Murray Place

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InnovateUK project number	450104
Project author	Hanover Housing Association
Report date	2014
[1]InnovateUK Evaluator	N/A

No of dwellings	**Location**	**Type**	**Constructed**
Three	Barrhead, Glasgow	Mid-terrace (MT) End terrace (ET) Flat	2010

Areas (TFA)	**Construction form**	**Actual space heating**	**Certification level**
MT: 93.1 m^2 ET: 75 .4 m^2 Flat: 75.8 m^2	2 Timber frame 1 Masonry (the flat)	81.3 kWh/m^2 per annum 175.3 kWh/m^2 per annum 120.4 kWh/m^2 per annum	Scottish *Building Regulations*

Background to evaluation

The Murray Place development comprised 16 two-bedroom amenity houses for older people. The housing design was developed with reference to the *Green Guide to Housing Specification* and the principles embodied in *EcoHomes.* Three dwellings were selected for BPE study: a mid-terraced two-story house with timber frame construction, a top floor flat with masonry construction, and a single story cottage flat with timber frame construction. The BPE project studied a range of design features including the breathing wall construction with Warmcell insulation, and the active solar strategies.

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

The breathing wall construction of the timber-frame dwellings performed within design expectations, despite a change in specification on site. There was some evidence that the vapour permeability reduced moisture, but other temperature and ventilation conditions masked this. No evidence of insulation slumping was apparent, although thermal integrity was compromised by some missing and misplaced insulation. The U-values of the masonry construction were poorer than design values. Energy consumption was higher than SAP calculations in terms of regulated energy, although hot water consumption was lower. Two years of data is available for electrical and gas consumption, solar hot water production, domestic hot water consumption, and sub-metered electrical consumption for up to six sub-circuits in the dwellings.

Occupant survey type	**Survey sample**	**Structured interview**
BUS domestic	9 of 15 (60% response rate)	Yes

Generally the occupants were satisfied with their homes, the location, and the orientation. However there were common concerns over the solar thermal systems and questions over whether they were working. After two years occupation only one of the households knew how to set the heating programmer, but admitted that they had only learnt how to do this recently. Students and researchers note: additional comments on the interpretation of BUS survey results are on pages 48 and 49.

BUS results are available at http://portal.busmethodology.org.uk/Upload/Analysis/ichljgnr.hgv/index.html (accessed January 2020)

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Acronyms

AASHP	Air to Air Source Heat Pump
ACH	Air Changes per Hour
ATTMA	Air Tightness Testing and Measurement Association
BPE	Building Performance Evaluation
BUS	Building Use Survey
GPRS	General Pocket Radio Service
GSA	Glasgow School of Art
HA	Housing Association
HFP	Heat Flux Plate
HSHA	Hannover Scotland Housing Association
HW	Hot Water
IAQ	Indoor Air Quality
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
PV	Photo Voltaic
RH	Relative Humidity
RRP	Robert Potter and Partners (Architects)
SPHC	Scottish Passive House Centre
ST	Solar Thermal
TRV	Thermostatically Controlled Radiator Valve
VOCs	Volatile Organic Compounds

1. Introduction and overview

1.1. Overview

Hanover Scotland is one of Scotland's largest housing associations - providing affordable, modern, and safe housing and related services to older people. It manages more than 5000 homes on more than 200 housing developments, offering rented housing and acting as factors to owner-occupiers. This development comprises of 16 two bedroom amenity houses for older people.

