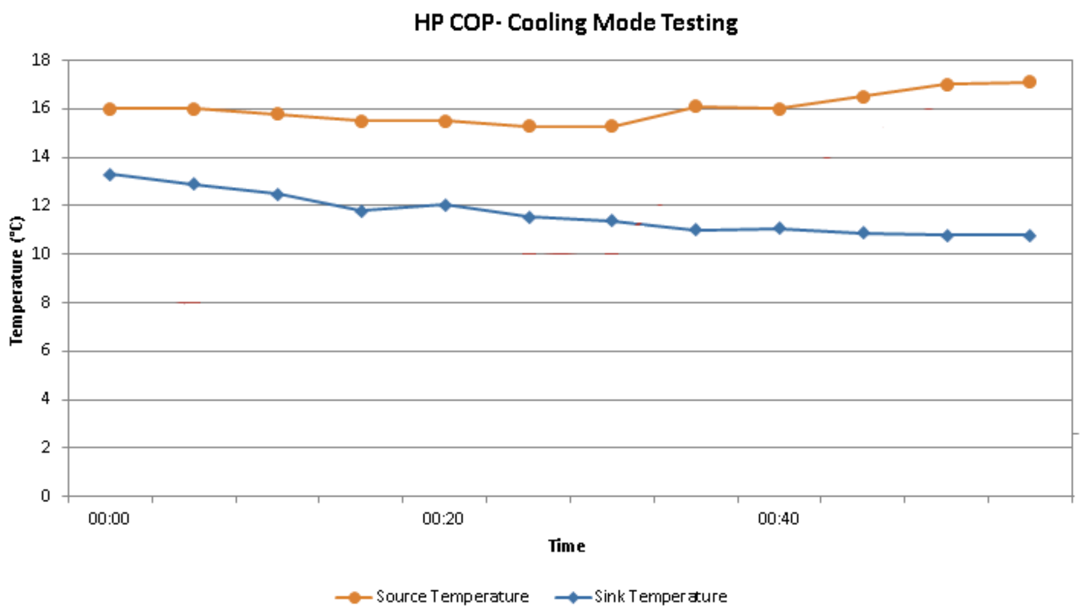



**Figure 6.11:** *AASHP* Temperatures during Cooling Test

The results show that this would be a highly inefficient method of cooling the passive house. Luckily the heat pump is only required for heating purposes. This highlights the importance of the *MVHR*'s operation to minimise temperatures above the comfortable range during the summer months

### 6.5.3 AASHP System Conclusions

From the system analysis, the *AASHP* should not be used to provide mechanical cooling. It performs poorly, and would result in high costs and energy consumption. Shading, natural ventilation and *MVHR* operation should be used to prevent overheating and maintain thermal comfort.

## 6.6 Key Findings and Conclusions for this section

This section has highlighted some fundamental system design and operational areas that still need to be addressed to optimise the building's performance. Firstly, the HW system currently achieves 36% of its *HW* contribution via solar thermal. A previous study by ESRU of the system's operation in early 2011; one year after the building was opened concluded that 40% annual contribution from solar irradiance would be a more realistic system target. Simply switching the control logic can raise the current summer contribution of 43% to approximately 71%. The system's current operation costs the occupant 28% less on average when solar irradiance levels are high when compared to days of poor solar conditions. The solar thermal circuit is saving the homeowner money and energy.

Secondly, the *MVHR* system meets the *PHI* criteria by recovering heat with an average monitored temperature transfer efficiency of 85% consuming a low level of electricity. The *MVHR* is therefore operating above the *PHPP* outlined temperature transfer efficiency minimum of 75% but slightly below the manufacturer's quoted 92%. Whilst the system prevents overheating of the dwelling by meeting the building's cooling load all year round, it does not provide the adequate volumes of fresh air supply should the building be occupied for the designed level of three or four people. At present that is not an issue. Furthermore, the low volume flow rates mean that heat may not be distributed sufficiently during winter operation to meet the building's high heating load. This was highlighted during the testing of the *AASHP* and contact with the homeowner. The testing highlighted why the *AASHP* may not be suitable to meet cooling loads. The testing did indicate that the heat pump can achieve an average COP of 3.49 in heating mode. In very low Scottish weather, a supplementary heat source may be required to successfully meet thermal comfort needs. The *AASHP* testing may be deemed inconclusive and further studies may be useful.

The home is now operating far better than originally constructed and commissioned in 2011. Incorporating the system suggestions within this section is expected to further enhance the performance of the UK's first affordable passive house. However, the dwelling is a marquee project operating at an extremely high performance with regards to energy. It has been constructed to meet the *PHI* design criteria and has been successfully certified. This study has highlighted the mechanical systems and building envelope's ability to work in conjunction to achieve a high level of thermal comfort and occupant satisfaction for the majority of the year.

# 7. Monitoring methods and findings

## 7.1 Introduction

This chapter discusses the selection of metering and monitoring methods adopted, issues arising with equipment over the course of the monitoring, a summary of electrical energy consumption and an environmental summary for each dwelling. A comparison is made of dwellings in each house type.

## 7.2 Monitoring Methods

A plan for monitoring environmental conditions and energy consumption of the three dwellings was developed by MEARU. Following a site survey and detailed discussions between MEARU and t-mac Technologies Ltd, MEARU ordered the required equipment suitable to the site conditions, nature of occupants, and the schedule of monitoring in accordance with the TSB guidance for project execution.

To minimise disruption to the occupants, a wireless system capable of gathering data locally and transmitting over GRPS networks to a central server was procured. Wireless apparatus proved less restrictive (removing the need for adjacent power sockets) and more robust (less risk of equipment being accidentally unplugged). The system transmitted real-time data to an off-site repository, to provide better security, reduce risk of data loss and to reduce the need for frequent access to the houses. The remote monitoring of data provided a useful portal for observation and data analysis by MEARU.

Combined wireless solar powered sensors for temperature, relative humidity (RH) and $CO_2$ supplied by t-mac Ltd monitored internal environmental conditions. Solar powered contact sensors monitored window opening patterns - to log the open or closed (Figure 7.1) status of the window. Four rooms per dwelling were fitted with wireless environmental sensors; and each of these rooms was fitted with a contact sensor placed on the most frequently opened windows. The installation and commissioning of these took place on 07/12/12 and 18-19/12/12 respectively. The monitoring equipment and sub-circuits monitors that were installed are summarised in Table 7.1. The site survey report and commissioning report from t-mac are provided in **6 and Appendix 7.2**.

| **Metering and monitoring**<br>*5 minute meter recording intervals* | **TA1**<br>*Low Energy House*<br>*3 Bed house* | **TA2**<br>*Low Energy House*<br>*3 Bed house* | **TB1**<br>*PassivHaus*<br>*2 Bed house* |
|---|---|---|---|
| **Electrical Sub-metering** | Mains incoming<br>Kitchen sockets<br>Downstairs sockets<br>Upstairs sockets<br>Downstairs lighting<br>Upstairs lighting<br>Cooker<br>Tumble drier<br>Living room storage heater<br>Hall storage heater<br>Upstairs storage heater<br>Convector ring<br>Bed 1 spur<br>Boost water | Mains incoming<br>Kitchen sockets<br>Downstairs sockets<br>Upstairs sockets<br>Downstairs lighting<br>Upstairs lighting<br>Cooker<br>Tumble drier<br>Living room storage heater<br>Hall storage heater<br>Upstairs storage heater<br>Shower<br>Convector ring<br>Boost water | Mains incoming<br>Kitchen sockets<br>Downstairs sockets<br>Downstairs lighting<br>Upstairs lighting<br>Cooker<br>Tumble drier<br>Solar panel<br>Water heater<br>Shower<br>Towel rail – bathroom<br>Towel rail - WC |
| **Environment** | Living Room<br>Bedroom 1<br>Bedroom 2<br>Kitchen<br>Living room (window only) | Living Room<br>Bedroom 1<br>Bedroom 2<br>Kitchen<br>Living room (window only) | Living Room<br>Bedroom 1<br>Bedroom 2<br>Kitchen<br>Living room (window only) |

**Table 7.1:** Metering and monitoring by house type.

**Figure 7.1:** Window contact sensor: closed.

**Figure 7.2:** Living room: installed environmental monitoring (CO2, Temperature and RH%) sensor.

**Figure 7.3:** Installation of sub-meter clamps to distribution board circuits.

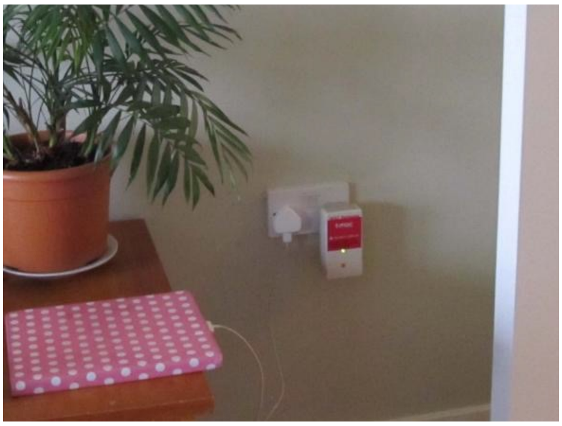


**Figure 7.4:** Plugged-in WiST repeater units - one in each dwelling.

The $CO_2$, RH and Temperature sensors; window contacts; and sub-meter sensors (Figure 7.2) were all linked wirelessly to the central data logger in each house to log at 5 min intervals in synchrony. The data collected was transmitted wirelessly to a central t-mac unit, which was hard-wired via a fused spur to the meter board, in the utilities cupboard under the staircase of each house. At the distribution board, electrical sub-circuits were monitored via CT clamps (Figure 7.3) which were connected to the t-mac unit. A wireless WiST repeater unit was plugged into a wall socket in each dwelling to boost signals and ensure robust communication from the sensors to the wireless gateway.

The t-mac system was configured to send an email alert to MEARU if a unit did not log in to communicate data for a pre-set period. Overall, the setup worked well, but the signal was weaker in TB1. Most of the time, the internal and GSM signal strength was good as the communication was boosted through the WiST repeater units (Figure 7.4). For the PassivHaus dwelling, TB1, the output from the solar thermal system was monitored, along with hot water immerser consumption.

Over the course of monitoring there were several issues with the operation of the equipment. The most significant issue was with the mobile telephone signal and connection with TB1. This was particularly due to:

1. The remote location; and
2. The high level of insulation.

## 7.3 Energy Summary

This section summarises the energy consumption based on the latest one year of metering and in some cases, compared with consumption before the one year. It is subdivided by Utilities, House Type, and DomEARM. Each section discusses the different types of electrical energy monitored: primary energy use, sub-circuit, space heating and water heating; in relation to the building design, construction, use and expectations. Issues discovered during monitoring, and adjustments are documented and their impacts explained.

### 7.3.1 Utilities

All of the monitored dwellings are connected to the mains electricity grid via a meter; none of the dwellings have on-site renewable energy generation for electricity. TB1, the PassivHaus, is the only dwelling to have solar water heating. The heating systems are summarised in Table 7.2 and described in more detail in Chapter 6.

| House Type | Electricity | Heating | Hot Water |
|---|---|---|---|
| **TA1**<br>*Low Energy House*<br>*3 Bed house* | Grid connected | Electric storage and convection heaters | Immersion Heater |
| **TA2**<br>*Low Energy House*<br>*3 Bed house* | Grid connected | Electric storage and convection heaters | Immersion Heater |
| **TB1**<br>*PassivHaus*<br>*2 Bed house* | Grid connected | Air to Air Source Heat Pump (AASHP);<br>Whole house mechanical ventilation and heat recovery system (MVHR);<br>Towel rail in bathroom and WC | Solar Thermal System with electric booster |

**Table 7.2:** Summary of heating and hot water systems by house type.

The annual energy consumption presented in Table 7.3 reflects the actual consumption from 01st September 2013 to 31st August 2014. The chart illustrates different consumption variations between the dwellings, in particular the higher patterns of heating electrical consumption of TA2, and illustrates distinct consumption differences between each House Type (discussed separately). Energy consumption varies depending on a range of factors including house type, heat loss parameters, airtightness and orientation as well as other factors such as occupancy patterns, number of occupants, user behaviour and energy efficiency of appliances. These factors make it difficult to compare the energy demand like for like in the three dwellings; therefore energy consumption is typically compared in dwellings per unit of floor area in kWh/m$^2$ as illustrated in **Table 7.3.** The floor areas in this report are those used for the SAP calculations to maintain consistency in comparison. It should be noted that the SAP area calculation includes the staircase area of both the first and second floor.

An alternative approach is to express it in consumption per occupant. The latter is a better way of comparing demand versus consumption, and the levels of energy wasted, particularly if the homes are highly insulated and the air is supplied on demand per occupant. This is illustrated in Table 7.4, where dwellings are compared by consumption of electricity and carbon by m$^2$ and occupancy. These figures are based on the total amount of metered energy consumed.

The annual consumption reviewed concentrates on both 'regulated' and 'unregulated' energy consumption, as termed by the Building Regulations. Regulated consumption refers to energy consumed for space heating, hot water, lighting and fans and pumps, while unregulated consumption refers to all other energy users in a home that the occupants typically plug in. The Standard Assessment Procedure (SAP: See Chapter 2) focuses on the regulated loads and assumes standard occupancy patterns to provide an estimate of the energy consumption of a dwelling. Table 7.3 plots delivered energy for regulated loads against the SAP predictions; $CO_2$ is calculated with an emission factor of 0.422 kg CO2/kWh (based on SAP calculations). Other energy usage is not included, as this is a direct comparison with SAP 2005.

| **Dwelling** | **TA1** | | **TA2** | | **TB1** | |
|---|---|---|---|---|---|---|
| ***Measurement*** | *SAP* | *Measured* | *SAP* | *Measured* | *SAP* | *Measured* |
| **Area m$^2$** | 120 | N/A | 120 | N/A | 104 | N/A |
| **Occupants** | N/A | 5 | N/A | 3 | N/A | 2 |
| **Electricity for heat KWh/year** | 4508.63 | 1361.18 | 4508.63 | 4547.21 | 1133.37 | 578.65 |
| **Water Heating kWh/year** | 3086.33 | 1090 | 3086.33 | – 2007* | 1404.82 | 1685 (64%) SWH (36%) |
| **Pumps and Fans** | N/A | N/A | N/A | N/A | 1061.48 | N/A |
| **Electricity for lighting KWh/year** | 839.41 | 38 | 839.41 | 354.34 | 533.20 | 54.66 |
| **Total Electricity KWh/year** | 8464.37 | 2489.18 | 8464.37 | 6909.55 | 4132.87 | 2318.31 |
| **Total $CO_2$ /year kg $CO_2$ /year** | 3571.96 | 1050.43 | 3559.31 | 2915.83 | 1744.07 | 978.33 |

**Table 7.3:** Comparisons between predicted (SAP) and measured (Sept 2013-Aug 2014) energy use and $CO_2$ emissions for all house types.

**This figure is from the Jan 2013 – Dec 2013 range; Sept 2013 – Aug 2014 range not complete.*

The comparison of different dwelling types in Table 7.4, with the SAP predictions and measured data, reveals a potential discrepancy with the measured data for TA1. This dwelling exhibited a particularly low level of consumption, comparable with that of TB1. One explanation for this may be the low level use of electricity on lighting and socket circuits, if circuits are used only in low levels, e.g. switching lights on one at a time, these types of consumption may not be identified by the CT Clamps. This will be examined in more detail in Section 7.4.2.

Overall the energy consumption and $CO_2$ emissions of TA1 and TB1 were well below designed predictions, excepting water heating for TB1. Apart from water heating for TA2 all projections were above the predicted amounts. The overall consumption for TA2 was closer to the SAP predictions than the other dwellings. The energy used for water heating and lighting was lower than predicted. For the later, in all houses, this may be partly linked with the inability of the CT clamps to detect small currents such as low energy lights as previously discussed.

The energy used in each plot for lighting is relatively small, in particular for TA1. This could be partly due to the generous size of windows for daylight; and the relatively private site which means that most of the windows do not actually need blinds for privacy for significant lengths of time. In dwelling TA1 users tended to switch on lights only when absolutely necessary.

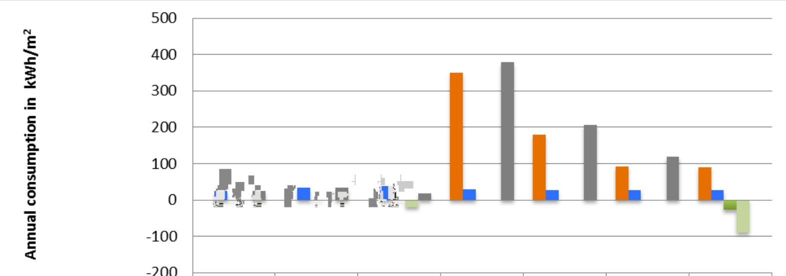
Overall, the total measured consumption, when compared like for like with SAP predictions, demonstrated that the dwellings actual consumption was lower than that predicted by SAP, based on national average patterns of consumption. In Table 7.3, large differences are apparent in the comparison of the as-designed SAP with actual performance; except for TA2. The margins of differences also differ between TA1 and TB1. SAP estimates for space heating are usually much less than the measured actual, as is the case for TA1 and TB1, although it is the opposite in TA2. A number of factors influence the actual: (1) For all dwellings the design air permeability was much poorer than the actual measured, which implies less than predicted heat is lost through air exchange with external fresh air; (2) It should be noted that SAP does not include some uses (such as appliances), and this could contribute to significant internal gains; (3) SAP calculation does not account for obvious and predictable occupancy factors, which in this case differ between continuous occupancy in TA1 and TA2 while TB1 has regimented occupancy; and differences in number occupants, which are likely to lead to differences in internal gains and lengths of heating periods; and (4) In Chapter 4, Figure 4.1 and Figure 7.25 in this chapter; it is apparent that much higher internal temperatures are being achieved in TA2 (than TA1 and TB1), which has the highest space heating consumption, which is also higher than the SAP predicted consumption. Winter and autumn temperatures were are mostly warm to hot in TA2. As observed during the initial walkthrough, the occupants of TA2 typically switched their heating on earlier in September and leave them on for longer than the typical Oct to March heating period kept in TA1. They also prefer warmer average temperatures than in TA1.

Further analysis takes into account full electricity consumption, see Table 7.4. Further investigation is required to ascertain whether or not SAP is a good prediction tool, particularly in the context of low-energy and PassivHaus homes. Further analysis of energy consumption of the three plots in relation to design intensions and measured will be made in the following section – for detailed spreadsheets see **Appendix 7.3**.

| Dwelling | TA1 | TA2 | TB1 |
|---|---|---|---|
| **Area m$^2$** | 120 | 120 | 104 |
| **Occupants** | 5 | 3 | 2 |
| **Total Electricity** *KWh/year Including all electrical consumption* | 4228.86 | 8480.08 | 4513.08 (Excludes SWH contribution = 36% of HW demand) |
| **Total Electricity** *KWh/m$^2$/year* | 35.24 | 70.67 | 43.4 |
| **Total Electricity** *KWh/occupant/year* | 845.77 | 2826.69 | 2256.54 |
| **Total $CO_2$ /year** *kg $CO_2$/year* | 1784.58 | 3578.59 | 1904.52 |
| **Total $CO_2$ /year** *kg $CO_2$/m$^2$/year* | 14.87 | 29.82 | 18.31 |
| **Total $CO_2$ /year** *kg $CO_2$/occupant/year* | 356.92 | 1192.86 | 952.26 |

**Table 7.4:** Dwelling comparison between consumption of electricity and carbon by m$^2$ and occupancy.

Table 7.4 demonstrates the difference between total energy consumed, and total energy predicted by SAP (Table 7.3), displaying energy and carbon consumption by m$^2$ and occupancy. For total energy consumption TA1 and TB1 are comparable, whereas TA2 is twice that of TA1. As discussed above, this may be a reflection of the exceptionally good performance of TA1, rather than reflecting very bad performance of TA2. When consumption is based on electricity/m2, TB1 has the lowest. In contrast, when consumption is based on occupancy, TA1 has 5no. occupants, TA2 3no. and TB2 2no., this results in TA1 having the lowest electricity consumption and carbon emissions out of the three dwellings.




| | TA1 | TA2 | TB1 | UK Average | Building Reg Compliant | CSH4 | CSH6 |
|---|---|---|---|---|---|---|---|
| Gas | 0 | 0 | 0 | 349 | 179 | 92 | 89 |
| Electricity | 24 | 33 | 38 | 29 | 28 | 27 | 27 |
| Renewable Elec | 0 | 0 | 0 | | | | -27 |
| Renewable Non-Elec | 0 | 0 | -19 | | | | -89 |
| Net | 24 | 33 | 19 | 378 | 207 | 119 | 0 |

**Figure 7.5:** Comparison of TA1, TA2 and TB1 energy consumption in kWh/m$^2$ with UK standards and CSH Levels 4 and 6.

**Comparison of energy consumption with UK standards and CSH.**

Energy consumption is compared with: the UK average, Scottish Building Regulation Compliance, Code for Sustainable Homes (CSH) Levels 4 and 6. Electrical consumption for TA1 is 24kWh/m$^2$, below all compared, whereas TA2 is 33kWh/m$^2$, higher than the UK average for electricity (29kWh/m$^2$), but significantly lower than the net consumption of 378kWh/m$^2$ without gas and building regulations: electricity (28kWh/m$^2$), 207 kWh/m$^2$ net value. The net energy consumption for each of the three dwellings is significantly lower than all other standards to which it is compared, except CSH6 which factors in renewable electricity and non-renewable electricity. These figures demonstrate that the design intent of affordable low-energy homes has been achieved.