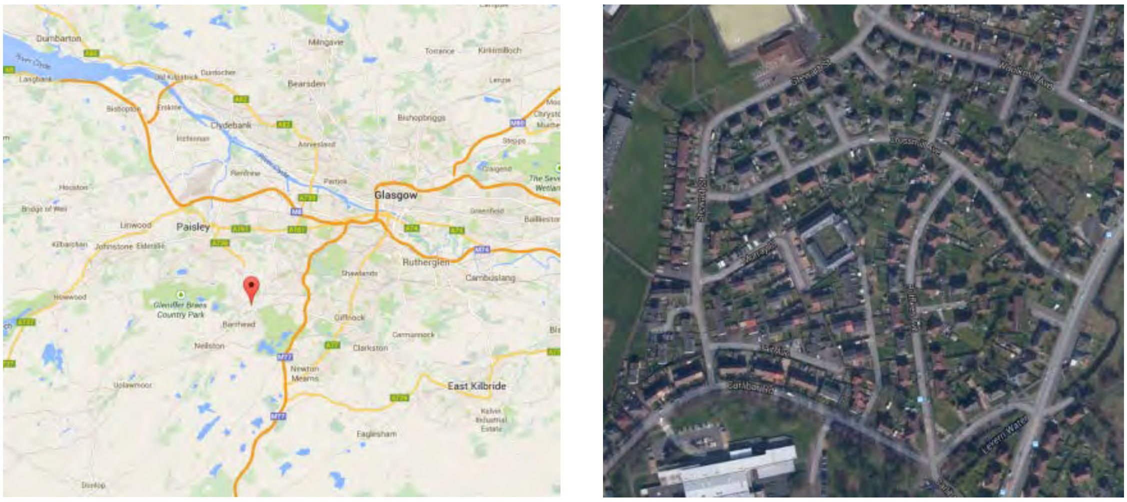

Figure 1: Location and aerial photograph of the site

1.2. Location and Site

The site is located in Barrhead, a small town on the periphery of Glasgow. The site at Murray Place, Barrhead, was identified in conjunction with East Renfrewshire Council as being potentially appropriate for an affordable housing development. The site lies in a well-established area of social housing, close to local amenities. It was formerly occupied by a car repair garage and as part of the works a small amount of ground remediation was required. Hanover Housing Association (HSHA) liaised with East Renfrewshire Council regarding housing need in the area and identified that sixteen houses for older people would be appropriate.

The project team were:

Client: Hanover (Scotland) Housing Association Limited

Architect: Robert Potter & Partners

Structural Engineer: Halcrow Yolles

Quantity Surveyor: TC Stewart

1.3. Outline Description

The design aimed to provide a safe residential environment for elderly people. To achieve the number of dwellings required within the available site area the design proposed three different dwelling types, namely two-bedroom cottages, two-bedroom flats, and two-bedroom two-storey houses. These were arranged around a central garden courtyard, with the courtyard accessed from a single point to provide natural passive surveillance and meet the guidance in Secured by Design.

A number of strategies were proposed in order to reduce CO_2 emissions from the dwellings during their lifetime. The design was developed with reference to the Green Guide to Housing Specification and the principles embodied in EcoHomes as HSHA endeavour to minimise energy in use in order to reduce the amount their tenants spend on fuel.

Summary of proposed design stage sustainability measures:

- Enhanced wall insulation to reduce heat losses.
- Enhanced floor insulation to reduce heat losses.
- High performance double-glazed windows, with controllable ventilation.
- Thermostatic temperature control to each individual room and water heating.
- Timber doors, windows and fascias for simplicity of cyclical maintenance.
- Long-life non-toxic paints and stains.
- Formaldehyde-free chipboard to reduce toxins.
- Good space standards to provide long-term flexibility and Lifetime Homes.

Figure 2: Design and as-built images

1.4. Occupancy

Three dwellings were selected for inclusion in the project, representing the difference forms of construction in the development. These are a mid-terraced two-story house with timber frame construction, a top floor flat with masonry construction, and a single story cottage flat with timber frame construction. The general occupancy of the three dwellings in the study are described in the table below:

Code	TFA (m^2)	No of Occ	B. Reg date	Const Type	Built Form	No. Beds	Monitored rooms	Characteristics	Design SAP kWh/m^2
BA1	93.09	2A	2010	Timber Frame	Mid-terrace 2 storey house	2	Living, Kitchen, Main bedroom	>50, generally continuous occupancy	99
BB1	75.80	2A	2010	Masonry	Flat - top floor	2	Living, Kitchen, Main bedroom	>50, generally continuous occupancy	114
BC1	75.44	2A	2010	Timber Frame	End-terrace 1 storey cottage	2	Living, Kitchen, Main bedroom	>50, generally continuous occupancy	123

Table 1: General occupancy and arrangement of the monitored dwellings

The occupants are all older couples (>55), who are in the house during the day. A number of the occupants have health issues, which affects how they use the houses (generally occupied during the day, but occasional absence for hospital stays), sensitivity to this and a desire to reduce disruption to a minimum has affected the BPE study. The location of the dwellings is shown below.

1.5. Aims of the BPE project

The mix of single storey cottages, two storey flats and houses provides a valuable opportunity to review in detail the qualitative and quantitative performance of a social housing development designed to meet the needs of elderly and disabled occupants.

The materials and method of construction used for the vapour permeable wall construction inner leaf were a departure from the more traditional options used by HSHA. The study compares results from the masonry flat and allows HSHA and the project team to learn from the project and utilise the knowledge gained on future housing developments.

The dwellings incorporate a range of design features including passive and active solar strategies; the study of which can inform the on-going industry debate on appropriate solutions for delivering energy efficient dwellings.

Specific research questions included:

1. How well is the breathing wall performing?

- In particular, are there any problems with interstitial condensation and are there vulnerabilities in any areas of the breathing wall construction?
- Is the breathing wall construction providing lower internal humidity than would be expected with a "standard" timber frame solution and what effect is this having on IAQ and concomitant window opening habits?
- Are there any variations between dwellings and rooms, and what are the reasons for these?
- Is there any evidence of Warmcell insulation slumping?

2. What are the effects of the passive solar strategy on environmental performance, IAQ, energy use and occupants wellbeing?
3. What is the contribution of the solar water heating to the energy demands of the dwelling compared to what was predicted?
4. How does the overall energy usage compare to what was predicted by SAP taking into account the nature of occupants, occupancy and in particular how do occupants interface with the control of their environments?
5. Do the results indicate either masonry or timber framed vapour permeable construction being preferable in relation to energy efficiency or internal air quality?

The aim of the BPE project was to undertake a series of physical tests and a longitudinal period of monitoring, which, combined with qualitative data on occupancy patterns, comfort and use, would identify how these buildings were working in practice. Three different dwelling types (with generally similar occupancy) were selected to allow some degree of comparison. The study was undertaken as far as practical in accordance with the TSB Guide for Project Execution.

This includes a series of standalone studies and on-going monitoring. The outcomes of these various areas of investigation and the location of source data from these in this document is described below:

Design and construction audit	Section 2 and Appendix C
U-value test	Section 3 and Appendix H
Thermography	Section 3 and Appendix G
Air Permeability testing	Section 3 and Appendix C2
Photographic Survey	Appendix C3
Design team Walkthrough	Section 4 and Appendix J

BUS	Section 5 and Appendix D
Occupant Walkthrough	Section 5 and Appendix J
Monitoring	Section 7 and Appendix I

1.6. Summary of findings

A summary of key findings from the project are as follows:

- The breathing wall is performing within design expectations, despite a change in specification on site. No interstitial condensation was noted during the monitoring. There is some evidence that the vapour permeability is reducing moisture, but other temperature and ventilation conditions mask this. No evidence of slumping was apparent at this time.

- The U-values of standard build-up elements of timber frame construction are close to design values – however the effectiveness of this is compromised by non-standard junctions and interfaces, for example: at eaves, roof joists, window and door openings. Thermal integrity was also compromised by missing and misplaced insulation in some areas. Revisions of standard details have been undertaken to address build-ability in some of these areas, including a revised eaves detail. The U-values of the masonry construction were poorer than design values. However this is compensated to some degree by greater thermal mass, which appeared to have beneficial effects.

- Control of moisture and indoor air quality was affected by varying ventilation strategies and regimes. Use of trickle vents in bedrooms in themselves do not provide a sufficiently robust ventilation strategy. Defects were found in a high proportion of the mechanical systems. Habitual night-time bedroom window opening was a clear mitigating factor for air quality. Given that overall air-tightness was good, even without a specific target, consideration of effective ventilation - taking into account usability for this occupancy type - is needed in future developments

- Overall performance is good, but not very low energy. Comparing across all of the Scottish / UK (TSB) monitored houses, energy use was above the mean, but this must be contextualized by the nature of the older occupants with all day occupancy and a tendency toward warmer conditions. The effect of high demand temperatures in consumption was clear.

- Energy consumption was in all cases higher than SAP calculations in terms of regulated energy, although hot water consumption was lower. However SAP does not take into account location nor occupant type. The relative performance between the three houses matched that of SAP, although the difference in actual consumption was higher.

- Notwithstanding fabric and active system differences, occupancy clearly plays an important part in overall energy consumption, including occupant preferences, but also occupant knowledge (or systems and controls), effectiveness and usability of controls. Poor occupant understanding of controls led to increased energy use. Areas for future improvement highlighted by the project included the need for better handover processes, especially of active systems and controls; and overall occupant guidance and these have been implemented in this and other projects.

- Affordable warmth was achieved in all the houses. The overall tendency was toward overheating with high temperatures were consistently achieved in all the houses and levels of satisfaction with comfort are consistently high throughout the scheme.

- The development provides a comfortable, safe and enjoyable environment. The passive orientation and courtyard space are successful.

- There was a tendency toward overheating in the properties in several areas. Bedroom spaces were generally warm, with the exception of the house that kept bedroom windows open. As a result of the temperature regimes, relative humidity levels tended toward the very low, especially in the winter and spring, which could have health consequences. Some overheating was observed in summer. This does not appear to be significantly affected by the solar orientation, with sufficient control provided by the passive shading and internal blinds etc.