### 7.3.2 House Type A

Overall, energy use was higher in TA2 than TA1, although they have similar physical characteristics; and house TA2 has fewer occupants. During the interview on 28.09.2012, the householders of TA2 exhibited habits of switching items on. The boiler remained switched on and the space heating had been switched on in September while the heating of TA1 had not been switched on. The occupants of TA1 seemed to be more careful with what they switched on. The instantaneous hot water shower fitted by the occupants of TA2 may explain the lower energy consumption from the electric boiler in this house compared to TA1, but this could also be explained by more occupants in TA1 using more hot water. For the electric heating, TA2 householders use both the economy 7 powered storage heaters and Rate 1 tariff convector heating. TA1 householders use predominantly the economy 7 powered storage heaters. This is a contributing factor to the higher ‘mains to distribution board’ (Tariff Rate 1) in TA2.

In dwelling TA1, there was an unusually high consumption by the bedroom spur. The rest of the consumption was dominated by the downstairs ring, hot water Cooker and Kitchen ring and downstairs storage heaters in that order. There was no high usage of lighting and the rest of the circuits. Lighting consumption is taken into account within the SAP assessment as a regulated load and consumption is low in comparison to other circuits (unregulated loads) within the dwelling.

**Comparison of electrical consumption from Mains incoming (DB) from Sept 2013 – Aug 2014.**

Dwelling TA1 DB electricity consumption was lower and flatter than that of dwelling TA2 throughout the year monitored. Dwelling TA2 consumption peaked during the months of December and January (404.79 – 408.79kWh), with the lowest consumption during April (247.86kWh). TA1 consumed the most electricity during April (290.85kWh) and the lowest during July (179.51kWh).

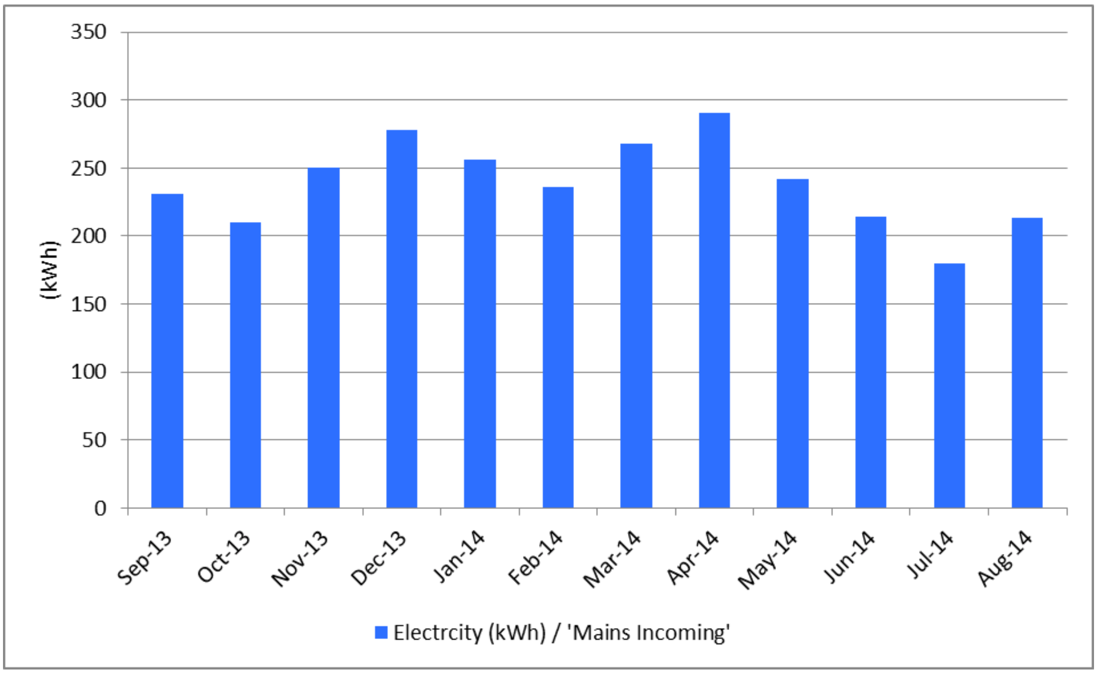



**Figure 7.6:** Electricity (kWh) Mains incoming (DB 1 Rate 1) for dwelling TA1 September 2013 - August 2014.

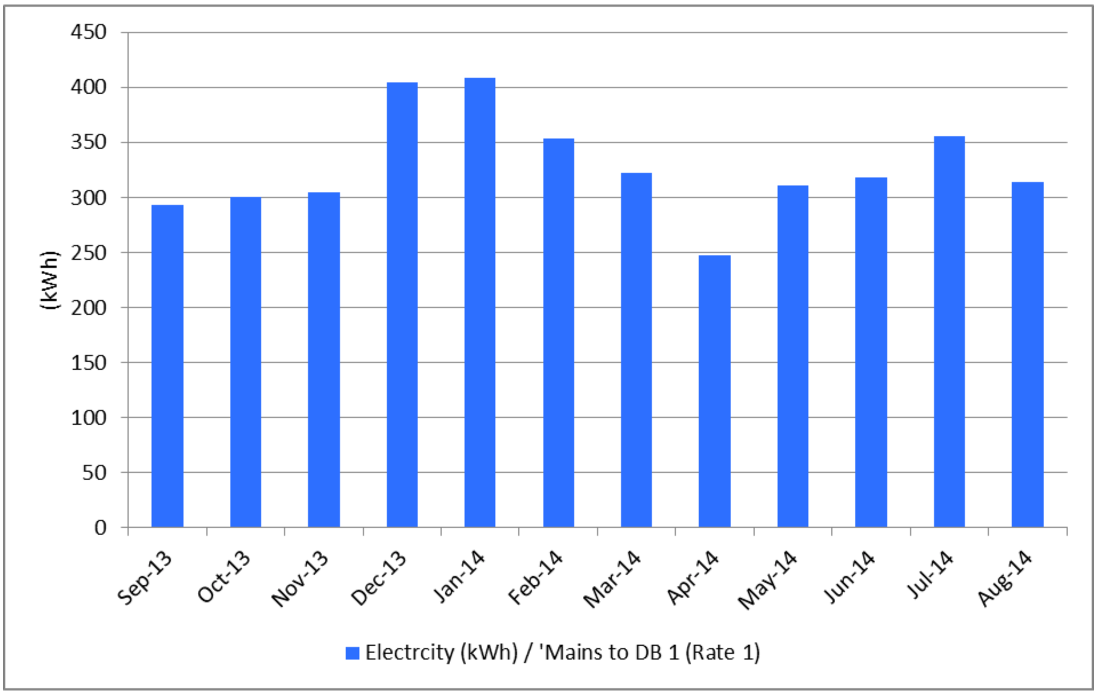



**Figure 7.7:** Electricity (kWh) Mains incoming (DB 1 Rate 1) for dwelling TA2 September 2013 - August 2014.

**Comparison of electrical consumption from Dec 2012 – Aug 2014.**

This indicates the electrical consumption in both dwelling TA1 and TA2 remains fairly consistent between both dwellings in 2013 and 2014. For electrical consumption, both dwellings are around or below the Building Regulation Compliant benchmark.

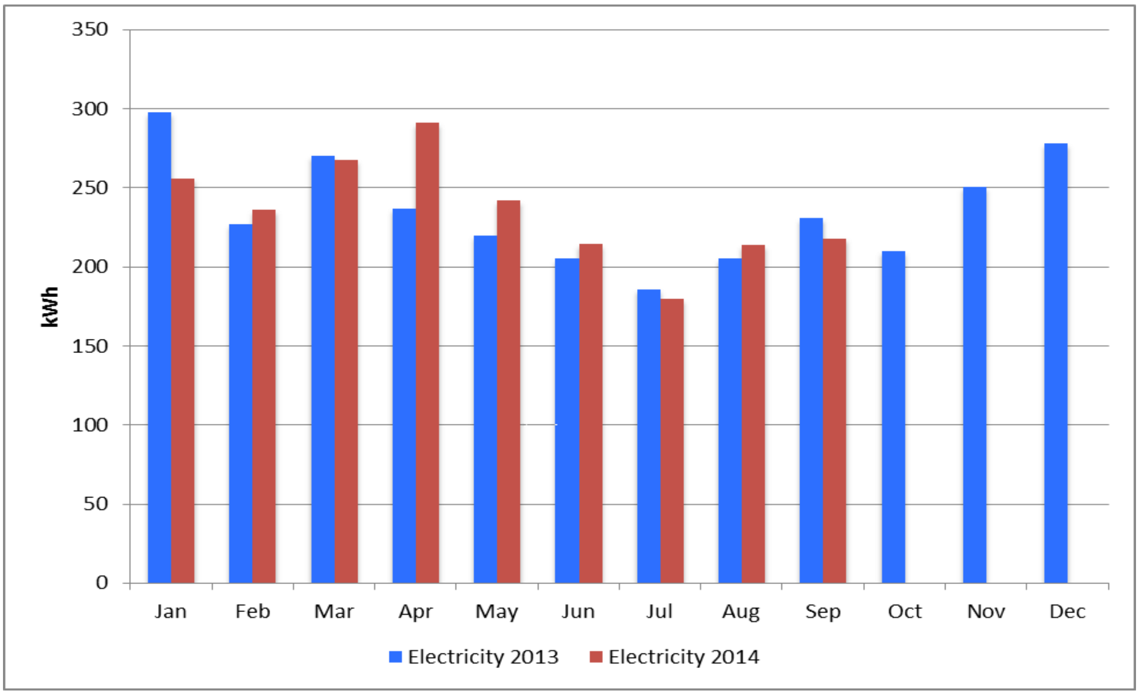



**Figure 7.8:** Electrical consumption from January 2013 - August 2014 for dwelling TA1.

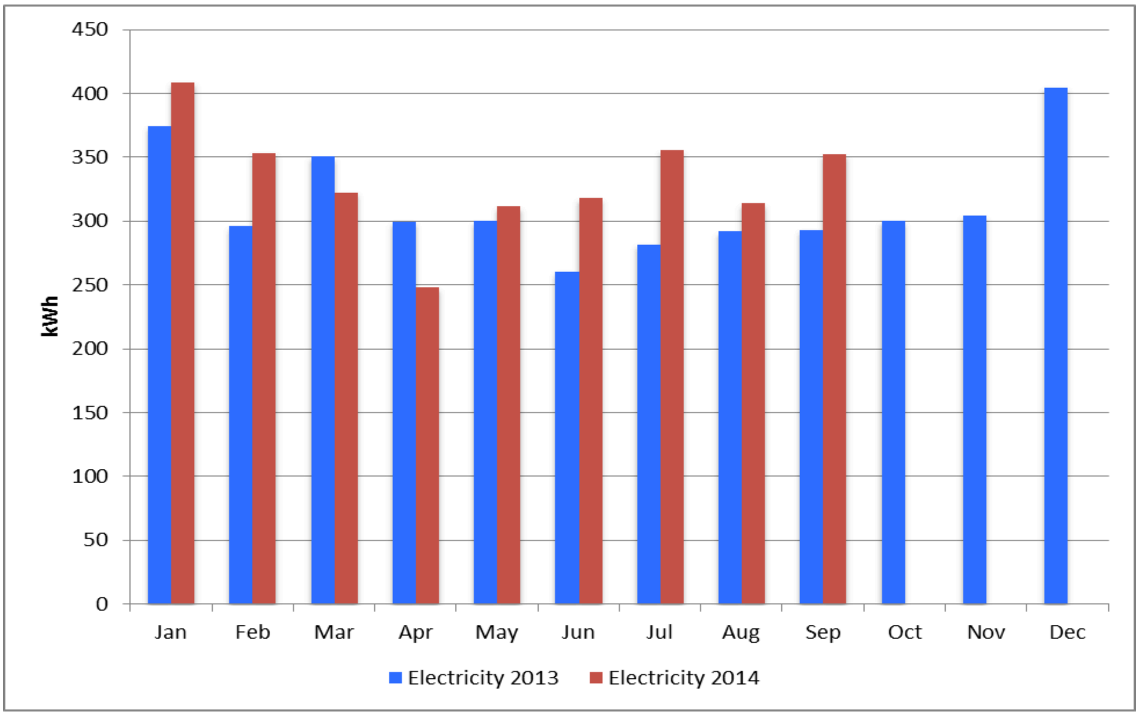



**Figure 7.9:** Electrical consumption from January 2013 - August 2014 for dwelling TA2.

**Comparison of electrical consumption from Dec 2012-Aug 2014.**

Dwelling TA1 shows a high level of water heating throughout the year, whereas the data for TA2 is inconsistent. This suggests a problem with the t-mac data recording for this dwelling and requires further investigation. After rechecking the original data and quarterly data sets, they confirmed that this is what was recorded. It could also be the case that the instant hot shower that was added in the house enabled the occupants to keep their immersion heater off most of the time. After February 2014, there is no data that was recorded and this suggests that the CT clamp was either removed during the underfloor heating installation works, or that the immerser was permanently switched off.

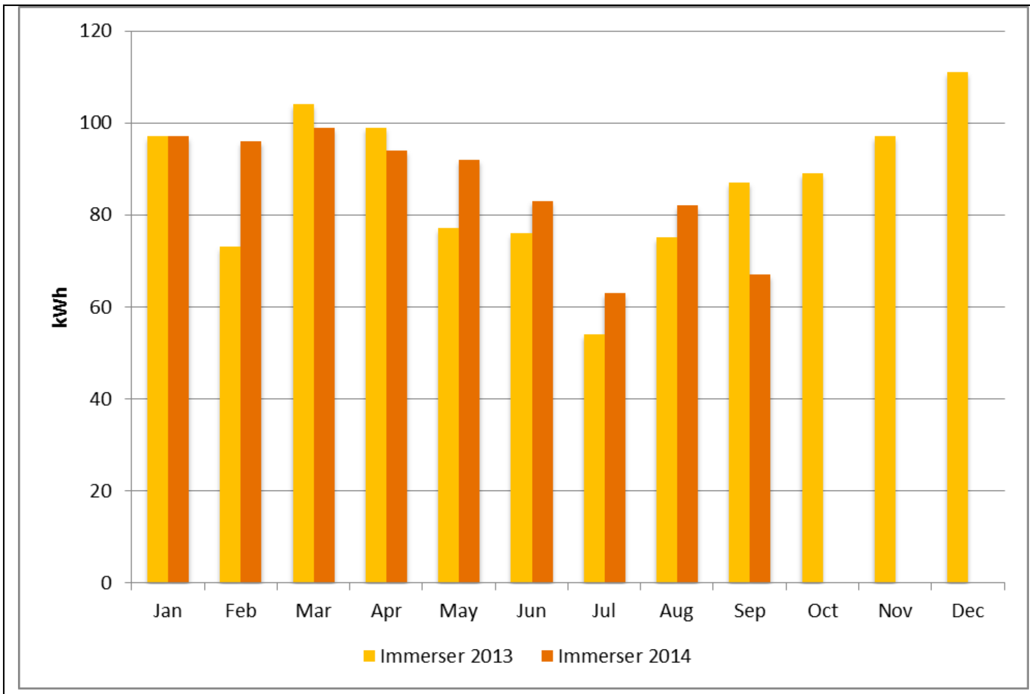



**Figure 7.10:** Immersion heater electrical consumption from January 2013 - August 2014 for dwelling TA1.

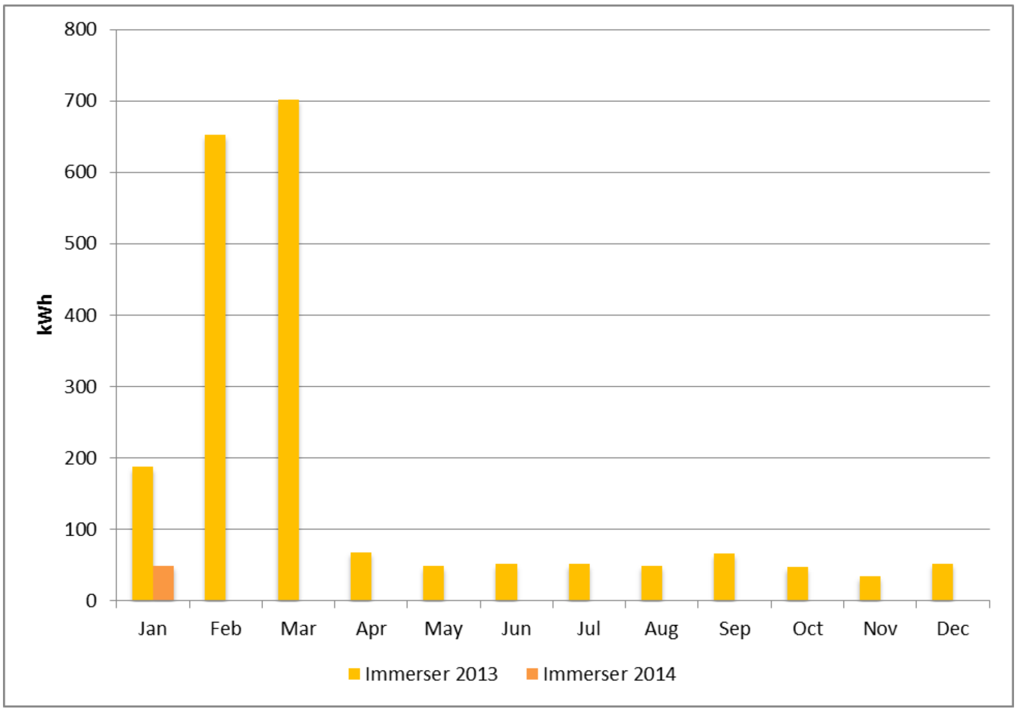



**Figure 7.11:** Immersion heater electrical consumption from January 2013 - August 2014 for dwelling TA2.

**Comparison of electrical consumption by sub-circuit from Dec 2012-Aug2014.**

This indicates that for TA1, the greatest electrical consumption between Nov – Mar are the living room storage heater and hall storage heater (until Jan only). Consumption from the bedroom spur is consistently high throughout the year. Lighting is of a minimal impact. The energy for the cooker remains almost constant throughout the year.

The overall consumption for TA2 is higher on average than that of TA1. For TA2 there is an autumn/winter pattern (Sept – Feb) of high consumption from the living room, upstairs and hall storage heaters. The convection ring, downstairs ring and kitchen ring remain fairly high and constant throughout the year. The cooker, tumble drier and hot water booster useage patterns are constant throughout the year with minimal impact from lighting.

Overall the profile in TA1 is what one might expect. The high consumption during Jul and Aug in TA2 is unusual.

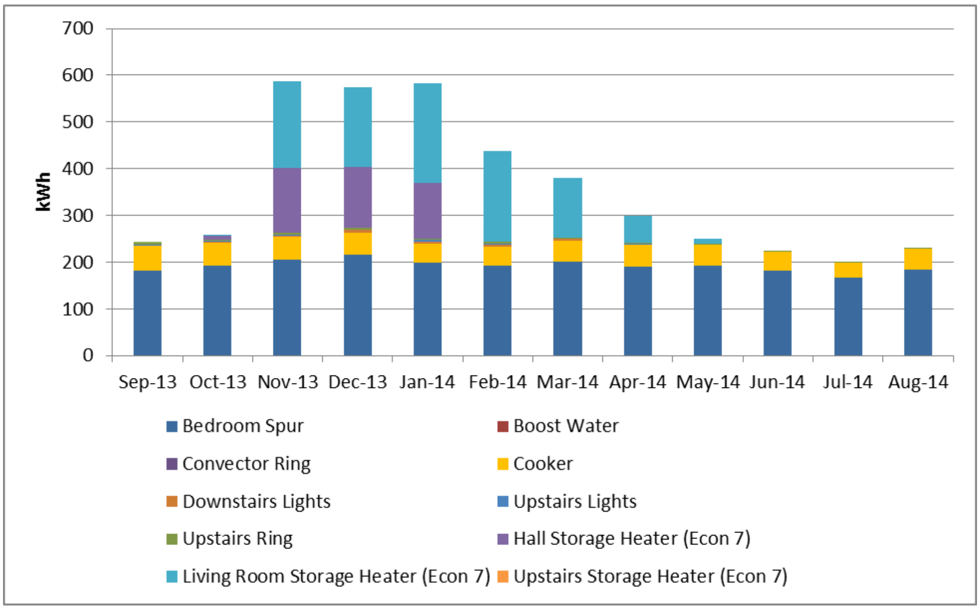



**Figure 7.12:** Electrical consumption by sub-circuit from December 2012 - August 2014 for dwelling TA1.

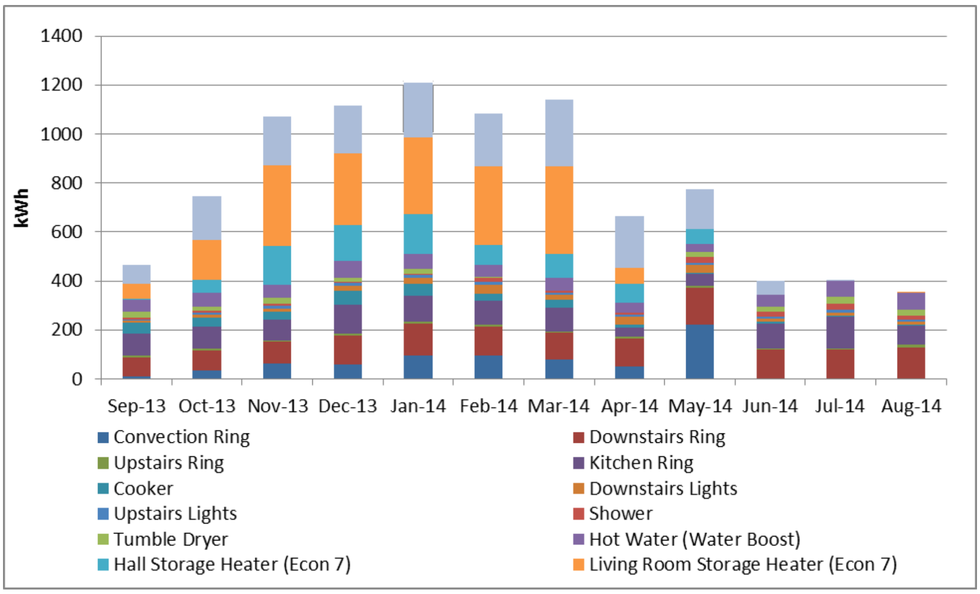



**Figure 7.13:** Electrical consumption by sub-circuit from December 2012 - August 2014 for dwelling TA2.

### 7.3.3 House Type B

Overall, energy use was lower in House Type B than House Type A. The overall energy consumption figures for this house type demonstrate that the design intent of an affordable PassivHaus home has been achieved.

Lighting consumption is taken into account within the SAP assessment as a regulated load and consumption is low in comparison to other circuits (unregulated loads) within the dwelling.

As noted in Chapter 6, there were a number of snagging problems with the PassivHaus systems. Following an initial period of higher energy bills, presumed by the occupant to be resulting from the MVHR system, MEARU determined that the problem was the extensive use of bathroom and WC towel rails (see **Figure 7.18** and **Figure 7.19**, below). Following the identification of this in May/June 2013, electricity consumption following this period was significantly lower (**Figure 7.15**). Additional assessments of the energy consumption of the MVHR were conducted by switching the fan to low speed in November 2013. Before then, it had remained at the medium speed and rarely adjusted. This is the speed that the installers had set it at.

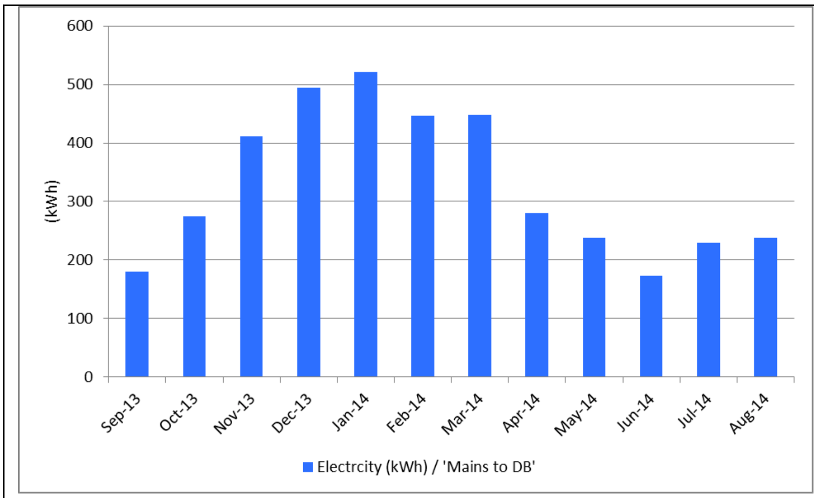



**Figure 7.14:** Electricity (kWh) Mains incoming (DB 1 Rate 1) for dwelling TB1 September 2013 - August 2014.

**Comparison of electrical consumption from Mains incoming (DB) from Sept 2013-Aug2014.**

The DB electricity consumption had a clear seasonal pattern. The highest being in January (520.85kWh) and the lowest being June (173.32kWh).

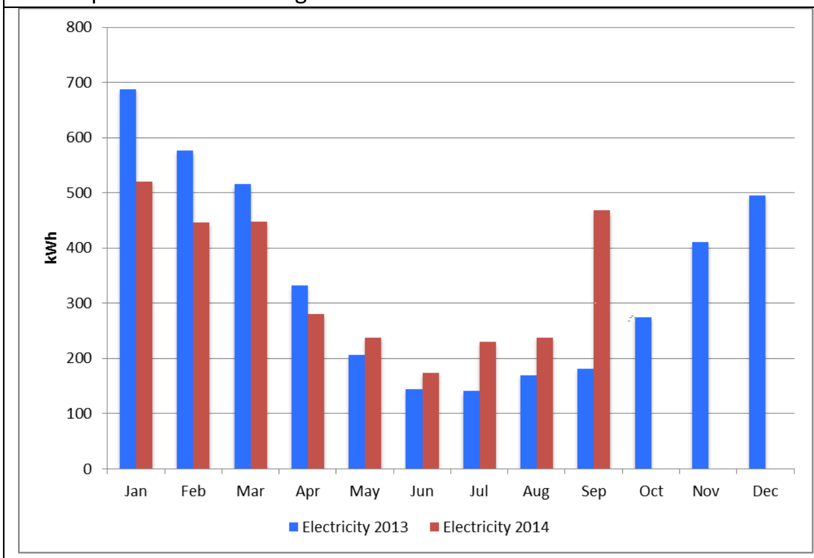



**Figure 7.15:** Electrical consumption from December 2012 - August 2014 for dwelling TB1.

**Comparison of electrical consumption from Jan 2013 – Aug 2014.**

This indicates the electrical consumption for dwelling TB1 has been reduced for most months during the second year (2013/2014). Electrical consumption is below the Building Regulation Compliant benchmark.

**Comparison of hot water immersion electrical consumption from Sept 2013 - Aug2014.**

This indicates the hot water immersion electrical consumption for dwelling TB1. This is higher than would be expected for a PassivHaus dwelling with a Solar Thermal System. It however reflects the finding that the SHW system is only meeting 36% of annual hot water loads and not 50% as originally envisaged

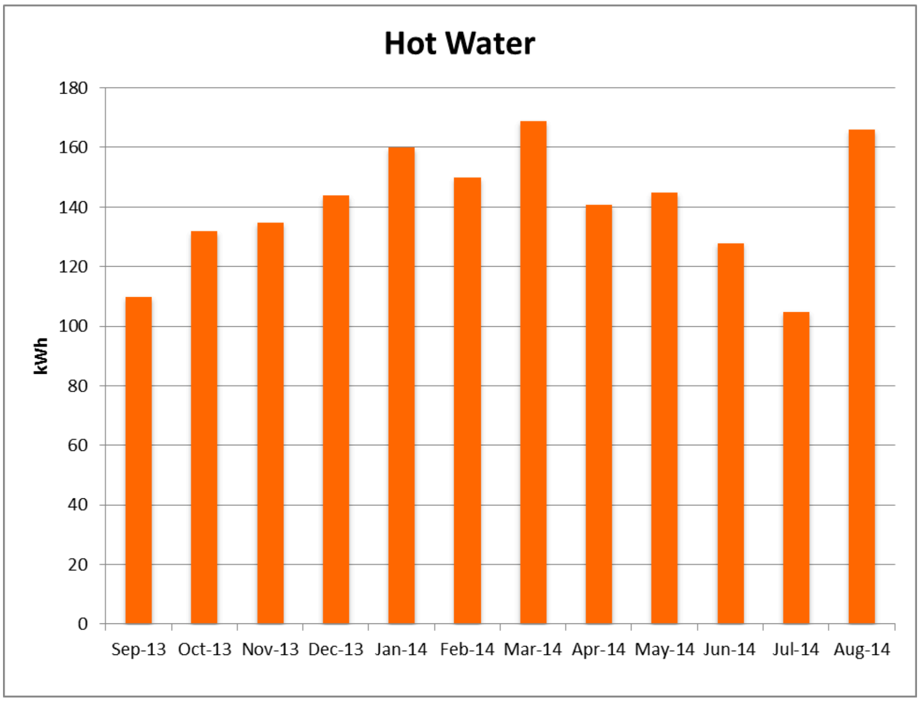



**Figure 7.16:** Electrical consumption for hot water immersion from Sept 2013 - Aug 2014 for dwelling TB1.

**Comparison of electrical consumption by sub-circuit from Sept 2012 – Aug 2014**

The highest consumers were the Sockets and the water heater. The sockets circuit seems to follow the pattern of the water heater, peaking in January. The towel rail WC is the third highest consumer concentrated between Nov 2013 and April 2014. The cooker useage patterns is almost constant throughout the year with a minimal impact from lighting, Towel rail and Tumble Dryer

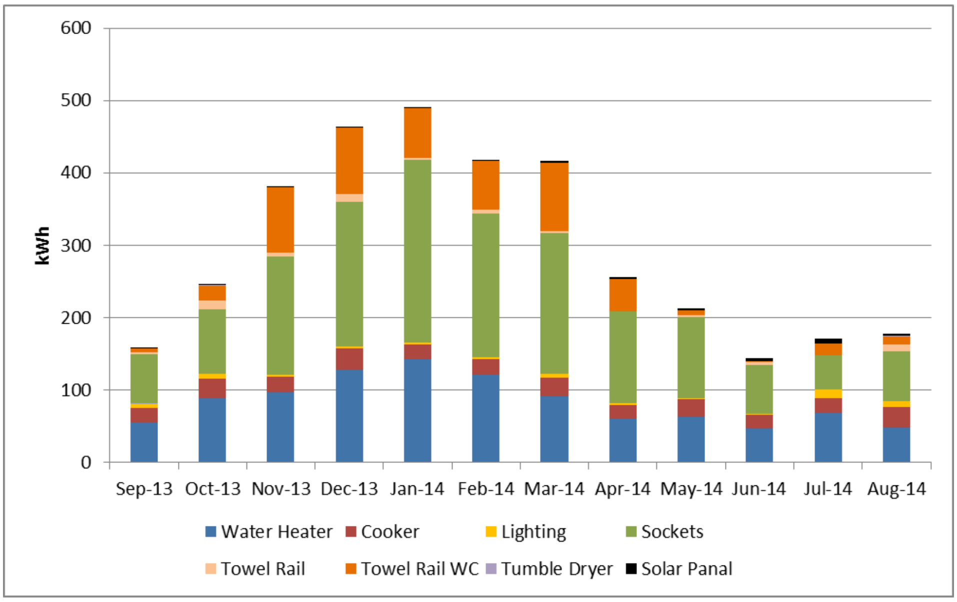



**Figure 7.17:** Electrical consumption by sub-circuit from September 2012 - August 2014 for dwelling TB1.

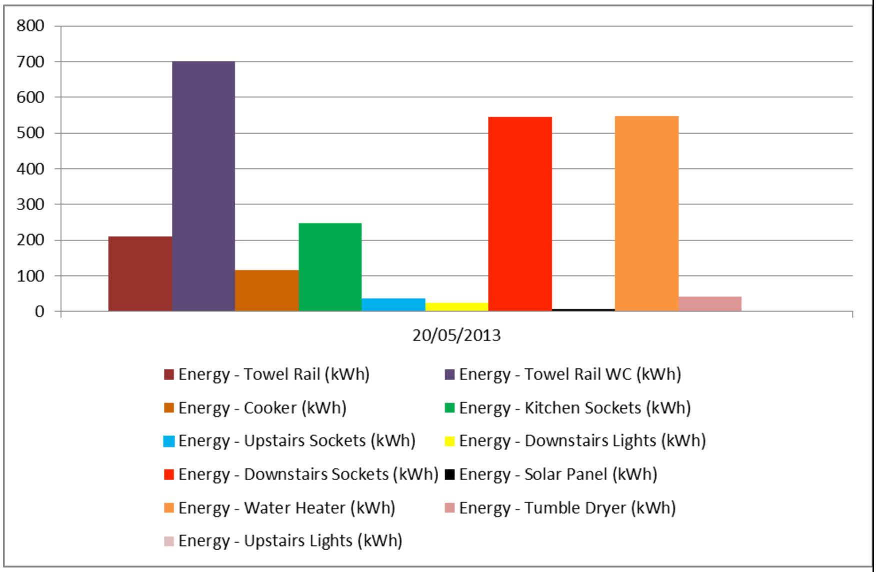



**Figure 7.18:** TB1 - Total energy use by different circuits for 5 months - between 20.12.12 and 20.05.13.

**Energy Consumption review – TB1**

Following Quarter 3, a review of energy bills; and data from sub-meters raised concerns that TB1 was consuming more energy than expected. This necessitated further and detailed investigation on the energy usage by various circuits since Dec 20th 2012 to May 20th 2013. Detailed data analysis was conducted to diagnose which of the 13 sub-metered circuits were contributing to unusual consumption of energy, and when this happened. The energy results showed (**Figure 7.18** & **Figure 7.19**) that the circuits using most energy are: the downstairs sockets; heat meter and water heater; and the two towels radiators. The results do not show the contribution of the solar and air-to air heat pump installations.

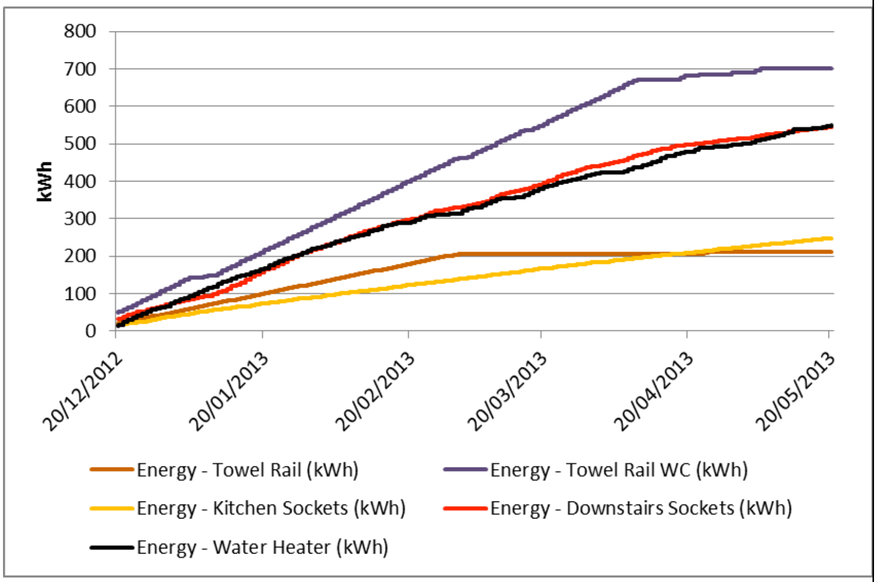



**Figure 7.19:** TB1 - Cumulative energy use by the different low consumption circuits for 5 months - between 20.12.12 and 20.05.13. Note the flat line of the tumble drier circuit.

Note the flattening of ground floor towel rail consumption (**Figure 7.19**) from the end of Feb; and near-flattening of the upstairs towel rail after early April, when the usage of the towel rails reduced significantly. These happened after high energy bills prompted the householder to seek explanations. MEARU visited the site and found out that the towel rails were responsible since they typically remained switched on even during the day when the house is typically unoccupied. After then, the householder kept them switched off most of the time and the consumption dropped significantly.

### 7.3.4 DomEarm

A DomEarm (Domestic Energy Audit and Reporting Method) survey was undertaken by MEARU staff in each dwelling. The survey uses three levels of information for benchmarking a dwelling. Levels one and two use basic energy meter readings and are considered simplified survey methods. The third level is a detailed method involving a survey of energy using appliances, equipment and lighting in each home. The survey involves an audit of every item drawing electricity in the home, from regulated use such as immersion heaters and lights to non-regulated use such as washing machines, kettles, TVs and mobile phone chargers. These were conducted on three separate visits to the site due to access restrictions, the survey in TA1 was undertaken on 23rd September 2013, TA2 27th September 2013 and TB1 24th June 2014. The information gathered from the survey was fed into a standard spread sheet (provided by TSB) which takes – in this case – accurately monitored energy consumption, building description, closest weather location, fuel supply type and an audit of the electrical appliances. The outputs provided are graphical indications of the actual consumption of the dwelling compared to typical and best practice consumption in the UK. The resultant outputs are summarised below and completed spread sheets are included in Appendix 7.4.

The level one assessment is a simple whole dwelling assessment which requires assessor details, construction type, fuel type and meter readings for each dwelling. From this a comparison is made which compares the 'Actual' consumption with 'UK Average' and 'Best Practice' benchmarks. Level 1 results are compared in $kWh/m^2$ of floor area. These indicate that the electrical consumption is greater in all three dwellings that the two benchmark, however the dwellings are electrically heated and as such the net energy consumption for these are significantly lower than the UK average benchmark. There is around a 13% difference between TA1 and TA2 with consumption being $65kWh/m^2$ and $75kWh/m^2$ respectively as indicated in the figures below. The dwelling in House Type B is significantly lower than both of these with a total of $39kWh/m^2$. This is below the net best practice total of $58kWh/m^2$.

The level 2 assessment builds on level one by adding information for heating, cooking and renewable technologies into the assessment. The results output were unaltered for dwellings TA1 and TA2 due to no renewables in this house type. However, it was noted that overall $CO_2$ emissions from TB1 reduced, due to solar thermal panels, but remained above the best practice benchmark net figure.

As noted above the level 3 assessment requires a physical audit of all the electrical equipment in the dwellings and results are output in tabular and graphical form by regulated and unregulated loads, graphical data is included in the figures below. However, the benchmark data for comparison does not contain data relating to non-regulated loads for computer equipment, consumer electronics, refrigeration appliances and wet appliances, therefore discounting direct comparison of these. The space heating for each of the dwellings indicate dwellings TA1 and TA2 require significantly lower energy demand than the UK Average benchmark and only TB1 performs better than the two benchmarks, however this result is as expected as TB1 is a PassivHaus dwelling. While all three dwellings have a hot water demand that is lower than the benchmark data. Comparing the water heating requirements of all three dwellings it is of note that the two dwellings forming House Type A have relatively similar demand while dwelling TB1 is significantly lower. This could be due to the lower occupant numbers in dwelling TB1.

However, it is worth noting that, unlike most UK dwellings, these dwellings are located in an area where this is not a gas supply and hence the occupants rely entirely on electricity to meet their thermal comfort and water heating needs. It could therefore be misleading to compare these dwellings with benchmarks based on dwellings supplied with gas and electricity. It is also of note that in DomEarm the benchmark figures are based on idealised, rather than actual measured data. Thus the Part L compliant is based on a calculated consumption (rather than benchmarks of actual consumption of Part L houses). It is also of note that the weather file included in the assessment uses data in the Glasgow area. The site is in an exposed coastal location and weather patterns and temperatures differ considerably in coastal locations from the urban environment. In addition to this, the benchmark data used in DomEarm relates to English dwellings and is not specific to Scotland where external temperatures are significantly colder and a large proportion of the Scottish housing stock are older stone dwellings and a significant portion of these are in rural locations.