- The solar thermal system - when installed correctly and properly maintained - did make a useful contribution to the energy consumption and was close to SAP estimates. However considerable problems were encountered with the installation and maintenance of the solar thermal systems, which meant that this performance was only achieved in one of the dwellings, on-going maintenance remains an issue. The location of the system was problematic. For future projects care is needed to load match production and demand in this house type.

- Electrical use was close to benchmarks, but examples of differences in key appliances were observed. Occupants bringing older, less efficient appliances with them when they move in may undermine improvements in energy performance by the houses.

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

2.1. Construction

Detailed information on the construction is found in the dwelling characteristic spreadsheets in Appendix F, additional construction information is contained in Appendix C.

In general the buildings take a fabric first and passive approach. The site is relatively flat, and the dwellings have been positioned to reflect the sun path during the course of the day and to achieve direct solar gain, thereby minimising overshadowing and ensuring advantage is taken of any available sunlight. The single storey dwellings are placed to the south of the courtyard, with the two-storey dwellings and flats to the north. The two-storey dwellings incorporate a “living wall”, being a trellis colonised by plants, with the planting dying back in winter to maximise sunlight and flourishing in summer to provide natural shading. Potential plants include Virginia Creeper which will give a variety of colour throughout the year and mark the passing of the seasons. The rainwater downpipes discharge into the planter at the base of the trellises, giving natural surface water attenuation and irrigation.

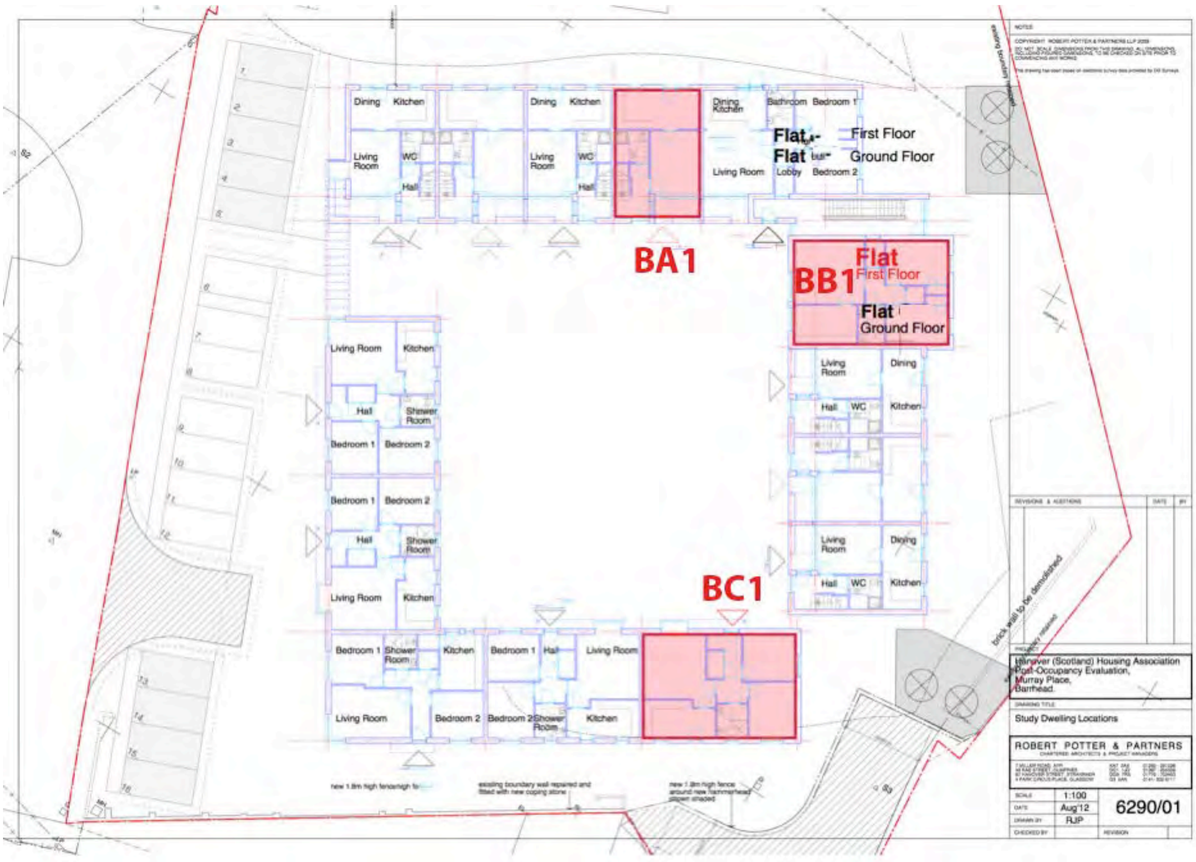

Figure 3: Dwelling locations

Figure 4: General view from the courtyard looking east. The solar panel in BB1 can be seen on the far left roof

Figure 5: General view from the courtyard looking south. The north facing living room of BC1 is in the centre

Active solar water heating is provided to all 16 dwellings (roof mounted solar collectors connected to a coil within the hot water cylinder). The balance of the water and general space heating for dwellings is provided by high efficiency gas fired condensing boilers.