**RESULTS OF SIMPLIFIED ASSESSEMENT - LEVEL 1** DomEARM

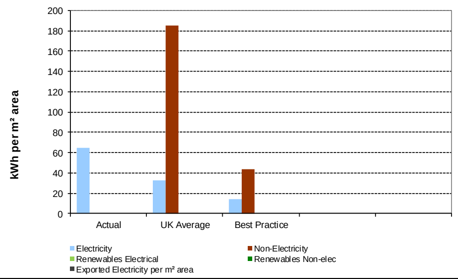
| | | |
|---|---|---|
| Date: | 23rd September 2013 | |
| Reference | 450081 | |
| Building Name | TA1 | |
| Building Area (m²) | 120 | QA: Approved |
| Annual energy use electricity (kWh) | 7804 | |
| Annual energy use non-elec (kWh) | 0 | |
| QA Status for energy readings | Not Approved | |
| Confidence Level for Carbon Emissions | Low Confidence | |

Select benchmark comparison: UK Averages/Best Practice
Select basis for results: per m² area

**Annual energy performance compared with benchmarks**

*Note: Benchmark figures include appliance energy use*

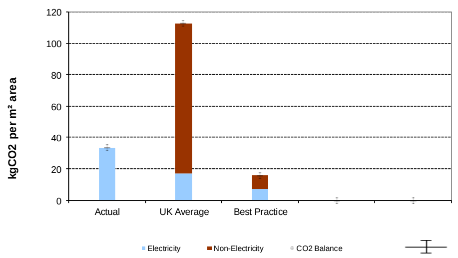
| | Actual | UK Average | Best Practice |
|---|---|---|---|
| Electricity kWh per m² area | 65 | 32 | 14 |
| % Difference between actual and benchmark | | +100% | +370% |
| Non-electricity kWh per m² area | 0 | 186 | 44 |
| % Difference between actual and benchmark | | -100% | -100% |
| Renewable Electrical kWh per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Renewable Non-Elec kWh per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Exported Electricity per m² area | 0 | 0 | 0 |




***Annual Emissions compared with benchmarks**

*Note: Benchmark figures include appliance energy use*

| | Actual | UK Average | Best Practice |
|---|---|---|---|
| Electricity kgCO2 per m² area | 34 | 17 | 7 |
| % Difference between actual and benchmark | | +100% | +370% |
| Non-electricity kgCO2 per m² area | 0 | 96 | 9 |
| % Difference between actual and benchmark | | -100% | -100% |
| Renewable Electrical kgCO2 per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Renewable Non Elec kgCO2 per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Balance kgCO2 per m² area | 34 | 113 | 16 |



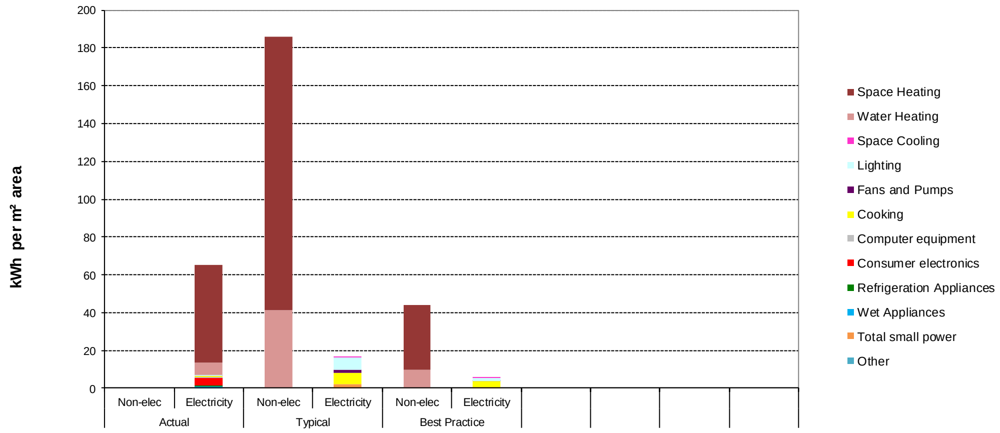




**Figure 7.20:** Results of dwelling TA1 DomEARM – simplified assessment – level 1 & 3.

**RESULTS OF SIMPLIFIED ASSEESSEMENT - LEVEL 1**

DomEARM

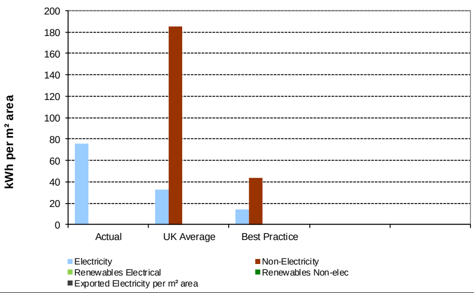
| | | | |
|---|---|---|---|
| Date: | 27th September 2013 | | |
| Reference | 450081 | | |
| Building Name | TA2 | | |
| Building Area (m²) | 120 | QA: | Approved |
| Annual energy use electricity (kWh) | | 9048 | |
| Annual energy use non-elec (kWh) | | 0 | |
| QA Status for energy readings | | Not Approved | |
| Confidence Level for Carbon Emissions | | Low Confidence | |

Select benchmark comparison: UK Averages/Best Practice
Select basis for results: per m² area

**Annual energy performance compared with benchmarks**

*Note: Benchmark figures include appliance energy use*

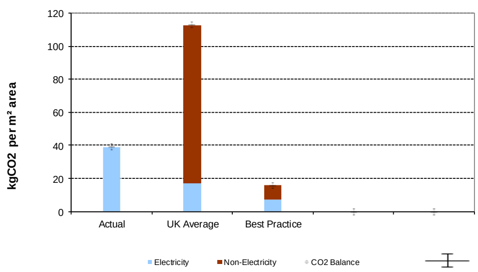
| | Actual | UK Average | Best Practice |
|---|---|---|---|
| Electricity kWh per m² area | 75 | 32 | 14 |
| % Difference between actual and benchmark | | +132% | +444% |
| Non-electricity kWh per m² area | 0 | 186 | 44 |
| % Difference between actual and benchmark | | -100% | -100% |
| Renewable Electrical kWh per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Renewable Non-Elec kWh per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Exported Electricity per m² area | 0 | 0 | 0 |




***Annual Emissions compared with benchmarks**

*Note: Benchmark figures include appliance energy use*

| | Actual | UK Average | Best Practice |
|---|---|---|---|
| Electricity kgCO2 per m² area | 39 | 17 | 7 |
| % Difference between actual and benchmark | | +132% | +444% |
| Non-electricity kgCO2 per m² area | 0 | 96 | 9 |
| % Difference between actual and benchmark | | -100% | -100% |
| Renewable Electrical kgCO2 per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Renewable Non Elec kgCO2 per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Balance kgCO2 per m² area | 39 | 113 | 16 |



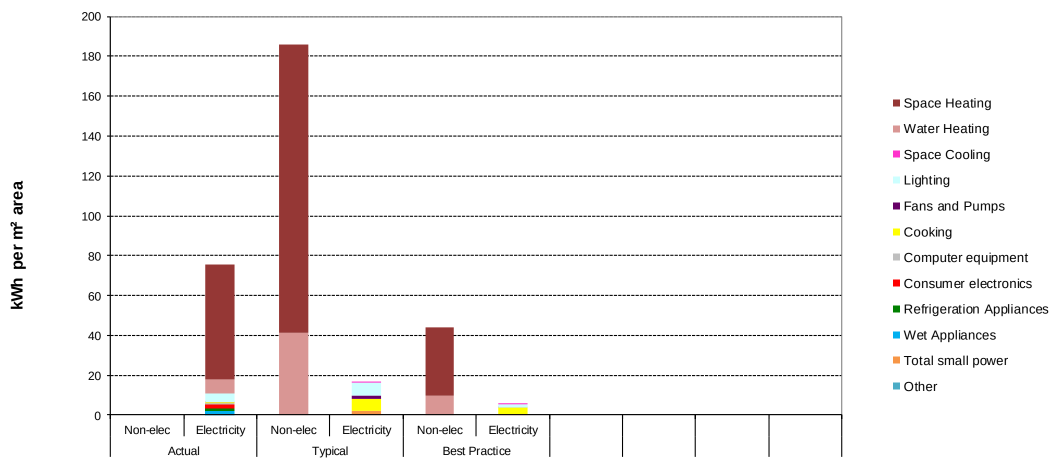




**Figure 7.21:** Results of dwelling TA2 DomEARM – simplified assessment – level 1 & 3.

**RESULTS OF SIMPLIFIED ASSESSMENT - LEVEL 1**

DomEARM

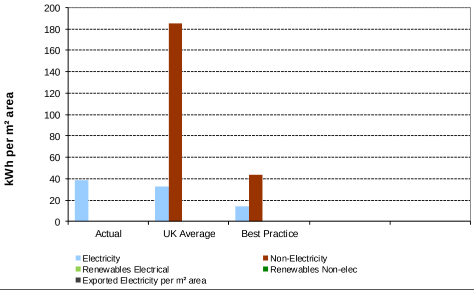
| | | | |
|---|---|---|---|
| Date: | 24th June 2014 | | |
| Reference | 450081 | | |
| Building Name | TB1 | | |
| Building Area (m²) | 107.2 | QA: | Approved |
| Annual energy use electricity (kWh) | | 4132.15 | |
| Annual energy use non-elec (kWh) | | 0 | |
| QA Status for energy readings | | Approved | |
| Confidence Level for Carbon Emissions | | High confidence | |

Select benchmark comparison: UK Averages/Best Practice
Select basis for results: per m² area

**Annual energy performance compared with benchmarks**

*Note: Benchmark figures include appliance energy use*

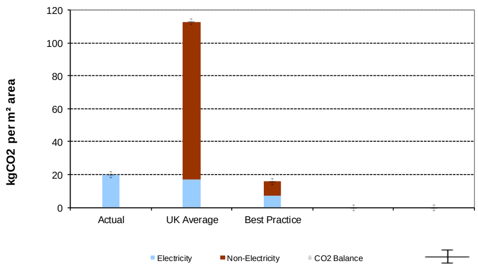
| | Actual | UK Average | Best Practice |
|---|---|---|---|
| Electricity kWh per m² area | 39 | 32 | 14 |
| % Difference between actual and benchmark | | +19% | +178% |
| Non-electricity kWh per m² area | 0 | 186 | 44 |
| % Difference between actual and benchmark | | -100% | -100% |
| Renewable Electrical kWh per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Renewable Non-Elec kWh per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Exported Electricity per m² area | 0 | 0 | 0 |




***Annual Emissions compared with benchmarks**

*Note: Benchmark figures include appliance energy use*

| | Actual | UK Average | Best Practice |
|---|---|---|---|
| Electricity kgCO2 per m² area | 20 | 17 | 7 |
| % Difference between actual and benchmark | | +19% | +178% |
| Non-electricity kgCO2 per m² area | 0 | 96 | 9 |
| % Difference between actual and benchmark | | -100% | -100% |
| Renewable Electrical kgCO2 per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Renewable Non Elec kgCO2 per m² area | 0 | 0 | 0 |
| % Difference between actual and benchmark | | NA | NA |
| Balance kgCO2 per m² area | 20 | 113 | 16 |




**Annual Energy Costs compared with benchmarks**

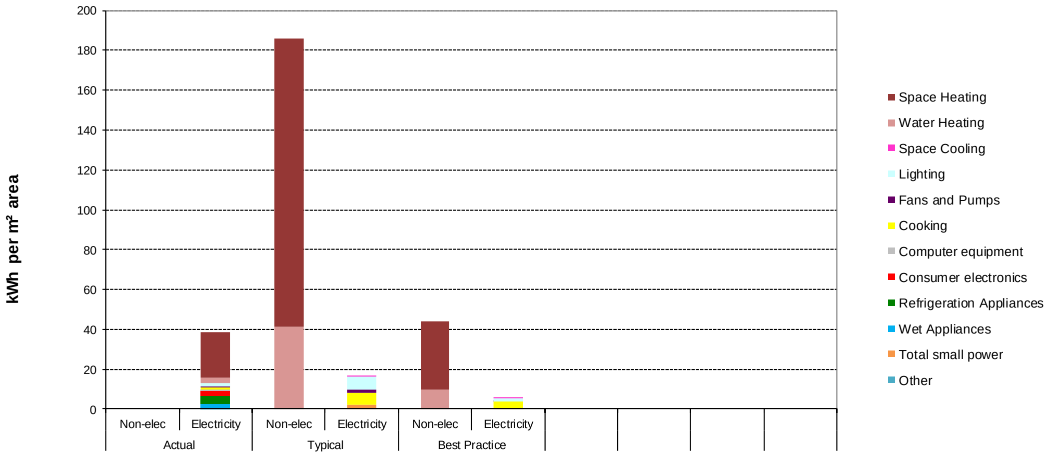



**Figure 7.22:** Results of dwelling TB1 DomEARM – simplified assessment – level 1 & 3.

## 7.4. Environmental monitoring summary

### 7.4.1 External Environment

Tigh-Na-Cladach faces eastwards to the estuary and is relatively sheltered by cliffs to the west. The location is subject to extreme weather conditions off the Atlantic, and high levels of humidity. The figure below shows the annual external temperature and relative humidity of the site from Sep 2013 – Aug 2014.

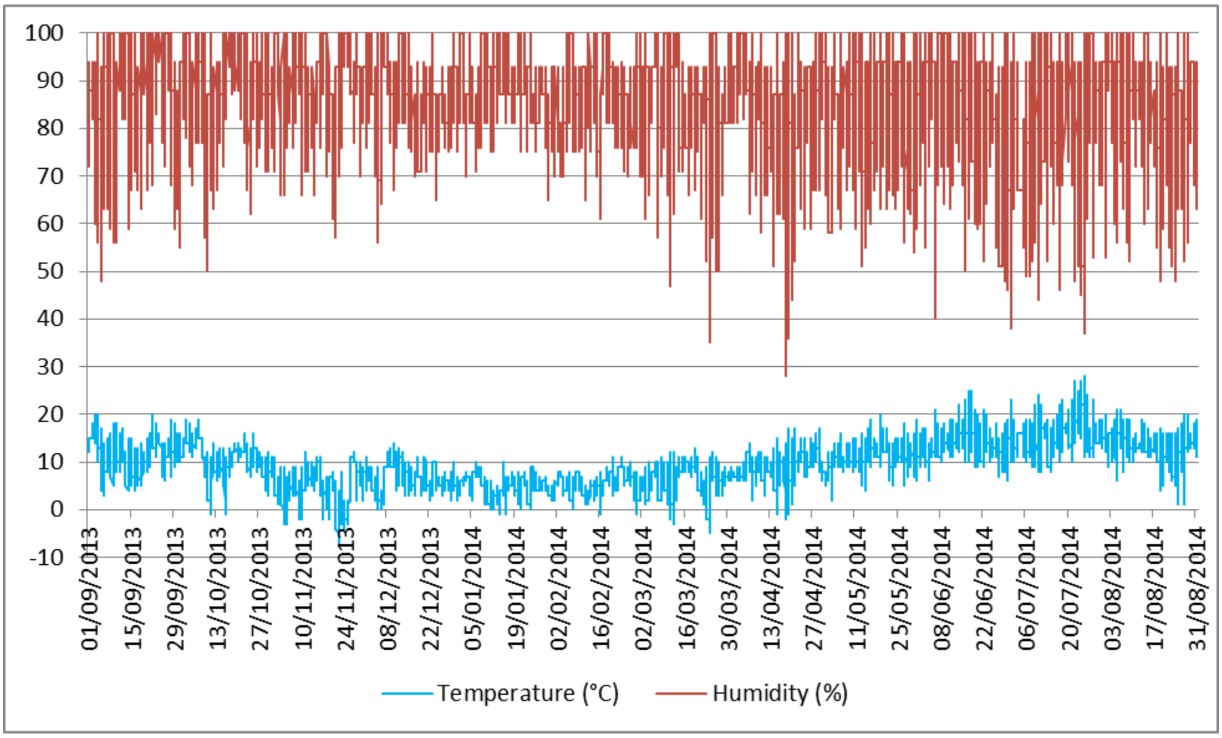



**Figure 7.23:** External Environment Graph, Sept 2013 – Aug 2014.

### 7.4.2 Internal Environment

As part of the project, internal conditions were monitored to determine comfort conditions and to provide an indication of indoor air quality. Temperature, relative humidity, carbon dioxide concentrations ($CO_2$) and window opening patterns were monitored on a five-minute grain for a 21 month period in selected rooms in each dwelling. Initially data collection was erratic for this element of the monitoring, particularly wireless signal strength and broadband transmission, which stabilised with time. This section of the report reviews the internal conditions for a complete year, and compares space temperatures with the design guidance for dwellings as recommended in CIBSE (Chartered Institute of Building Services Engineers) design guide A (CIBSE, 2006). This data provides information with which to assess whether the subject rooms were considered comfortable during summer and winter periods.

CIBSE GUIDE A (2006) recommends an upper limit temperature of 24 °C and lower limit of 18°C in interiors of occupied spaces. It is also recognised that occupants in dwellings are able to adapt their clothing to suit internal temperature conditions during waking hours, however, temperatures exceeding 24°C in bedrooms may affect sleeping patterns of occupants. Dwellings in winter are mostly intermittently heated which allows the space temperature to fluctuate during the day and night. If the air temperature drops below 16°C and/or internal surface temperatures drop to below 12.6°C there is a risk condensation and mould growth could occur on surfaces. Both of these temperature extremes have been linked negatively with issues around fuel poverty (cold) and health and well-being (cold and hot), particularly in the young, elderly and infirm.

This section of the report discusses internal environmental conditions for the period between September 2013 and August 2014, raw data files containing 21 months data for each dwelling are located in **Appendix 7.5**. The conditions in each room are reviewed and compared to CIBSE guidance data for comfort. The data is then compared for each pair of dwellings to review the extent differing occupancy has on internal environment conditions.

The analysis is based on temperature, CO2 and Humidity range descriptions by CIBSE Guide A as shown in Table 7.5. It contains the ranges and corresponding factors for the environmental data graphs in Section 7.4. The temperature ranges differ between living rooms and bedrooms during different seasons, as defined in CISBE Design Guide A (2006).

| Variable | Factor | Autumn | | Winter | | Spring | | Summer | |
|---|---|---|---|---|---|---|---|---|---|
| | | Living Room/ Kitchen | Bedrooms | Living Room/ Kitchen | Bedrooms | Living Room/ Kitchen | Bedrooms | Living Room/ Kitchen | Bedrooms |
| Temperature °C | Cold | <16°C | <15°C | <16°C | <16°C | <16°C | <16°C | <16°C | <16°C |
| | Cool | 16-18°C | 15-17°C | 16-18°C | 16-17°C | 16-18°C | 16-19°C | 16-18°C | 16-19°C |
| | Comfortable | 18-22°C | 17-19°C | 18-22°C | 17-19°C | 18-23°C | 19-23°C | 18-23°C | 19-23°C |
| | Warm | 22-23°C | 19-24°C | 22-23°C | 19-24°C | 23-25°C | 23-25°C | 23-25°C | 23-25°C |
| | Hot | 23-28°C | 24-26°C | 23-28°C | 24-26°C | 25-28°C | 25-26°C | 25-28°C | 25-26°C |
| | Overheating | 28°C | 26°C | 28°C | 26°C | 28°C | 26°C | 28°C | 26°C |
| Air Quality: Carbon Dioxide ppm | Ambient | <500ppm | | | | | | | |
| | Ideal | 500-1000ppm | | | | | | | |
| | Poor | 1000-1500ppm | | | | | | | |
| | Very Poor | >1500ppm | | | | | | | |
| Humidity % | Dry | <40% | | | | | | | |
| | Comfortable | 40-60% | | | | | | | |
| | Humid | >60% | | | | | | | |

**Table 7.5:** Key for environmental ranges for the graphs in section 7.4

### 7.4.3 House Type A

In this house type four rooms were monitored – the living room, west facing ground floor bedroom (Bedroom 1) and an east facing first floor bedroom (Bedroom 2) – Figure 7.24. The number and patterns of occupancy in both dwellings can be found in Chapter 2.

**Dwelling TA1**

The analysed environmental data shows that, overall, there were periods within CIBSE comfort bands in all rooms during all seasons. However, the temperature range varies considerably; there was evidence of the temperature rising above the 'comfortable range' during the summer in the Living Room and Bedroom 1. This corroborates with the occupant surveys, in which occupants said the dwelling was too hot during some days in the summer of 2013. The summer temperatures in the Living Room were 59% warm and 11% hot. In Bedroom 2, the summer temperatures were less than expected: 1% overheating, 3% hot, 21% warm. The comfort level in the autumn was only 6%, and fluctuated between 4% cool and 90% warm. This is significant, as warm temperatures can affect health and sleep patterns. Contrary to this, Bedroom 1 experienced cool temperatres in all seasons, most significanlt in the spring, rating 48% cool versus 52% comfortable. The kitchen has the most stable comfort level thoughout the year: with the lowest level being 54% in the summer; and most comfortable during this time was Winter at 99%. In all rooms except Bedroom 1, the lower ranges of temperature (cold and cool) bands are negligible. This could be attributed to the homes being occupied continuously (stay at home parents); or temperature settings being set not to drop below the comfort range lower limit. The later implies some energy waste happens if rooms remain heated when not occupied. In addition to humidity and temperature, the internal thermal comfort of occupants is influenced by other factors such as clothing and their activity. Further analysis using TM52 could show if the dwellings actually overheated, and for how long.

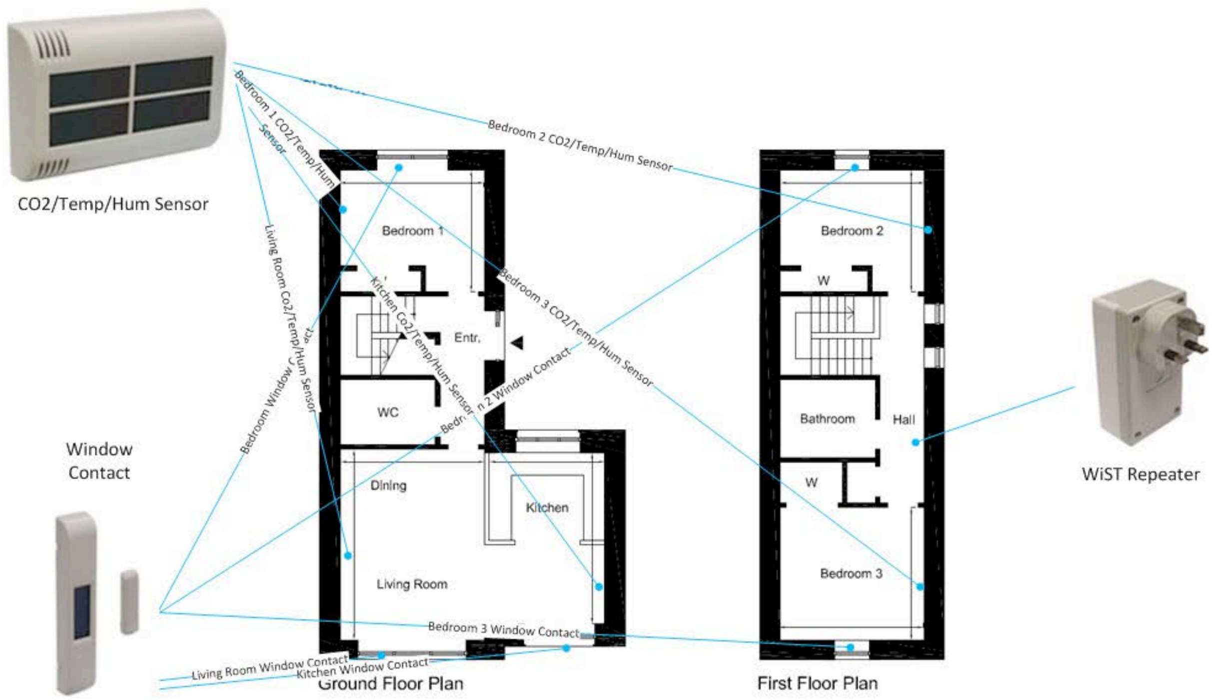



**Figure 7.24:** House Type A, Floor Plans: Indicating locations of environmental monitors.

The $CO_2$ concentrations provide an indication of ventilation rates. On the whole, the Indoor Air Quality (IAQ – represented by $CO_2$ ppm) was within the recommended range. However, all rooms showed instances where IAQ reached 1500ppm and borders on poor air quality during each season. This is of concern as high levels of CO2 indicate poor ventilation regimes which allow contaminants such as VOCs, formaldehyde, moisture, dust mites etc. are also remaining in the property. The window opening/closing rates do not always correlate with the CO2 levels, which would suggest that other ventilation is impacting these results, or that the cross ventilation or window placement in these rooms is not as effective as it could be.

Relative Humidity (RH) and temperature follow a similar comfort range. The room showing the highest humidity levels is Bedroom 1, which also had the lowest temperature comfort ranges of the four rooms.

Overall, there is less correlation between the data for the Living Room and Kitchen; this is surprising as they are adjacent and open plan. This may be a consequence of better cross-ventilation and less glazing in the kitchen, and an extract fan. For temperature, it could also be partly attributed to the significantly higher internal heat gains in the kitchen.

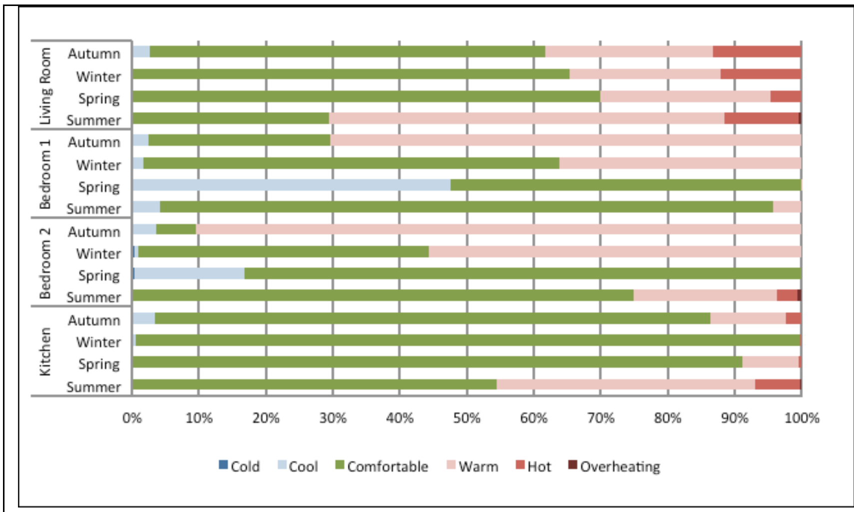



**Figure 7.25:** Dwelling TA1 – Thermal Comfort by Season.

**Temperature profile by season for dwelling TA1.**

This graph indicates that the dwelling temperature fluctuates between comfortable and warm temperatures throughout the year. The most comfortable and consistent room was the kitchen. The room with the greatest fluctuations and coolest temperatures was Bedroom 1. The 'cool' range approaches 50% in this bedroom during the spring; and is also significant in Bedroom 2.

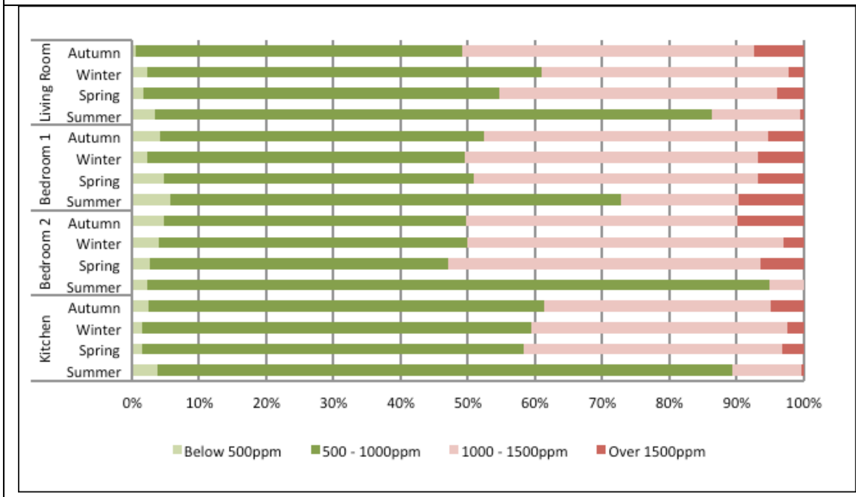



**Figure 7.26:** Dwelling TA1 – Carbon Dioxide concentrations by Season.

**$CO_2$ concentrations by season: Dwelling TA1.**

The concentrations shown in pink and red (above 1000ppm) indicate poor indoor air quality and low ventilation rates. While $CO_2$ at these levels are not known to be a threat to health it indicates poor ventilation regimes which allow contaminants such as VOCs, formaldehyde moisture, dust mites etc. to remain in the property.

TA1 was above 50% within the recommended range in all but 4 instances, 3 of which were in Bedroom 2 between autumn and spring. All rooms showed instances of high $CO_2$ levels, over 1500ppm.

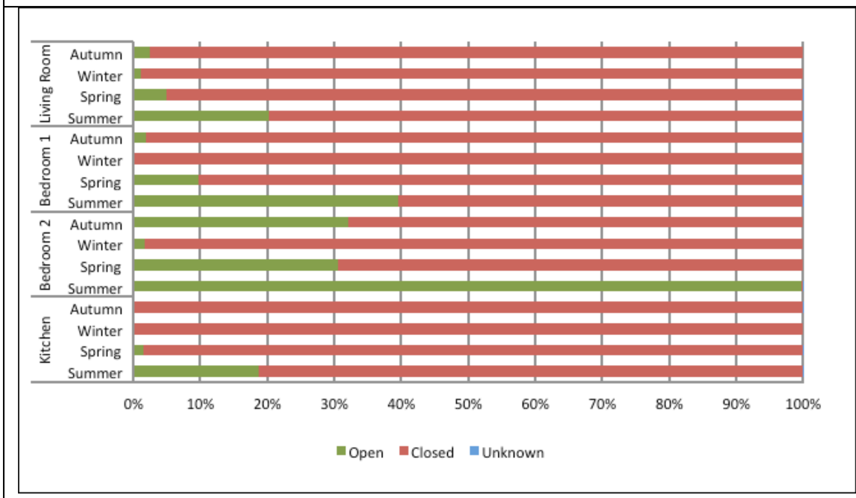



**Figure 7.27:** Dwelling TA1 – Window opening patterns (Ventilation) by Season.

**Window opening patterns by season: Dwelling TA1.**

This graph shows annual window opening expressed as percentage. In all rooms, the window opening increased during the summer and autumn; and was less frequent in winter and spring. However, the windows in bedroom 2 were open in the summer. This is consistent with the occupant feedback that this room was had temperatures above the comfortable range during the summer months.

There are clear links between window opening patterns and $CO_2$ concentrations in some cases. For example, when the window was open in bedroom 2 during most of summer, the $CO_2$ concentrations remained predominantly within the recommended levels.

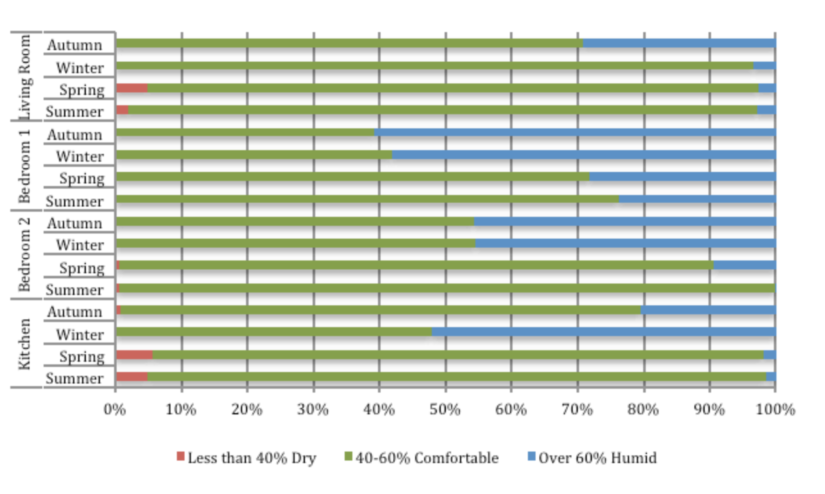



**Figure 7.28:** Dwelling TA1 – Relative Humidity (RH %) by Season.

**Relative Humidity by season: Dwelling TA1.**

This graph shows % humidity within the dwelling. Overall, humidity remained mostly within the comfort range (green) for most of the year for all rooms except for Bedroom 1 in the autumn and winter, and the kitchen in the winter, when the air was more humid.

Drier air was less common, and only recorded with any significance in the Living Room and Kitchen during the spring and summer.

**Dwelling TA2**

There was a tendency in this dwelling, as observed by MEARU during several visits, to have the heating on for most of the time throughout the year and at higher temperatures than in dwelling TA1. Therefore the temperatures were often above the CISBE recommended 'comfort' range during autumn and winter, rating 'warm', in the bedrooms: Bedroom 1, 92-93%; Bedroom 2, 95-99%. In the living room, although the period in which the temperature was within the 'comfort' range was greater during autumn and winter, it also rated 'hot' during autumn and winter for 46-50% of the time. During the spring, all rooms experienced 'cool' ratings, of significance was the 'cold' rating (lower than 16°C) in the Living Room for 9% of spring.

Windows were opened more in TA2, but not as regularly as the temperature would suggest, however, when compared with dwelling TA1, the IAQ is better overall, although typically there are more people in TA1 than in TA2. Understandably, $CO_2$ levels in bedrooms were the only ones which peaked with higher temperatures, but these were only on a few occasions, the highest being 10% in Bedroom 1 during the summer. The difference in heating levels compared with TA1 was also reflected in the RH: TA2 was drier on average than TA1 and was not within the comfort zone as much.

Occupant feedback highlighted periods of winter cooling in Bedroom 1 and summer temperatures above the comfortable range in Bedroom 2. Although the spring cooling in Bedroom 1 was greater than Bedroom 2 (16% to 2% respectively), the winter remained in the 'comfort' region or 'warm'. In contrast, Bedroom 2 overheated during the summer months, a common problem for both TA1 and TA2. The window to this room remained open throughout the summer season. The Kitchen was also above a comfortable temperature range (66% 'hot') during the winter months and had higher than average (57%), opening of windows.

The initial monitoring period revealed that the kitchen window in TA2 was permanently open. The mean external temperature during this time was 3.6°C with minimum temperature of -6°C being recorded. It was doubtful that this would be happening especially due to the open plan living arrangement of this dwelling. A fault was detected on the window contact sensor and corrected on 1st March 2013 – the opening patterns thereafter seemed what one might expect for a heating season. For the period between September 2013 and August 2014, Figure 7.11 shows higher than the expected percentage of period when the kitchen window was opened. This coincides with temperatures above the comfortable range in the kitchen, suggesting that it is possible windows may have been open for 57% of the time.

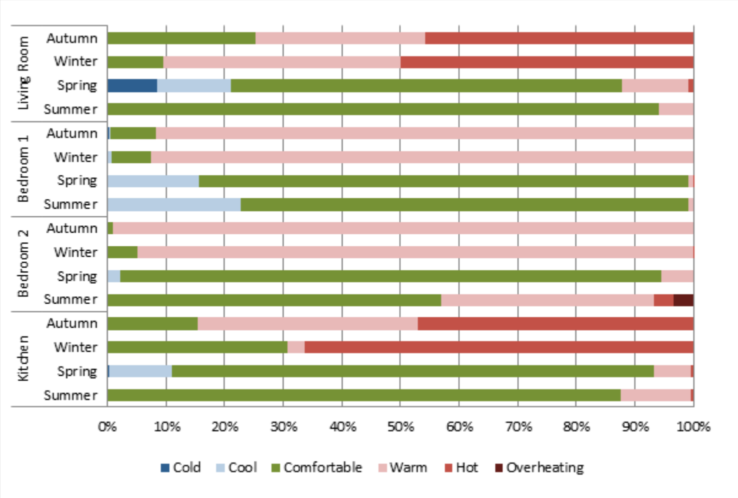



**Figure 7.29:** Dwelling TA2 – Thermal Comfort by Season.

**Temperature profile by season for dwelling TA2.**

This graph indicates that the dwelling temperature fluctuates mainly between cool and warm/hot temperatures throughout the year. Apart from the spring and summer in the bedrooms, a comfortable temperature is not consistently achieved. On the whole the spring temperature extremes are 'cool' to 'cold'. Winter and autumn temperatures are mostly 'warm' to 'hot'. One explanatition for the higher temperatures in TA2 than that in TA1, is that the occupants of this dwelling have their heating on earlier in the year and leave them on for longer than the typical Oct to March heating period kept in TA1. They also prefer warmer average temperatures than in TA1.

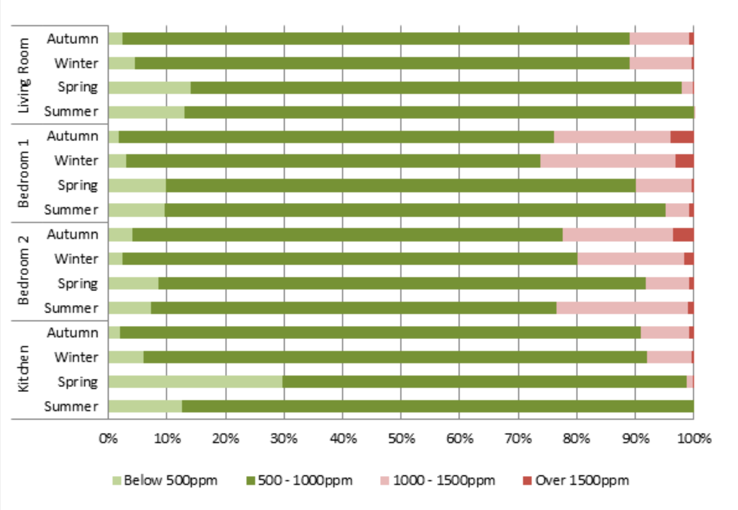



**Figure 7.30:** Dwelling TA2 –Carbon Dioxide concentrations by Season.

**$CO_2$ concentrations by season: Dwelling TA2.**

The $CO_2$ concentrations provide an indication of ventilation rates, concentrations shown in pink and red indicate poor indoor air quality and low ventilation rates.

TA2 was within the recomended levels most of the year in all rooms. Of the 4 rooms monitored, Bedroom 2 had the longest cumulative times when levels were higher than recommended. Both bedrooms had instances of high $CO_2$ levels – over 1500ppm. These were not above 10% of the total.

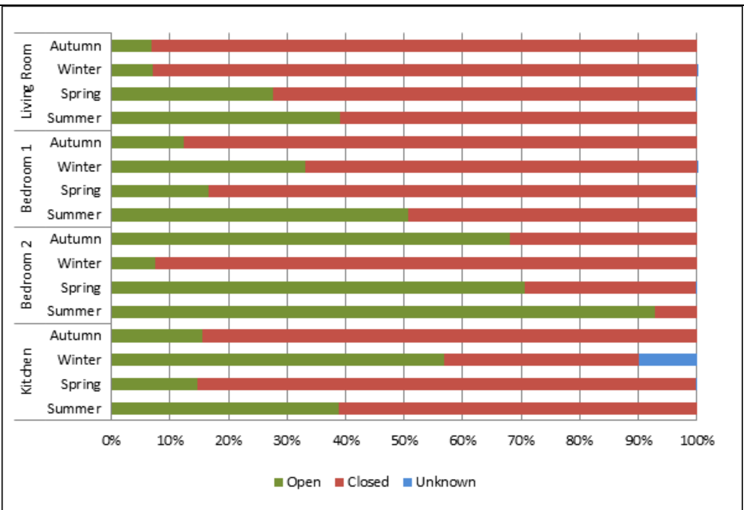



**Figure 7.31:** Dwelling TA2 – Window opening patterns (Ventilation) by Season.

**Window opening patterns by season: Dwelling TA2.**

This graph shows annual window opening expressed as percentage. This indicates that, in all rooms the patterns are fairly consistent with seasonal occupancy.

During the winter, the kitchen window is open 57% of the time, closed 33%, with the remaining 10% unknown due to sensor problems. This is the 4th highest level of window opening and the highest in the winter. This is consistent with the temperatures above the comfortable range noted in the kitchen during this season.

The windows in Bedroom 2 were open for over 90% of summer time. This is consistent with the occupant feedback that this room was hot during the summer months.

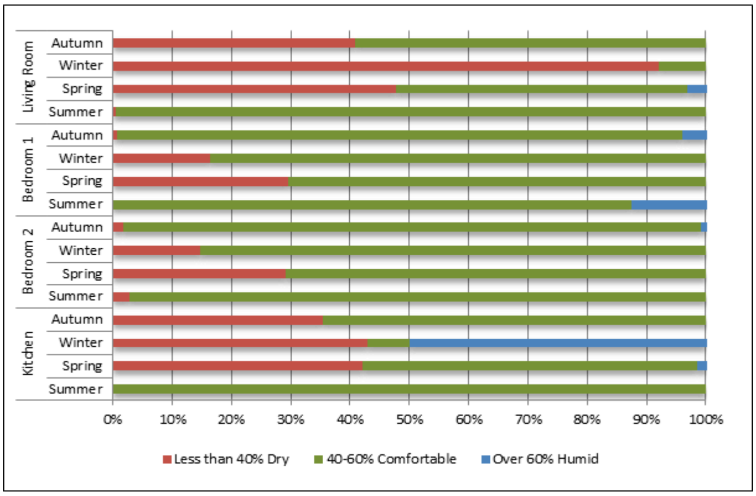



**Figure 7.32:** Dwelling TA2 – Relative Humidity (RH %) by Season.

**Relative Humidity by season: Dwelling TA2.**

Overall, humidity remained within the comfort range (green) for all rooms for most of the time, except for the Living Room, particularly during winter. When not in the comfort range, the air was mostly in the dry range than the humid range, except for Bedroom 1 in the summer, and the Kitchen during the winter.

**House Type A: Summary**

Although the Type A houses are of the same design, there were differences in the internal $CO_2$ and temperature differences. Partly as a result of different occupancy patterns, in particular, use of heating and window opening.

## 7.4.4 House Type B

In this house type four rooms were monitored - the living room, the kitchen, the west-facing first floor bedroom (Bedroom 1) and the east-facing first floor master bedroom (Bedroom 2).

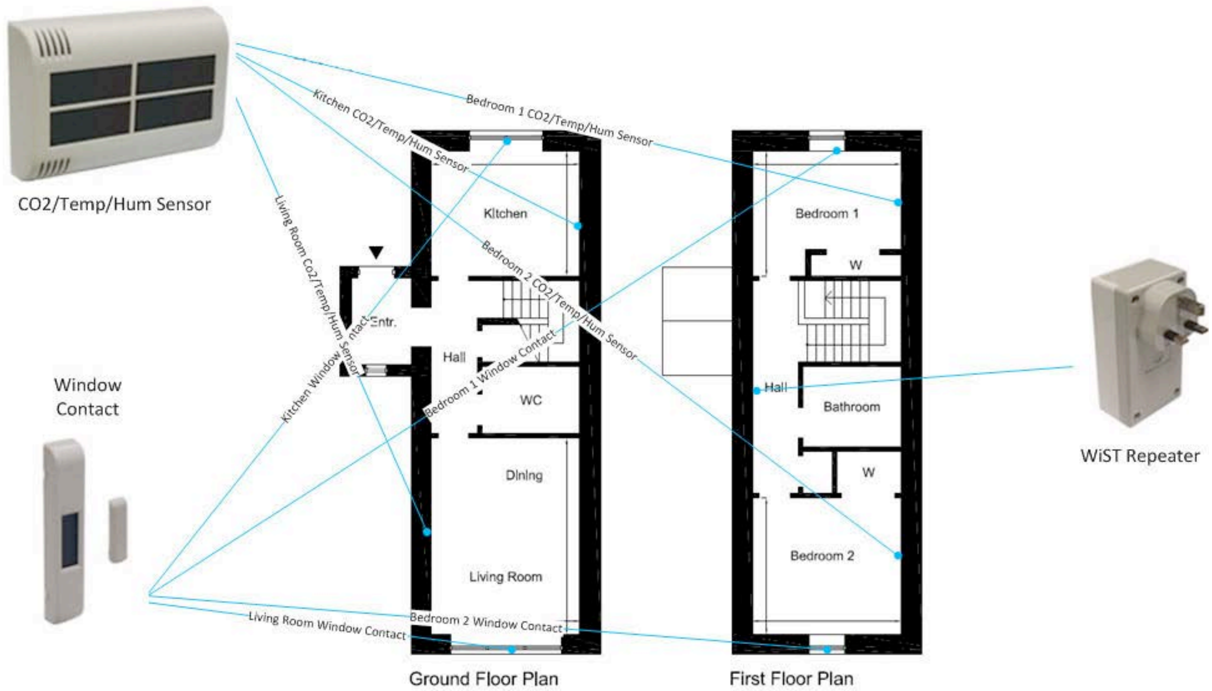



**Figure 7.33:** House Type B, Floor Plans: Indicating locations of environmental monitors.

### Dwelling TB1

PassivHaus homes are designed so that windows can remain closed in winter to ensure heating and ventilation efficiency through MVHR systems. However, users have the option to open windows as desired. The results of the monitoring indicate that, in the case of dwelling TB1, windows remained closed most of the time. The users of this house lived previously in a house where the control of the internal environment was through the traditional opening of windows. The force of habits of window opening developed in their previous dwelling does not seem to have influenced how they operate the windows of their current PassivHaus home.