Timber frame construction has become the norm in Scotland, primarily for cost reasons and would be the normal form of construction. However, following attendance by the architects at lectures on internal air quality/humidity and dust mite propagation, the decision was taken to incorporate a vapour permeable construction (sometimes referred to as 'breathing wall') in the bungalows and two-storey houses.

This specification utilises a modified timber frame build -up with vapour barrier omitted from the plasterboard lining in favour of a highly vapour resistant board (Paneline). The OSB sheathing on the outside of the inner leaf was replaced with a highly vapour permeable board (Panelvent), to ensure vapour is dispersed from the building in a controlled manner and the risk of interstitial condensation minimised. Warmcel cellulose insulation (made from recycled newspapers) was pumped into the cavity between the inner and outer lining boards to ensure that all of the voids were filled. This ensures that vapour is dispersed from the building in a controlled manner and the risks of interstitial condensation are reduced. The performance of Warmcel is only marginally less than the performance of mineral wool insulation.

The outer leaf of external cavity wall is of facing brick/ rendered masonry construction. Traditional masonry (blockwork) construction was used for the flats to ensure good sound attenuation between storeys and to provide thermal mass. The common stairs to the flats have been provided with windows to reduce reliance on artificial light.

The two storey dwellings have a decorative galvanised steel trellis acting as a frame for the growth of planting providing natural modification of solar gain throughout the year. This maximises solar gain when winter sun is low and the branches are bare, and maximises shading when the plants are in leaf and the sun is high in summer.

Insulation levels were generally enhanced compared to the minimum required by Building Standards, with a view to reducing the energy demand. All dwellings have concrete ground floors overlain by rigid insulation and plywood/chipboard flooring, and all lofts have mineral wool quilt insulation.

The materials selected for the external envelope were generally durable, low-maintenance materials in order to minimise cyclical maintenance costs, while still being attractive in order to weather gracefully, e.g. clay facing brick, and self-coloured render. The double glazed timber windows have a microporous stain finish to reflect HSHA's preferred material for the simplicity of cyclical maintenance. The "living wall" frame is in galvanised steel to avoid the need for painting.

The central garden court provides a variety of garden areas for residents; this is a popular place for sitting out in fine weather. The houses form a natural windbreak and the layout of the scheme maximises available sunlight to create a sun-trap. One resident has utilised part of the perimeter garden for vegetable growing and has achieved good crops that he shares with the other residents.

Figure 6: General views of the courtyard looking north (left) and east (right).

The project achieved Secured by Design accreditation; feedback from the residents indicates that they feel it is a pleasant, safe environment and that they take pride in their homes.

Other sustainable strategies for the project include:-

- Resource conservation by utilising reusable and recyclable materials, including timber, brick, pan tiles, concrete and glass.
- Increased recycled content in specified materials, with reference to the WRAP Initiative.
- Use of locally sourced materials, including native timber, and locally manufactured facing brick and roof tiles, reducing transportation costs and CO_2 emissions associated with transportation.
- Use of materials with low embodied energy, such as timber, clay and concrete, and minimising the use of steel and aluminium.

Construction and layout information is contained in Appendix C and typical floor plans, sections and elevations are provided below.