### Temperature / Thermal comfort

The temperatures suggest that there is an issue with temperatures below 16°C in this dwelling between autumn and spring. In the case of Bedroom 1 the issue is observed during days in winter and spring; and in the Living Room during days in the winter. In particular, there is a period of three days in early January where the temperature ranges from 12.6°C – 13.8°C in the afternoon and evenings. What is not clear is whether these periods were occupied, perhaps still away on New Year holiday.

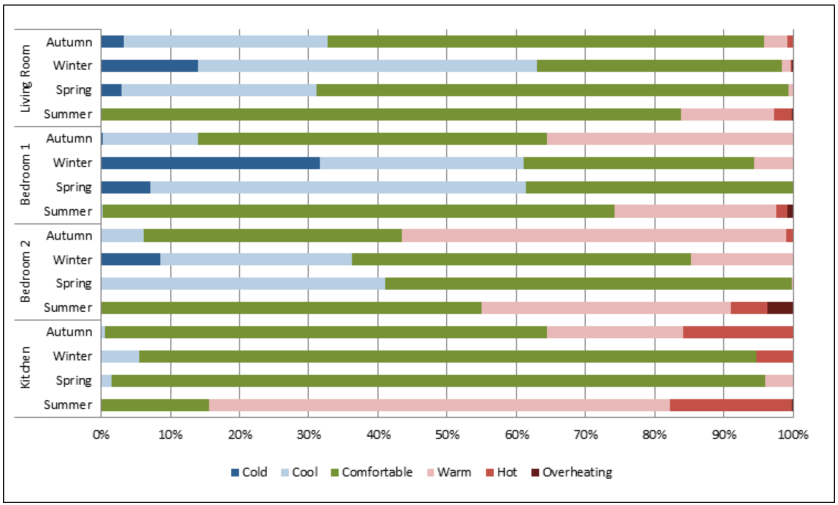



**Figure 7.34:** Dwelling TB1 – Thermal Comfort by Season.

**Temperature profile by season for dwelling TB1.**

There are significant periods of 'cool' to 'cold' temperature ranges during the autumn, winter and spring in the Living Room, Bedroom 1 and Bedroom 2. In particular, Bedroom one is below 16°C for 32% of winter, and between 16-17°C for 29% of the winter period. Further analysis is required to show times when these were concentrated (day/night).

The Kitchen temperature remains fairly stable during the autumn, winter and spring months. However, in the autumn and winter, there are incidences of over 28°C. During the summer months, the kitchen temperature is the least comfortable (only 16% of the time), with the temperature 'warm' 67% to 'hot' 18% of the time. There were periods of temperatures in the 'warm', 'hot' and 'overheating' in Bedroom 2 during the summer. This had been referenced by occupants finding this room too warm.

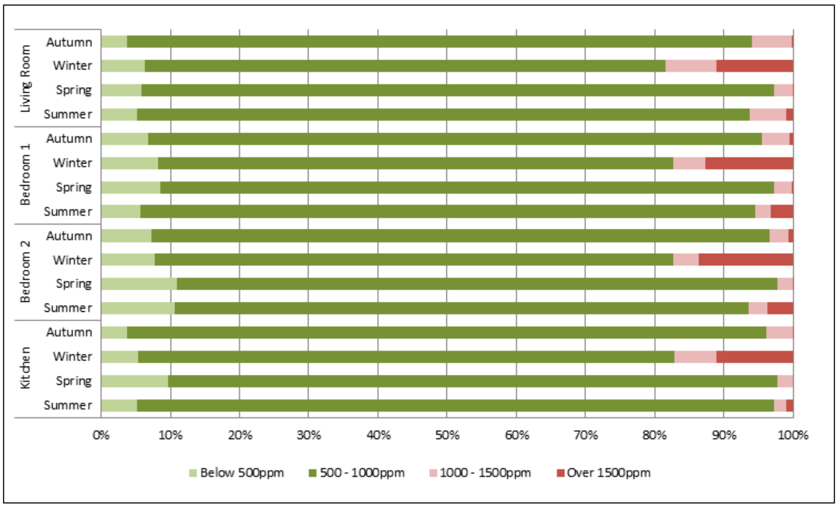



**Figure 7.35:** Dwelling TB1 – Carbon Dioxide concentrations by Season.

**$CO_2$ concentrations by season: Dwelling TB1.**

The $CO_2$ concentrations provide an indication of ventilation rates, concentrations shown in pink and red indicate poor indoor air quality and low ventilation rates.

TB1 was within the recommended $CO_2$ levels (green) for most of the time, in all rooms and across all seasons. During the winter, all rooms experienced levels higher than 1500ppm for slightly over 10% of the time during the Winter months.

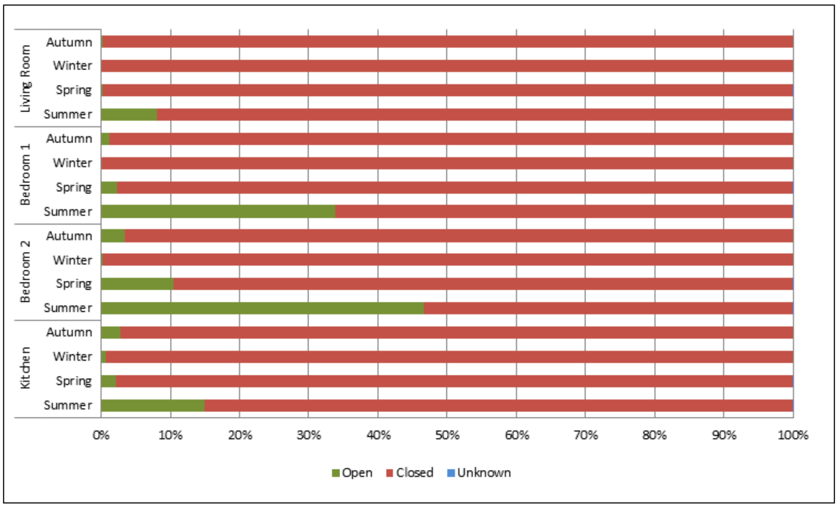



**Figure 7.36:** Dwelling TB1 – Window opening patterns (Ventilation) by Season.

**Window opening patterns by season: Dwelling TB1.**

This graph shows annual window opening expressed as percentage. This indicates that, in all rooms the patterns are fairly consistent with seasonal occupancy.

The windows in Bedroom 2 were opened more (47%) throughout the summer than in other rooms. This is consistent with the occupant feedback that this room was hot during the summer months.

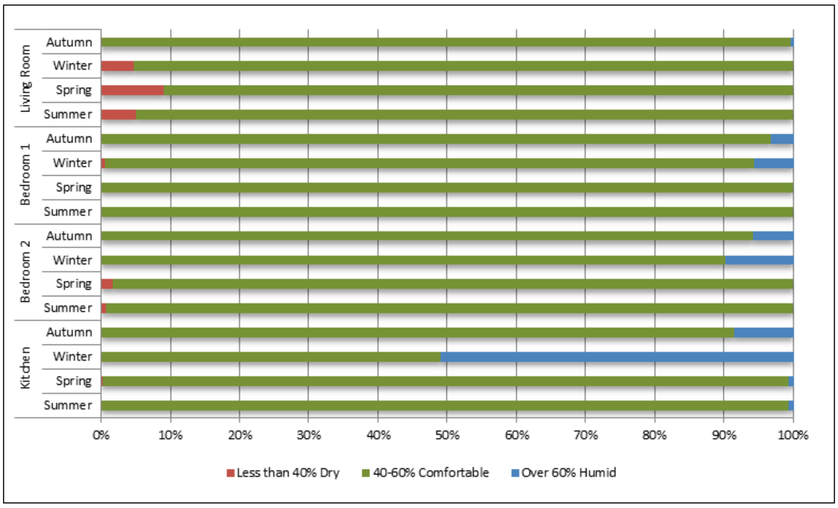



**Figure 7.37:** Dwelling TB1 – Relative Humidity (RH %) by Season.

**Relative Humidity by season: Dwelling TB1.**

This graph shows % humidity within the dwelling.

Overall, humidity remained within a 90% comfort range for all rooms except for the Kitchen during the winter, which was 'comfortable' for 49% of the time, and 'humid' for 51% of the time. When not in the comfort range, the air was mostly dry in the Living Room, and mostly humid in the Kitchen and Bedrooms.

## Detailed analysis of window opening patterns and internal environment

The following graphs in Figures 7.35, 7.36, and 7.37 show sample profiles of internal environment and window opening patterns from 6th to 27th January 2013.

Passivhaus homes are designed so that windows can remain closed in winter to ensure heating and ventilation efficiency through MVHR systems – users have the option to open windows as desired. The results of the monitoring indicate that, in the case of the Passivhaus, windows remained closed most of the time. Although the users of this house lived previously in a house where the control of the internal environment was through the traditional opening of windows; the force of habits of window opening developed in their previous dwelling does not seem to have influenced how they operate the windows of their current Passivhaus home.

In the low carbon houses (TA1 and TA2) where environmental control is through the option to open or close windows, the results show that window opening happens more frequently in these two homes compared with the Passivhaus. TA2 experienced the most frequent opening. It is not certain whether the force of habit, or indoor drying of laundry influenced this. In the Passivhaus, all the window opening took place in the kitchen. In TA2, opening happened most frequently in the kitchen followed by bedroom two. In TA1, bedroom two has the most frequent window opening pattern.

The corresponding monitored internal $CO_2$ levels are generally lower in the Passivhaus (TB1) in a narrower range generally between 500 and 900ppm. They are most varied in range and fluctuation in TA2 between 500 and 1200ppm; and slightly steadier in TA1 ranging generally between 700 and 1200ppm. The corresponding monitored air temperature levels are also generally lower in the Passivhaus TB1. They are highest in TA2 and vary least in TA1. The air temperature in the Passivhaus kitchen is generally higher than the other rooms by about 2 to 3°C; compared to the other two houses where they are closer across all rooms. TA1 has the most stable temperature profiles. The Passivhaus exhibits a more distinct pattern of maximum and minimum internal air temperature levels. The corresponding monitored relative humidity is generally lowest in TA2 that experiences the most frequent window opening patterns; and is highest in TA1. It is lowest in the living rooms across all houses; and fluctuates most in the kitchens. In TA1 and TA2, the RH is significantly higher in the bedrooms and kitchen. The RH levels vary least across all rooms in the Passivhaus except the spikes in the kitchen.

Although there could be other variables, the significant fluctuations of air temperature, RH and $CO_2$ concentrations in TA2 could be associated with the frequent window opening patterns.

Further analysis demonstrated the window opening patterns of each of the three plots over a six week period after January 27th 2013. In each dwelling the windows were opened most frequently in the living room in TA1, bedroom 2 in TA2 and the kitchen in TB1. Overall the windows were opened most often in TA2 and the least in TB1. During the six week period, the window to TA2, bedroom 2 was open most frequently and for the longest intervals. The close monitoring period revealed that the kitchen window in TA2 was permanently open. A fault was detected on the window contact sensor and corrected on 1st March 2013. The opening pattern after correction seemed more plausible for a heating season.

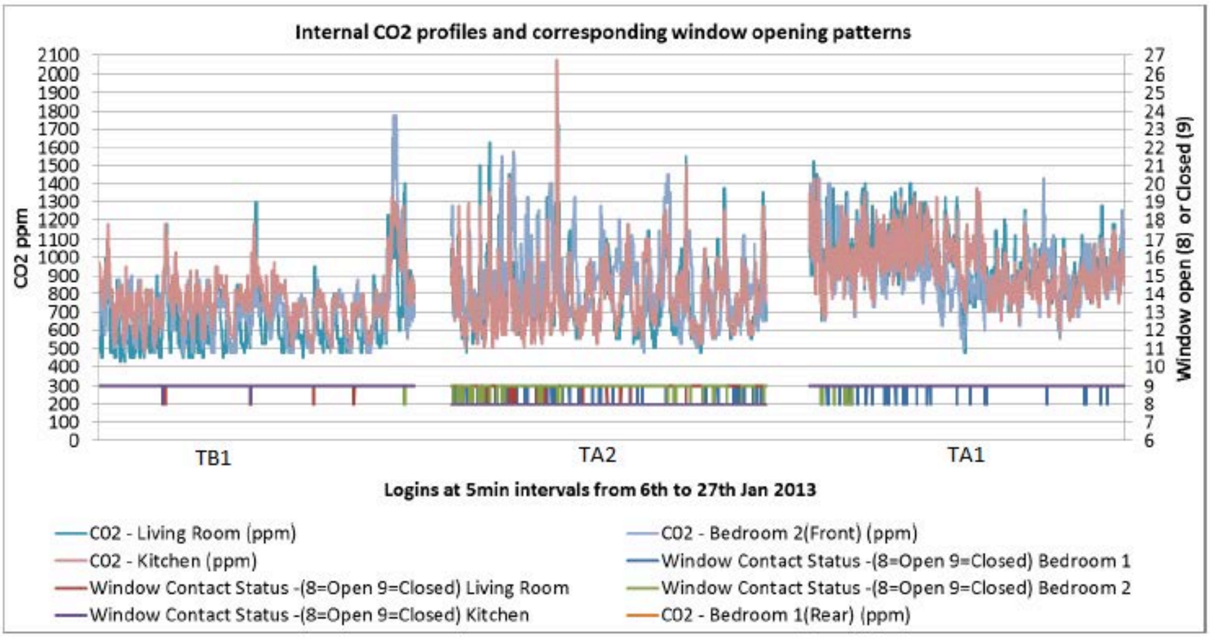



**Figure 7.38:** Internal $CO_2$ profiles and corresponding window opening patterns at the three dwellings

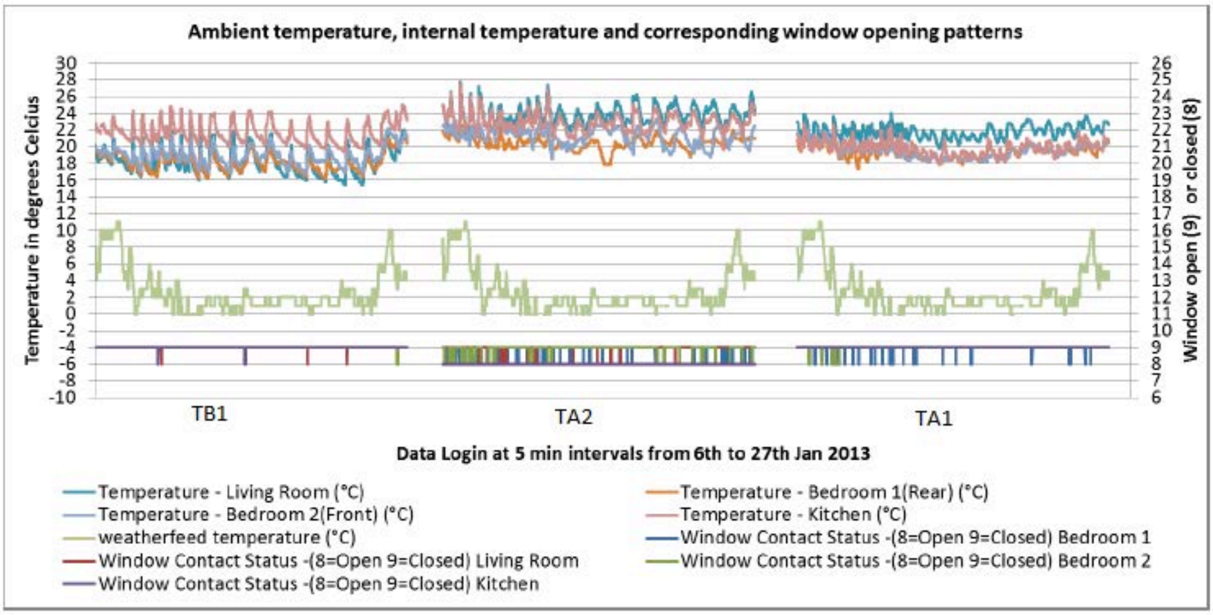



**Figure 7.39:** Internal and external temperature profiles and corresponding window opening patterns at the three dwellings

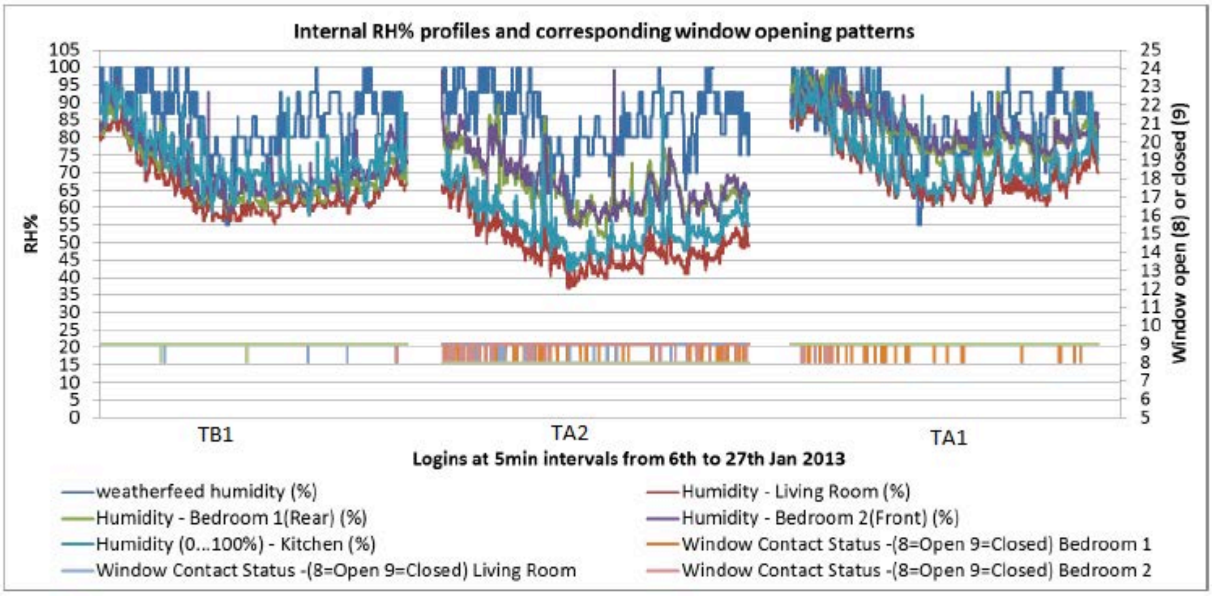



**Figure 7.40:** Internal Humidity profiles and corresponding window opening patterns at the three dwellings

## Combined effects of humidity and temperature

To observe the combined effects of RH and temperature, scatter plots for different rooms and seasons are shown in Figure 7.38. It is evident from this that the houses have different environmental characteristics. There are a few incidents of unusually high temperatures in the living room during winter.

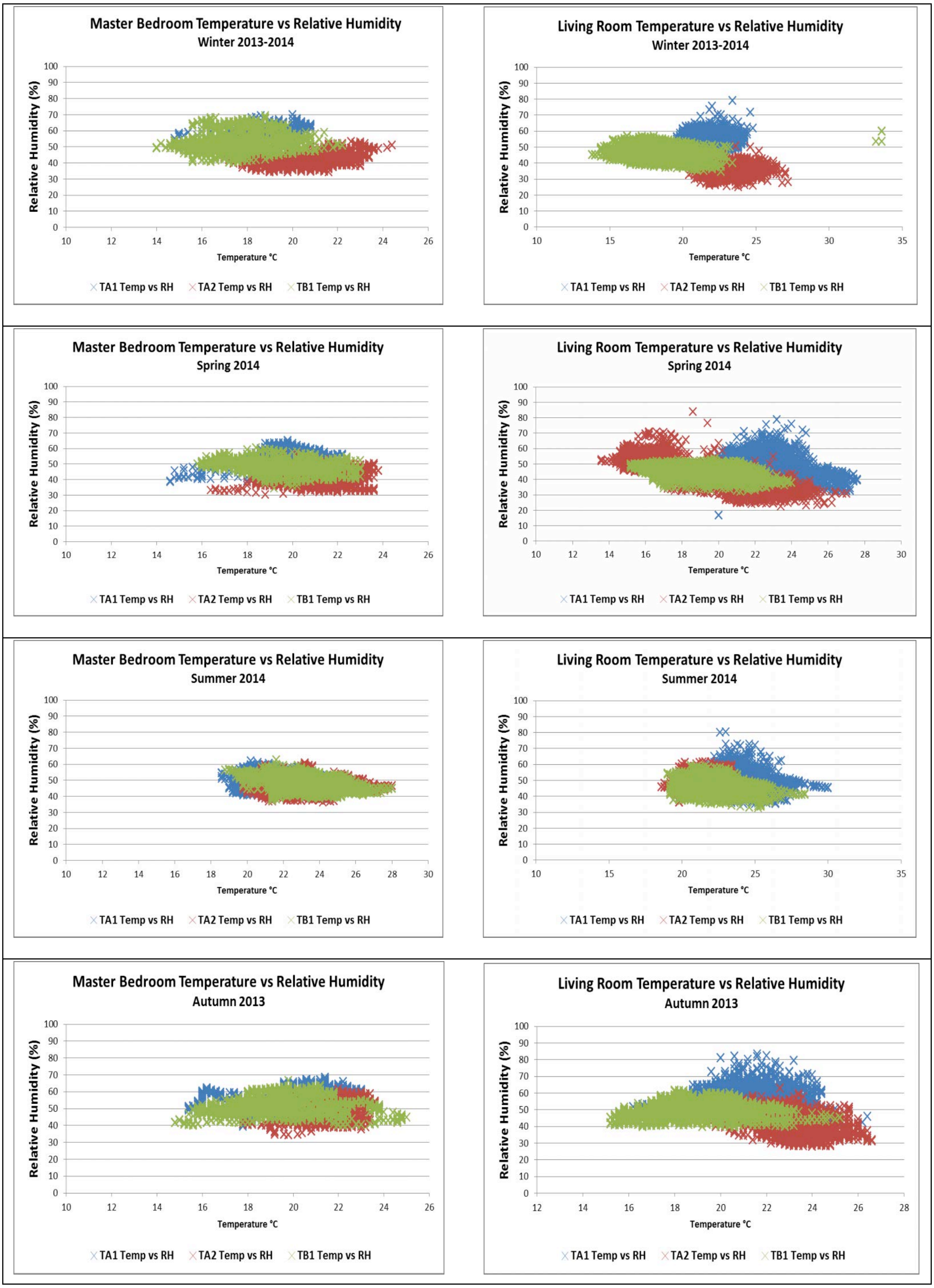



**Figure 7.41:** Scatter plots of bedroom and living room temperature and RH comparison during winter, spring and summer 2013-14

## 7.5 Discussion

In the low-energy houses where environmental control is through the option to open or close windows, the results show that window opening happens more frequently in these two homes compared with TB1. TA2 experienced the most frequent opening. It is not certain whether the force of habit, temperatures above the comfortable range, or indoor drying of laundry influenced this. In TB1, the entirety of window opening took place in the Kitchen. In TA2, opening happened most frequently in the Kitchen followed by bedroom two. In TA1, Bedroom 2 had the most frequent window opening pattern.

The corresponding monitored internal $CO_2$ levels are generally lower in TB1 in a narrower range generally between 500 and 900ppm. They are most varied in range and fluctuation in TA2 between 500 and 1200ppm; and slightly steadier in TA1 ranging generally between 700 and 1200ppm.

The corresponding monitored air temperature levels are also generally lower in TB1. They are highest in TA2 and vary least in TA1. The air temperature in TB1 kitchen is generally higher than the other rooms by about 2 to 3°C; compared to the other two houses where they are closer across all rooms. TA1 has the most stable temperature profiles. TB1 exhibits a more distinct pattern of maximum and minimum internal air temperature levels.

The corresponding monitored relative humidity is generally lowest in TA2 that experiences the most frequent window opening patterns; and is highest in TA1. It is lowest in the living rooms across all houses; and fluctuates most in the kitchens. In TA1 and TA2, the RH is significantly higher in the bedrooms and kitchen. The RH levels vary least across all rooms in TB1 except the spikes in the kitchen.

Although there could be other variables, the significant fluctuations of air temperature, RH and $CO_2$ concentrations in TA2 could be associated with the frequent window opening patterns.

The window opening patterns, (Figure 7.27, Figure 7.31, Figure 7.36), demonstrate that in each dwelling, the windows are opened most frequently in the Living Room in TA1, Bedroom 2 in TA2, and the Kitchen in TB1. Overall, the windows are opened most often in TA2 and the least in TB1.

## 7.6 Key Findings and Conclusions for this section

**Key Points**

- The importance of the development of the use of t-mac monitoring kit and the complimentary portal as a tool for use in BPE projects was demonstrated through the data acquired and subsequent analysis. Some problems were encountered with data transfer. However, the sheer quantity of data provided a reliable sample size;

- A margin for error is required in the energy data recorded, due to the reduced accuracy of T-Clamp monitoring for small currents;

- The total measured consumption when compared like for like with SAP predictions, demonstrated that the dwellings actual consumption was lower than that predicted by SAP. These margins were greater with TA1 and TB1;

- The net energy consumption for each of the three dwellings is significantly lower than the UK average, Building regulations compliance, CSH4; but such comparisons in DOMEARM need further analysis.
- Large variations in energy consumption are observed across the dwellings and are mainly a function of user behaviour;
- Extensive use of the bathroom towel rails by TB1 resulted in a period of high energy bills. The occupant presumed that the MVHR system was responsible. MEARU identified the problem; and subsequently, electricity consumption was significantly lower;
- Internal temperatures vary significantly across dwellings and this, like energy use can be largely linked with user behaviour;
- Issues of temperatures higher than the comfort range were recorded in occupant interviews and BUS. However, measured data does not suggest as great a problem as occupants concerns would indicate. High summer temperatures are a problem with these house types, further monitoring is required of occupancy responses to high internal temperature. It is anticipated that window opening and occupant measures played a contributory role in lower temperatures being recorded during periods of high external temperatures;
- Usefulness of $CO_2$ concentration as an indicator of occupancy and behaviour;
- $CO_2$ concentrations in the dwellings are generally within the recommended levels, but can get overly high, particularly so during the heating season and in bedrooms;
- There is evidence of poor levels of ventilation some of the time across all dwellings, this is worst in TA1, which was indicated by $CO_2$ reaching over 1500ppm, suggesting poor ventilations regimes. TA2 and TB1 mitigate the effects to an extent through increased window opening and MVHR respectively. Poor ventilation is of concern as it allows contaminants, such as VOC's, formaldehyde, moisture, dust mite etc. to also remain within the property;
- Internal RH is normally good in all the dwellings.

**Learning points**

- Considerable insight was developed during the BPE project into methods and systems for remote monitoring. Whilst the systems used have considerable benefits, they remain in development for domestic projects;
- Improvements are required in the monitoring equipment, including: sensing and recording accuracy data connection reliability, t-clamp accuracy, and data transfer;
- Occupant behaviours and equipment issues, such as towel rail use in TB1, identified by MEARU in the BPE study helped to fine tune the houses and reduce occupants overall energy bills. This is turn contributed to the occupants engagement with the project;

- Actual building performance compared to SAP values suggests that this tool is not suitable for making predictions for these housing typologies; further investigation is required as to whether SAP is a good prediction tool in the context of low-energy and PassivHaus homes;

- Effects of incidental gains to internal temperature is an important contributory factor in high performing fabrics such as the ones in this development;

- It is very difficult to disentangle 'regulated' and 'unregulated' electrical loads. Incidental gains are an important factor - electrical loads that (with the exception of hot water which may be lost through drainage) ends up as heat in the dwelling;

- Increased demand of high temperatures in TA2 is leading to higher fuel consumption. Design decisions about environmental strategies ought to reflect occupancy types; and should override SAP assumptions;

- Further work is needed to identify health effects of ventilation rates in dwellings with high air-tightness below 5 and without MVHR, such as in in TA1 and TA2

- Heating and ventilation strategies, in particular occupant usability, need to be considered more carefully by the design team;

- Except for TB1 in extreme winter low external temperature, the dwellings are providing warm, dry conditions for residents and the problem has shifted to one of overheating and dryness; improved monitoring of existing properties can provide information about occupancy and demand patterns which may inform design decisions. However, care is needed to manage the transfer of user habits from older, less efficient properties to newer low energy dwellings.

# 8. Other technical issues

This section addresses:

1. Links between the factors of environmental and energy performance of the dwellings: the dwellings' fabrics, the installed services systems; and the occupants.
2. Issues relating to the monitoring kit, data transmission, storage and processing.
3. Issues relating to the tools used in the BPE study

## 8.1. Environmental and Energy performance

The ultimate performance of any building is a function of three interlinked factors - fabric, services systems; and the occupants. The findings from the two Code Level 4 dwellings, for example, confirms that dwellings constructed to similar fabric standards may not necessarily result in similar performance if the occupants operate the systems and system controls differently; and/or if they have differences in occupancy patterns or environmental preferences and habits. That the energy performance of the PassivHaus was close to that of one of the Code level 4 dwellings, which in-fact, had more occupants, is clear evidence of the influence that energy conscious occupants can have on the energy saving and consequently, overall performance. The high energy use in the PassivHaus was happening before problems with the installed systems were fixed; and before MEARU provided feedback on where energy was being consumed. This shows that it is not enough to construct highly efficient fabrics. There has to be continuing reviews of the services performance and occupant effort to achieve continuing environment and energy performance. The following subsections discuss the results of the seasonal performance in the context of the combined effects of the three factors.

#### 8.1.1 Seasonal weather variations

Traditionally, energy use in UK buildings is considered in the context of space and water heating plus artificial lighting – all concentrated in the period between October and April. However, in Dunoon, the dwellings demonstrated that better U-values and airtightness increases heat retention indoors if it comes from internal heat gains and through windows. This increases incidences of temperatures above the comfortable range in summer and has potential to create a cooling load, which is not typically expected in UK buildings. Designers should therefore balance specification for high performance in the heating period without creating overheating risk during hot weather. Ultimately, the overall performance is a function of the building design, systems, and the occupant. The designer has a responsibility to provide as much adaptive opportunity to the occupant to adjust to seasonal variability; and the occupant has a responsibility to optimise the design and systems adaptive opportunities provided to stay comfortable and minimise energy use.

The Scottish weather poses some challenge for PassivHaus performance if only limited heating is provided in a house with low occupancy and low internal gains; and the external temperature drops below zero deg. C. In the case of the Dunoon PassivHaus the air to air source heat pump was found to struggle in very cold weather, and the occupant said it can feel cold indoors in cold weather, and the occupants remedy was to leave the bathroom towel rail on as a temporary heat source. The issue with this was that one of the rails is 500W and if occupants left it on and forgot to switch off when they went for work, it led to significant energy consumption. After the BPE study identified this issue, the occupants became more careful with its usage.

At Dunoon, the monitored summer data and occupant interviews indicated that, in hot weather, the three representative properties are warmer than they should be. Addressing this will require measures to balance heat gains and losses to maintain comfortable interiors by:

- Limiting summer solar gains from the west windows: Planting high enough deciduous trees could facilitate summer shading and allow winter and midseason solar gains. The residents could also employ and use their blinds well.

- Opening windows and controlling of midges: This would enable through draughts to purge heat and cool the interiors when the external summer temperature drop towards the evening. The limiting factor with this is security concerns in the living rooms at ground level, but occupants do shut them at night.

**Appliances** – households do not typically keep upgrading appliances to the latest efficiencies, partly because they are not items that they replace frequently; and partly because the capital cost of buying the best available could be prohibitive.

**MVHR control** – the heat recovery system is intended to minimise the heating loads arising from ventilation. The low, medium, high, and summer bypass adjustment settings, if used well by householders in TB1, can determine the effectiveness of the MVHR in minimising such loads.

**Conclusion**

The building performance evaluation confirms that the Dunoon Development delivers expectations – the residents are almost always comfortable, generally resulting in low electricity bills. Early snagging issues in thermal and hot water systems in TB1 that affected performance during the defects liability period were addressed and lessons learnt. A number of factors contribute to the PassivHaus being slightly below the lower limit of thermal comfort in very cold Scottish weather; and all the three properties being slightly warmer than the comfort upper limit in summer. Occupant actions can mitigate most of the contributing factors.

**8.1.2 Lessons**

The risk that properties might overheat should be considered in more detail in PassivHaus and Low Carbon Designs. Options for mitigating this should be considered:

1. Reducing gains, for example by:
    - Increased shading in the form of shades in the building fabric or deciduous trees
    - Proper insulation of the hot water tank and pipework to reduce internal gains from waste heat
    - Replace appliances with highly energy efficient ones when due for replacement – typically if the payback from reduced energy bills makes economic sense
2. Stabilisation of internal temperatures by more thermal mass

Increasing excess heat losses in summer:

- Occupant switching to the summer by-pass on the MVHR
- Increase summer natural ventilation air flows whilst addressing security or insects concerns

It is vitally important to provide guidance to occupants on how to operate dwellings and take responsibility when ambient conditions call for either heating or potentially cooling. M&E design and specification must consider likely occupancy regime – density and intensity.

Investment in energy efficient development, by housing associations such as Fyne homes Ltd make a significant contribution to reducing occupants' energy bills; and a wider benefit to society targets for reduction in greenhouse gas emissions. So do occupant efforts to develop low energy living habits and use of and energy efficient appliances.

## 8.2. Installation, commissioning and maintenance of monitoring kit

The monitoring of a building, its systems, and occupants in the context of environment, energy, and occupant comfort and operation of systems facilitates performance diagnostics and comparisons between expectations and performance in use. Results from monitoring provide a reference point to address any gaps in the monitored building or inform future building.

**8.2.1 Data validity and reliability**

Data that is collected must be accurate and reliable. The appropriate monitoring kit must be specified, installed, and commissioned correctly to suit the nature of monitoring. Kit for long term monitoring must be robust and non-disruptive to building users. The data transmission from sensors to the end users must be verified and validated to confirm that the monitoring kit and transmission are all working correctly. Long term and detailed monitoring is currently costly and the purpose for which the data is needed must be thought through carefully to balance quality, quantity, and affordability.

**8.2.2 Dunoon monitoring**

The kit at Dunoon monitored three properties in detail – two 3-bed and one 2-bed house. A vast quantity of performance data has been collected, providing useful comparisons with data collected from the occupants. MEARU had a more accurate Eltek kit but it required to be plugged into sockets, which was inconveniencing to the householders. MEARU decided to go for a solar-powered kit which suited the occupants but had not withstood the test of time. There are incidents when the broadband transmission signal dropped. The collected data therefore contains some gaps and inaccuracies. The signal strength was, to some degree, affected by the thick insulation; and accuracy affected by the quality of the monitoring kit. The clamps for monitoring electricity usage, for example, could not sense small current circuits. The clamps monitoring the mains circuits were more reliable and the difference between the mains and sub circuits was what the clamps could not detect. It was not very clear from the supplier of the environmental monitoring kit that it required re-calibration during the two year monitoring period.

However, MEARU did accuracy tests across different sensors at different periods when the monitoring was underway; and reported findings to the suppliers for actions. This involved placing the Eltek kit against the installed kit and comparing data collected from both kits. There were some inconsistencies in the small grain data but the overall profiles were within acceptable limits. Validation checks were done on downloaded data by checking the minimum and maximum values and arranging data in ascending or descending order in Excel spreadsheets. A number of unusual (too high and too low) recordings and gaps were noted and reported. Unintentional mistakes that can occur when importing of data for analysis were checked and corrected in one incident were data for TA1 and TA2 were identical. There was an issue of scaling of the environmental data during the first year, but this was reported and acted upon. After identification of Identify invalid or inaccurate data – e.g. when transmission dropped and the data recorded suddenly becomes say 'zeros', the reasons for the bad data were investigated and actions taken to correct the data. Minor sections of data were cleaned by either deletion or insertion and the original uncleaned data kept intact for reference.

The implications of these issues are that it is not possible to be absolutely confident of:

- The environmental data collected during the first quarter of 2013 with a margin of approximately 5-10% error. However, the data is reliable enough on confirming general environmental trends within the dwellings.
- The energy data from circuits for the low wattage lighting

**8.2.4 Lessons**

It would not have been possible to carry the detailed monitoring required by TSB without inconveniencing occupants with plug-in kit, and with the available budget. Shorter representative periods of monitoring with plug-in kit would have resulted in less compromise of the data reliability. The key lessons from the monitoring experience at Dunoon kit are:

1. Designers should design in monitoring or anticipation of post occupancy monitoring. Monitoring decisions should be made early to integrate kit design into that of the building space and the M&E systems.
2. Kit should be selected to meet the nature of monitoring and flexibility to meet and changes in monitoring requirements when the monitoring is underway.
3. Calibration and recalibration requirements and frequency should be clear from the start to ensure continuing good performance of the kit
4. The accuracy of sensors should be considered early
5. Ensure that the kit installation and commissioning is by a qualified person and it is done as specified and designed.
6. Verify data early to ensure that sensors are capturing valid data and transmitters and archive/backups and transmitting and storing accurate data.
7. Consider the impact on the occupants to ensure it is not obtrusive or located in inconveniencing locations. If possible, ensure that access by the monitoring team for checks and recalibration is easy and of minimal disruption to occupants.
8. Choose locations of sensors to best represent the space being monitored, and minimise risk of resident interference with the kit.
9. Facilitate alerts to be sent should data sensing or logging fail.
10. Minimise the risk of data loss through signal failure by providing adequate time lag through local data storage so that this can be transmitted when signal reconnects.
11. Good rapport and communication with the residents is essential so that access is easy when needed
12. Engage and consider householder throughout to ensure their continuing active participation.
13. The discrepancy in SAP rating for TA1 and TA2 versus TB1 highlights areas of potential further investigation with regards the SAP methodology use on PassivHaus

## **8.3.** Occupant engagement

Better information and guidance is required to communicate aspects of design intent, operation issues, required performance, and the entire BPE process to occupants. MEARU researchers visited the three dwellings a lot more than they envisaged at the start of the BPE project, resulting in what seemed to be occupant survey fatigue, particularly for dwelling TB1. Future BPE projects should be structured to minimise the tasks that collect similar information, such as similar questions that were asked thrice – during the occupant walkthrough, occupant interviews and BUS survey. The occupants appreciated the quarterly monitory incentive and compensation for their power draw.

Undertaking a domestic BPE study requires a lot of goodwill and forbearance from the building occupants. Whilst we had included a financial incentive, the study would not have been possible without the support of the occupants of the dwellings.

Communication with the participants to obtain their feedback to the BPE project and to establish whether the various activities undertaken were disruptive and whether the process was how they had imagined it to be at the beginning showed that occupants found the process to be straightforward except for the technical tests which they did not understand, and slight disruption related to airtightness testing. Occupants in dwelling TA2 were keen to know how their home compared to others, and sought MEARU staff opinions regarding their installation of underfloor heating. The occupant of TB1 was very appreciative of MEARU's monitoring and diagnosis of energy consumption; and the realisation that it was the towel rail resulting in high demand, and not the MVHR as she had thought. Both this dwelling had made changes to how they operate their house as a result of the BPE project feedback from MEARU researchers. In TB1 the towel rail was used switched on much less, and in TA2 the boiler that was contributing to high internal temperatures was also switched down.

There was evident reduction in energy use in TB1 as a result, but overall further monitoring is required for another full year to find out if the BPE process has had an impact on energy use and environmental performance as a result of occupant learning and awareness.

The occupants were satisfied with the overall BPE project and found that they had learnt more about the operation of their homes; and did not object to a request to leave the monitoring kit for another year of data collection. The occupants were pleased to help, especially if the lessons learned are used to help others in the future.

## **8.4.** Conclusions and key findings for this section

- Further development is required for BPE processes in domestic environments. A balance needs to be struck between the need for comprehensive data sets and the disruption of occupants' lives and privacy.
- For mechanical systems and natural or mechanical ventilation strategies, better information and guidance is required for occupants to communicate design intent, operation issues and required performance to occupants.
- The project was probably too long – the lengths of the project and extensive reporting requirements have led to a feeling of exhaustion amongst the participants, particularly survey fatigue.
- Quarterly reporting was counterproductive to undertaking tasks which would have run more easily across longer periods of time
- It would have been very beneficial to have had clear reporting requirements, templates and exemplars available from the beginning of the project.

- Whilst raising awareness of energy and health issues can be a really useful dimension of BPE processes in domestic properties some consideration is also required of the Hawthorn effect in reporting results and impacts. There are limitations of using BUS on Domestic projects.

- This project shows evidence of reductions in energy use due to some technical improvements from the BPE feedback (e.g. repair of solar thermal system controls and addition of insulation to ducts in TB1), and improvements in users knowledge (information on the MVHR energy usage in TB1), and general awareness of energy issues.

- However some issues remain (e.g. preference for high internal temperatures); and leaving of settings at the default position.

# 9. Key messages for the client, owner/occupier, and design team

The findings from the BPE study could inform future procurement and development of housing by Fyne Initiatives Ltd, and the householders. The key lessons from the entire project are as follows:

1. Overall, there were generally high satisfaction levels with the development – by occupants and delivery team, and the development demonstrates that affordable housing can be highly energy efficient. With less money for construction compared to standard houses, meeting the full Passivhaus Standard was a significant achievement. They are evidence that very low carbon dwellings do not necessarily have to cost significantly more to build than conventional homes; and affordability can be achieved without being at the expense of architectural design or construction quality.

2. The houses are providing affordably warm and safe living environments, with a high degree of amenity. The good performance of the dwellings in the context of fabric, internal environment and energy suggests that overall, the fabric standard is one that the housing association could repeat in future projects, with improvement on systems installation, commission and maintenance.

3. The project demonstrates that innovative processes and strategic approaches can deliver housing to meet low carbon targets in the affordable sector of the market.

4. In terms of the procurement and construction processes, the project is evidence of a high potential for professionals and clients to drive higher compliance of low carbon standards.