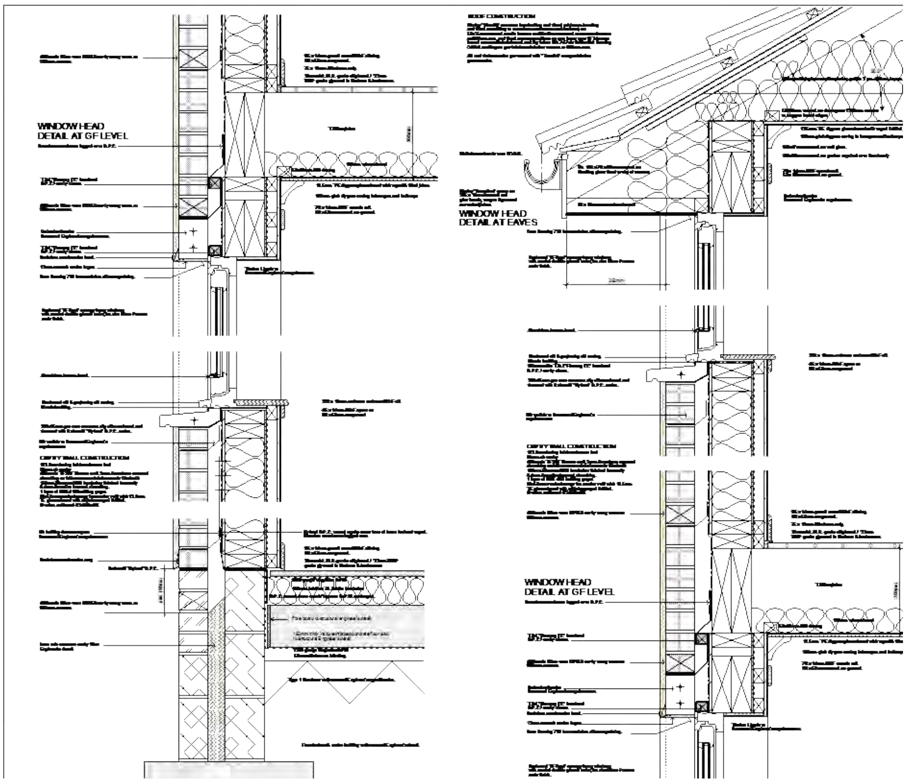

Figure 7: Timber frame construction details

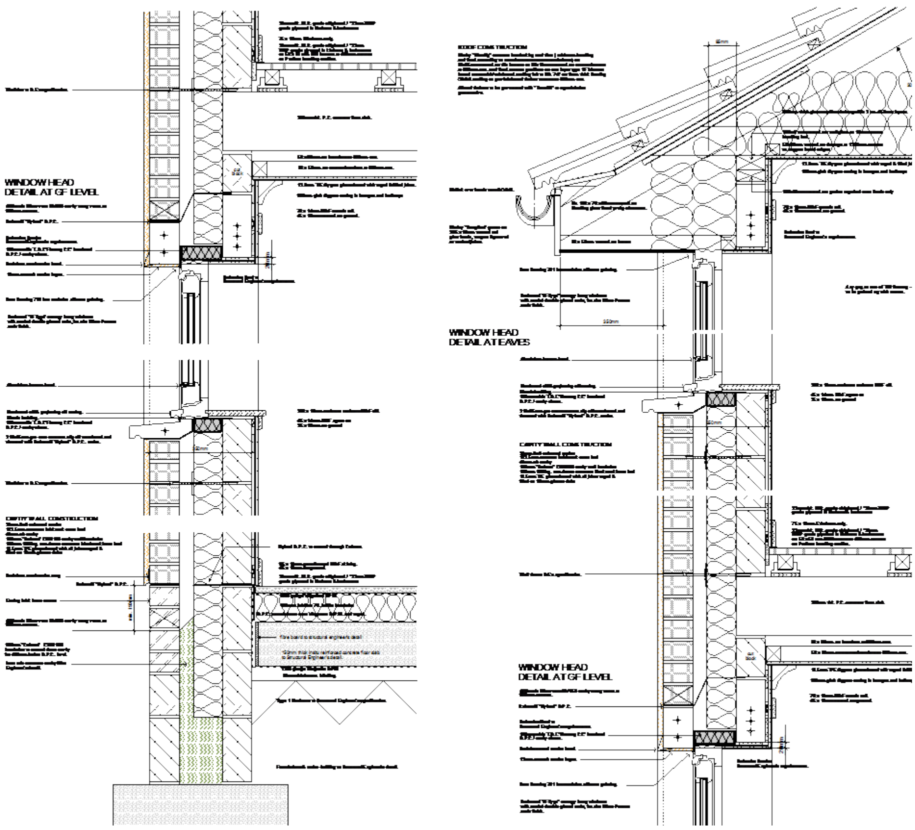

Figure 8: Masonry construction details

Figure 9: South elevation - note 2 solar panels on the roof of BB1 (left); North and east elevations - note reduced window sizes (right)

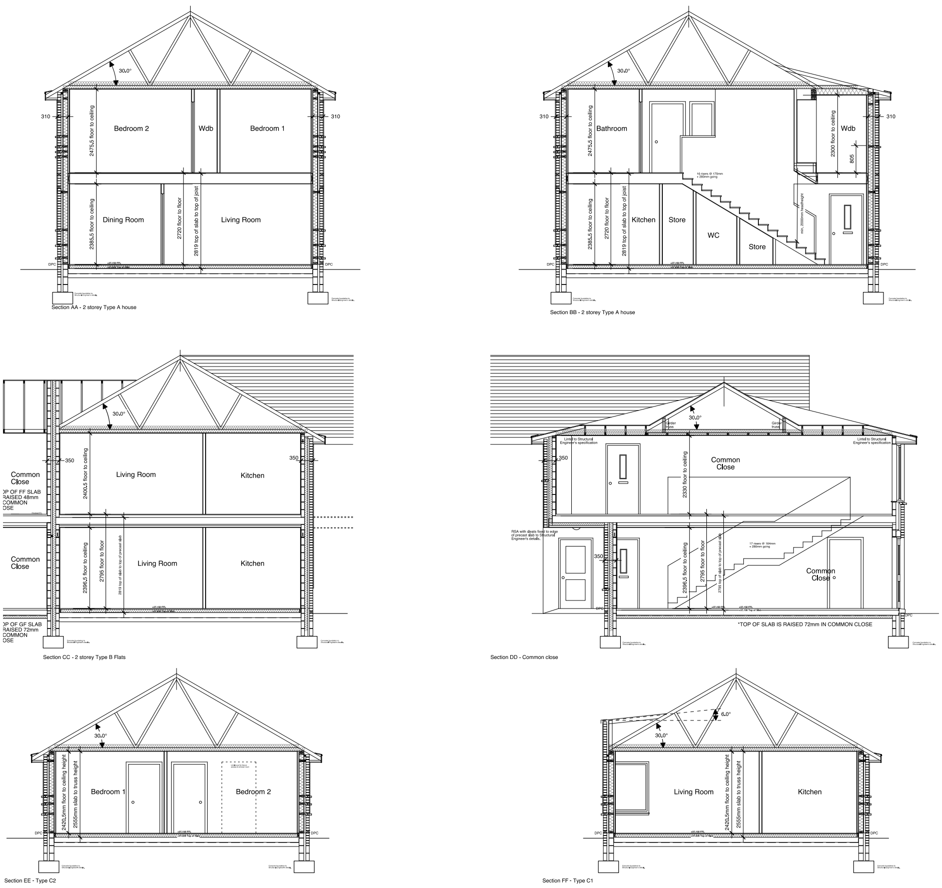

Figure 10: Typical sections

Overview of the monitored properties

Dwelling BA1:

2 residents.

2 storey, 2 bed/ 4 person terraced house.

Timber kit construction, design U-value of walls 0.21 W/m^{2o}C, floors 0.22 W/m^{2o}C, roofs 0.14 W/m^{2o}C. Windows are double glazed timber framed with U-values of 1.8 W/m^{2o}C.

Space heating is provided by a gas fired boiler with water heating provided by a mix of gas and solar assisted means.

Ventilation is provided by natural ventilation via background trickle vents, openable windows and intermittent mechanical extract fans to 'wet' spaces.