5. The Housing association needs to look into improving the briefing process on environmental performance objectives and early involvement of the design team. An example is the unofficial agreement that happened between the architect and the contractor, which ensured that most difficulties were ironed out prior to going to site. The association should also consider and discuss costs for environmental elements very early. An example is the post-briefing revision that happened, requiring one of the dwellings to achieve Passivhaus standard; and removal of shading.

6. In addition to briefing, the housing association should provide adequate lead time before site works future projects with high ambitions to achieve new standards and to integrate new technology. This would enable detailed investigations and testing before commissioning; and minimise errors and problems such as those that occurred with the AASHP and MVHR in TB1.

7. Overall, the projects performs better than current standards and meets proposed future standards. This is a strong lesson that developers and designers should aim higher than the regulations of the day. The Fabric (U-values and Air tightness) and energy performance of the three dwellings is better than the requirements in the building regulations at the time they were constructed, and also exceeded the current Scottish regulations (2013) requirement; despite the challenge of using a timber-framed system.

8. Overall, there are generally high satisfaction levels with the development – by both the delivery team and occupants. The occupants are generally happy with the dwellings and comfortable, except in TB1 in very cold winnter weather, and in all the three dwellings for a short period of summer temperatures above the comfortable range. While the summer issue can be mitigated, the winter issue in TB1 calls for development or specifications of AASHPs that can perform better in cold weather such as that of Scotland.

9. Although it is clear that energy use reduced in house TA1 in year two, it is not clear from the BPE results, the degree to which the occupant guide developed by MEARU influenced householders operation of their homes, and consequently energy use. However, the occupant feedback on how they were helpful in clarifying issues; and how the original manuals were not entirely easy to understand; suggests that simplified occupant guides should be included in the occupant welcome pack. There is a need for the housing association to review the building user manual supplied to occupants to ensure that it is user friendly whilst remaining comprehensive. It is noted that a 'Quickstart Guide' (developed by MEARU) required by Scottish Building standards for low energy buildings will be a mandatory requirement in the 2015 regulations. The principle of this is that essential information, supported by graphics and pictures, capable of being quickly absorbed by occupants is provided at, or prior to, the handover process.

10. BPE feedback to occupants can be a good tool for housing association to improve occupant understanding of the performance of their dwellings and influence how they operate them. For example in TB1, MEARU's feedback to the householders on energy profiles had a direct impact on reducing consumption by the towel rails.

11. The successes and problems of the installed services systems encountered provide important lessons on how PassivHaus and low energy strategies can be progressed for adoption in the affordable housing sector in the context of design, installation, commissioning, and user education.

12. The project demonstrates the importance of following quality assurance procedures throughout the planning, design and construction stages of dwellings.

13. Whilst efficient active systems are important and useful components in reducing energy consumption and carbon production, their choice and specification needs to be carefully considered in relation to a given design. The requirement for solar thermal systems, AASHPs, MVHR should be reviewed on a case by case basis, to minimise installation of systems that would struggle to perform in a given context, such as the AASHP in very cold Scottish weather.

14. Clearer targets and performance standards are needed to assist the design, installation, commissioning and handover processes. Existing industry tools such as SAP have limited value when considering a range of performance requirements. Better predictive and decision making tools are needed, taking into account varying patterns of occupancy, margins of error (and sensitivity analysis) for fabric and system efficiency.

## Key messages for Fyne Homes Housing association

From the successes and the errors made in the project, key messages of what Fyne homes should continue doing and what they should review are:

1. Be very clear on the objectives of the development, and engage all relevant parties early, including the consultation with neighbours. Clearly spelt objectives in the clients brief will enable all parties to focus on delivery throughout the lifetimes of the dwellings (programming, design, construction and in-use) and reference upon which the success of the project may be evaluated. Clear quality assurance measures is best achieved when all parties in the delivery team work together to ensure all the part come together in harmoniously in a high quality whole.
2. Ensure all parties have the appropriate skills and experience. New innovations for low energy dwelling will continue to come into the market and Fyne homes will require delivery teams with up-to date skills from the outset of any new development.

3. Settle the design early, and if changes have to be made, the client should know the cost environmental and energy performance implications of the changes, and where possible changes should minimise negative implications. All architectural, structural and M&E services designs need to be fully realised before construction starts to ensure that all components work together harmoniously. Change on site must be minimised; and unavoidable changes must be fully assessed and thought through by all parties to minimise negative impacts.
4. Ensure that the design meets occupant needs.
5. Ensure that the design is occupant-friendly, and simple to operate.
6. Consider the commissioning, settings, and maintenance of systems. Plan and execute handover to occupants properly, with necessary education of special features of their homes, support, and simple user guides. Design, and installation, must be done to ensure ease of maintenance. MVHR filters, for example, should be easy to change. Maintenance must be done regularly and any issues that arise resolved expeditiously.
7. Achieving an energy efficient fabric and efficient M&E services are not the only factors to achieving desired performance. Occupants must also play their role to ensure that the dwellings deliver as expected and the designers and developers should carefully consider and support the occupant factor.
8. Select experienced contractors and plan proper site supervision to ensure high quality is achieved
9. Don’t omit essential design features such as shading to cut cost
10. Evaluate the performance of innovative installations and resolve any issues expeditiously
11. Design decisions must be documented and installations settings must be labelled for later reference.
12. Include performance evaluation as a practice in delivery of dwellings to gather information on whether the new dwellings actually work as expected, and inform remedies, if required, and future developments.
13. Although there were problems with the SHW, AASHP and MVHR, the association should not feel discouraged from installing such systems and other design aspects of Tigh-Na-Cladach in future projects. There are many good aspects in the overall performance of the development which can be carried forward in their current and future projects; if procured and implemented correctly by an experienced team.

## Key messages for occupants

1. Occupants should be aware that continuing effort on their part is necessary to operate the building systems in ways that optimise the environmental and energy performance.
2. While designers should develop designs that minimise changes to occupant behaviours, occupants should reform habits that they may have developed while living in previous inefficient dwellings.
3. Occupants should seek opinion from the housing association and design team if they think that energy consumption and environmental performance are not what one might expect. The occupant of TB1 for example did point out the higher than expected energy consumption to the housing association, the architect, SPHC, and MEARU. This prompted the circuit diagnostics that MEARU did, which established that it was not the MVHR, but the towel rails causing high consumption.

## Key messages for design team

1. The design team should involve manufacturer of solar thermal systems, MVHR and AASHPs equipment earlier at both the design and commissioning stage and again at handover to assist with commissioning, ensure the gap between what the manufacturers say and actual performance can be addressed.

2. The architect, G. Deveci, should use the good fabric detailing and specification in this project for future projects. The practice has already has used the knowledge gained from this project in: two other projects in Aberdeen – a project of three newly built Passivhaus dwellings; and another of thirty dwellings designed to achieve different (current and future) Scottish building standards within the same development; and in a countryside house, in which individual ventilation units were installed instead of whole house MVHR.
3. Futurkomfort, which was started after the closure of SPHC, should review their processes of specification, installation and commissioning of MVHR and AASHP systems to avoid the errors that happened in TB1. They should review the quality of commissioning to ensure that proper evaluation and tests are conducted, to minimise abortive installations as happened in TB1.
4. The architect should consider very early and discuss cost items that may look less important to the client, to avoid changes such as the removal of shading devices that happened to reduce the project cost.
5. The contractor should continue following quality assurance procedures and delivering the good workmanship of the fabric achieved in this project in future projects.
6. The contractor should coordinate the quality and be clear with suppliers on who is responsible for the custody of supplied materials/elements before they are installed to minimise what happened with supplied windows regarding who was responsible to protect them from rain on site.

# 10. Wider Lessons

The findings from the BPE study are expected to inform future procurement, development, and occupation of dwellings in the UK at large, and the affordable sector in particular. The following sections summarise the key findings, recommendations and lessons in the context of the four stages of Dwelling Lifetimes namely: Programming, design, Construction, utilisation. There is also a section that describes areas of potential further studies.

## Key lessons

The key lesson is that, overall, the development has delivered most of the expectations and confirms the PassivHaus reputation of being a proven complete standard; and the potential of Code Level 4 rated homes to be low energy comfortable dwellings in-use and to perform much better than conventional homes in most aspects of occupant comfort and utilities.

The PassivHaus in the development has delivered the expected benefits, in large part. The dwelling is comfortable to live in most of the time, but for the rare days when Scotland can get very cold, and given its low occupancy and limited internal gains, the indoors temperature can go slightly below the lower comfort limit, when the air-to-air source heat pump ceases to be very effective at –ve 6 deg. C.

Both the Code Level 4 dwellings also perform better than conventional homes. The dwelling (TA1) that performed pretty close to the PassivHaus dwelling in terms of energy use, demonstrated that continuing efforts by occupants to save energy can enable a lower rated dwelling to perform as well as a higher rated dwelling. The comparison of TA1 and TA2 shows that similar low carbon dwellings can result in vastly different consumption levels if the occupant environmental preferences and behaviours are different. These can have a major impact on carbon emissions.

For the wider industry, the findings have proved that BPE is a crucial strategy in examining the energy and environmental performance of housing. The evaluation has revealed significant, useful information on performance; issues that would otherwise have remained unreported and led to problems in the future; and it is able to identify improvements in existing and future buildings and is a vital component is producing effective buildings in contemporary contexts. Organisations need to develop capacity for undertaking BPE and feeding this back to occupants and into specification, design procurement and construction processes. Changes are required in the industry to ensure that BPE processes are undertaken as a matter of course.

## Lessons across the four stages of dwelling lifetimes - Programming, design, Construction, utilisation.

**Project team communication**

Of particular success in this project was the good communication and collaboration between the client, architect and contractor which was established. Because they had agreed common ground prior to construction, the informal 'partnering' relationship agreement between the architect and the contractor reduced significant changes on site, and subsequently as-built variations from design. This is something from which other projects could learn. All agreements were made prior to site, when there was a problem, on the whole it was quickly resolved.

**Regulatory bureaucracy**

The project went smoothly through planning permission and received no objections from the local community since the team made an effort to consult neighbours regarding three design options.

**Skills and knowledge gap in the Industry**

Training and knowledge sharing is required for new technology and practices such as the PassivHaus in this project. Highly skilled teams of consultants are necessary to deliver such high spec. projects. A skills gap and limited local experience was identified regarding the programming, design, installation and utilisation of the MVHR, air-to air source heat pump and solar systems in the PassivHaus dwelling. Although SPHC was involved early, their limited experience resulted in poor performance of the system installed. Although government authorities, training institutions, and developers have put efforts in training schemes for energy assessors and assessors to use the Code for sustainable homes, more needs to be done to support the expansion of training programs for building professionals and builders by various institutions, e.g. BRE Scotland; University Strathclyde’s PassivHaus course. Architects/Engineers Registration Boards and training institutions should review curriculums to promote new skills and learning in the emerging areas of low energy/low carbon buildings.

**Design and Space programming**

The entire development was programmed and designed to accommodate different sizes of households. If energy consumption per capita is considered, this approach optimises area per occupant and consequently energy use per person. This suggests a need to emphasize thorough space programming as a key aspect to achieving energy & carbon saving targets. Little was found to suggest that significant changes to the design would be made if the project were to be repeated, unless it has to do with the installation of the systems in the PassivHaus, and a better orientated site.

**Lack of interest and motivation**

There is a general lack of interest and motivation for low energy dwellings in the sector at all stages of dwelling life times from programming through to utilisation. In this development, the ambition by the client and architect to achieve PassivHaus shows a high potential for professionals and clients to counter the typical lack of interest and motivation by championing for better performing developments. They can also drive higher compliance of standards. Another area that could increase interest and motivation is to look at approaches in which standards are driven by consumer demand, in place of housing producers, as it is the current practice.

**Cost and perceived cost**

The Tigh-Na-Cladach development provides vital lessons on how PassivHaus strategies can be progressed for adoption in the affordable housing sector. It is evidence that very low carbon dwellings do not necessarily have to cost significantly more to build than conventional homes. It demonstrates that affordability can be achieved without being at the expense of architectural design and construction quality. The total build costs excluding preliminaries, external works, and site servicing was 10.8% higher in the PassivHaus than the total build costs non-PassivHaus. Energy bills showed that, apart from the period when the towels rails in TB1 were contribution to high consumption, they were generally performing significantly better than UK average, and tending towards best practice performance. This is a good indicator of what extra financing might be required to achieve the Code Level 6 target for new build dwellings from 2016 onwards. Actual figure for the construction costs of the development are confidential and were therefore not provided.

The main additional costs for the PassivHaus were the MVHR, Solar hot water and heat pump. These are likely to reduce as demand increases, the market matures, and these systems are produced locally instead of importing. The timber kits skills will improve, and be produced much more locally and the market will be more competitive. The solar additional costs are expected to be offset in the long term. The servicing cost of the MVHR could make the margin bigger in the long term. The requirement for frequent servicing of filters to protect the heat exchanger and ensure air quality, can add up to significant costs in the long term and disrupting to householders. A different maintenance regime which would locate filters such that maintenance would not require access to the dwelling would help.

If a similar development was to be done, it would be difficult to cut out anything else, (in addition to the shading that was omitted) to save costs without negatively impacting the performance. One area which could be considered is whether it would be cheaper to develop, supply and maintain hot water for heating and bathing in a communal system.

**Lack of technology & standard solutions**

That the developer had to import some low energy components or source them from far, calls for an urgent need to innovate and develop local low carbon products to reduce importation costs.

**Systems design improvements**

Systems design, specification, implementation and in-use operation and maintenance must be integral to the rest of the development aspects at these stages. Future innovations must consider how householders will operate the systems in ways that can adapt to the needs of different household sizes and use patterns. They must be simple to learn and to use to the average user who would typically leave systems on the default settings than adjust to suit changing needs.

System designs, specification and settings for SHW should provide adequate hot water for space heating and bathing, while protecting against legionella, maximising the contribution from the solar thermal. Thermal losses from storage and distribution constitute a significant percentage of the hot water demand, and potential contribution to temperatures above the comfortable range as was the case in dwelling TA2. Care should be taken to minimise or eliminate such losses.

The sizing of AASHP and climate context should be considered carefully. The testing indicated that the current heat pump can achieve an average COP of 3.49 in heating mode – the COP quoted by the manufacturer (Mitsubishi) is 4.0. The AASHP design specification should be improved to perform better on the required defrost operation during extreme winter conditions when external temperature falls below 6°C for prolonged periods of time. Such drop negatively impacted the systems *COP* and reduced the energy delivered to the dwelling, as heating operation ceased during these periods. The *PHPP* design tools had resulted in an undersized original installation, which had to be replaced. The second model performs better but is still inadequate during very cold weather.

**Legislation and Legislation differences**

Current compliance patterns suggest a need to discontinue minimum targets and advocate for the highest possible standard, although this would have some cost impacts. The Dunoon development achieved higher than the requirements in the regulations at the time, and therefore future proofed and enabled it to meet current tighter standards. The government should continue making advance announcements for future tightening of standards to enable developers to plan and prepare.

**Improvements to standards - PassivHaus versus Code for sustainable homes and Eco homes standards**

The PassivHaus is a complete standard in the sense that achievement is based on certification of the completed building, as opposed to enforcement at the planning stage. The code for sustainable homes and Eco homes should use a similar approach to ensure compliance post-planning.

Overall, the PassivHaus dwelling has proven robust since the system problems were solved. However, in extreme cold weather, which occurs occasionally at Dunoon, there might be need for supplementary heating. The sensitivity of PHPP to variations in internal gains based on occupancy and appliance use against the floor area/volume of space is worth investigating especially for a double volume ceiling as the one in the Dunoon development.

**Quality assurance – Coordinated/Uncoordinated efforts (Programming, design, Construction)**

The Dunoon development, they demonstrate the importance of following quality assurance procedures, throughout the planning, design and construction stages of dwellings. Quality assurance procedures helped to achieve very high quality of workmanship in most aspects, except the snagging issues with the M & E systems.

**Split incentives**

There seemed to be no issue of split incentives between the developer and householders on who took responsibility of the low energy aspects of the development. The developer took their responsibility from programming, design, and construction, ensuring they delivered low energy homes; and the householders seemed to be taking care to ensure continuing low energy performance. The government has a responsibility to provide economic & financial incentives to such developments. If these had been in place, perhaps the association would have developed the entire development to PassivHaus standard.

**Information on benefits & user behaviour**

A cultural change, to some degree, is required if the PassivHaus Standard and UK's Zero Energy Standard are to be effective for UK homes in general. It took some learning and adjusting for the household in the PassivHaus to learn and operate the systems in the house and get used to living in a house without conventional heating. In 2010, the Building Standards Division of Scotland commissioned "Guidance for Living in a Low Carbon Home" in building regulations and this is expected to adjust the market to living in higher standard homes.

We recommend other promotion instruments: such as demonstration projects; and Persuasion on benefits of low carbon to change public opinions and attitudes. The importance of occupant interaction; the available strategies; and advice for occupants need to be considered more carefully at design stages.

**Further study**

The Dunoon BPE study has provided a wealth of valuable information. However, it has also identified a number of other areas where further study would be worthwhile, either elsewhere or within the development

**In-use changes by occupants**

To monitor across the entire development, and changes to environmental control systems by users in a few years to find out is there might be emerging patterns and/or deterioration of performance over time.

**Air quality, Health and Wellbeing**

The filtered air from the MVHR in the PassivHaus is expected to bring health and wellbeing benefits. A long term more detailed study of the air quality in the PassivHaus versus that in the other dwellings in the development without MVHR installation could provide useful knowledge.

**Internal gains, heating and ventilation**

The PassivHaus has typically low occupation and air flow rates may be a little high for only two occupants. It would be useful to investigate whether the MVHR low, medium and high settings could be reconfigured to maintain air quality and thermal comfort and how this might impact energy use. Such a study could compare settings reconfiguration with integration of CO2 sensors to facilitate demand driven ventilation.

**Occupancy and occupant actions**

The two code level 4 homes demonstrate significant impact of occupant practices on electricity use. A wider monitoring of other similar dwellings in the development would improve an understanding of how occupancy and occupant practices could be approached to improve the performance.

**Solar water heating**

An exercise to consider the economics and environmental impact of a communal SHW system for the 14 dwellings compared with the current systems serving a single dwelling. This would consider life-cycle costs, in the context of Dunoon weather, demographics; and establish if the contribution of solar panels over a long period would make economic sense in the wider Dunoon region.

**Summer hot weather**

All three households reported temperatures above the comfort range during the July 2013 hot weather. High insulation, high solar gains due to shading that was omitted, and high air tightness have been identified as contributing factors. Further detail to quantify the relative contributions of these might help to identify the degree to which deciduous planting and/or advice for occupants on how to operate the homes could reduce the potential higher than comfortable temperatures during future hot spells. A study comparing the Tigh na Cladach development insulation data with other similar properties with traditional fabrics in Dunoon would enable this to be examined further.

## The BPE Process, costs, and reporting

- The outline costs indicated in the bid process were unrealistic for a Phase 2 project which had not undertaken a Phase 1 analysis. Several costs that MEARU did not envisage at the start of the BPE project came up when the project was under-way, and it made it way more expensive than the TSB funding. The key ones include costs for kit, installation and demounting; and decommissioning costs; time to execute the project and report.
- It is clear that important and useful data and knowledge has been produced about the Tigh-Na-Cladach development through participation in the BPE project, information that would not otherwise be available,

or would have been piecemeal reports on maintenance call-outs. This has led to improved insight and application of this knowledge by the design team and client.

- The processes and methods required by the BPE program have affected the nature of the process. Whilst it has been a thorough process, it relies significantly on the goodwill of the occupants. Although the intentions behind the mandatory tools are sound, these were insufficiently developed. There were frequent revisions to spread sheets such as DomEARM, which were also buggy and difficult to use.
- A lack of access to EMBED meant that data has had to be captured and analysed using spreadsheets.
- BUS is not yet sufficiently developed as a methodology for domestic environments and this, combined with its high cost and requirement for a licence means that it is not easily available for surveys in the affordable domestic sector. The reporting process was unduly burdensome and has directed time and effort away from the project itself.
- Considerable insight has been gained into the processes and methods for remote monitoring and data capture. Whilst the system used has considerable merits and advantages, it is not sufficiently developed, nor robust to be used in domestic environments, and a lack of support was a constant source of frustration. Environmental sensing is a rapidly developing area of technology and it is likely that lower costs units will increase in availability. It is noted that consumer level monitoring is now widely available.
- Work is needed to develop better systems for the metering of energy, in particular low current electrical sub-circuits, appliances and hot water consumption. The need for electricians and plumbers, with requisite knowledge of kit such as heat flow meters, means that installation costs will remain high. In future projects it is recommended that sufficient space is provided within consumer units to allow for the retrofit of sub-circuit monitoring equipment.
- The capacity for performance monitoring of active systems – in this case the solar thermal systems, MVHR, AASHP – should be provided at installation, or integrated in the manufacturing process. Whilst this may represent an additional cost, equipment costs are reducing and it is suggested that it may be cost effective in reducing losses and defects in use. It also provides a source of data for decision making in future projects.
- The quarterly reports took away a lot of time that would have been better spent executing different tasks of the project. Although a quarterly review would have been very useful, the requirement for quarterly reports did not help much in improving the final quality of the BPE project delivered.
- MEARU received conflicting feedback from TSB on the depth of analysis and reporting required for the final report. At one point the message was for a simplified report meant for lay public to understand. In the end, the message and feedback was for detailed level of analysis close to what one would do for an academic paper. The template had multiple sections asking for the same information.