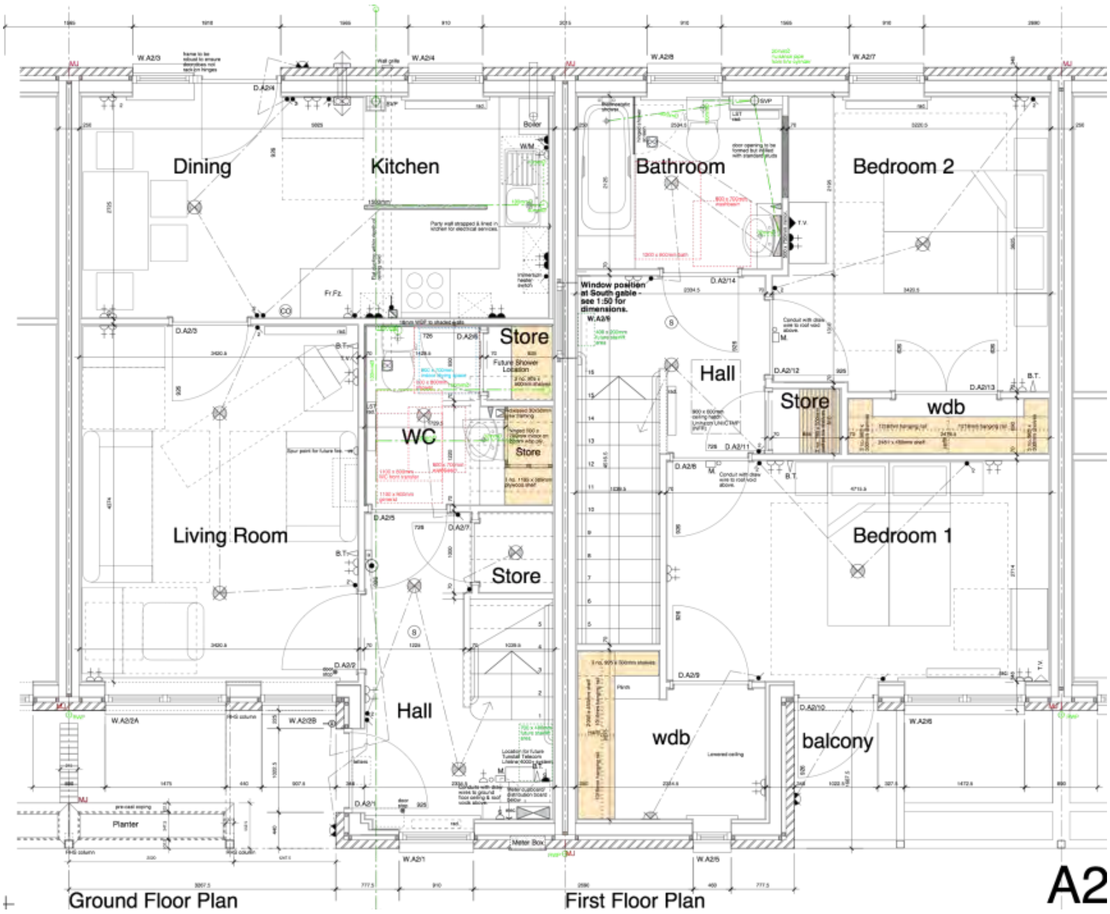

Figure 11: Floor plans for BA1, 2-story terraced house

Figure 12: BA1 South elevation (left) and north elevation (right)

Figure 13: BA1 Living room facing south (left) and master bedroom facing south (right).

Dwelling BB1:

2 residents
1st floor, 2 bed/ 4 person flat.
Masonry construction.
Space heating is provided by a gas fired boiler with water heating provided by a mix of gas and solar assisted means.
Ventilation is provided by natural ventilation via background trickle vents, openable windows and intermittent mechanical extract fans to ‘wet’ spaces.

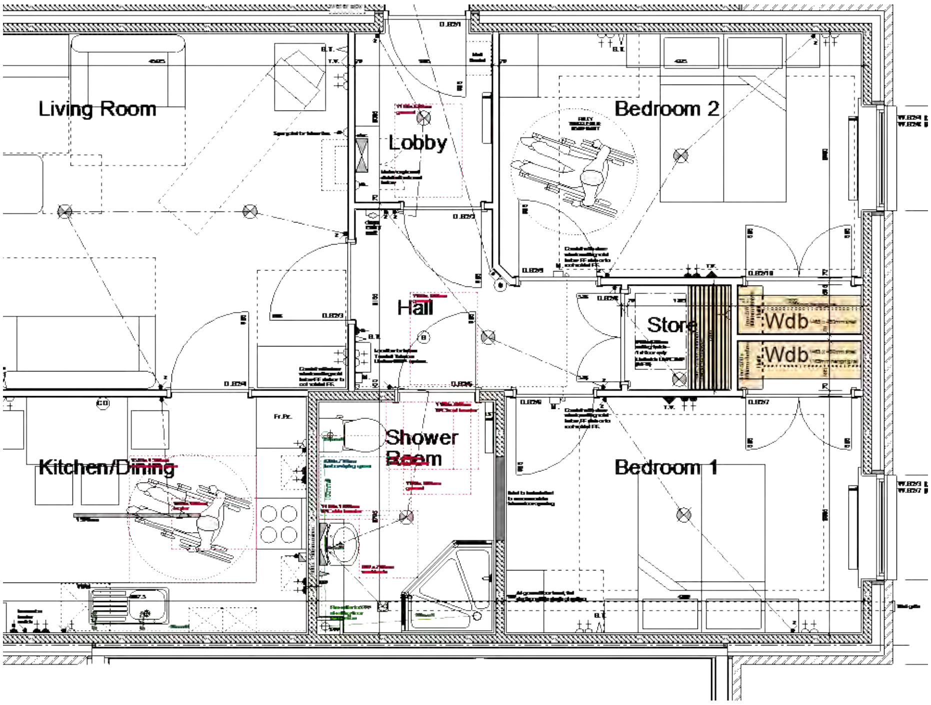

Figure 14: Typical floor plan for masonry flat

Figure 15: BB1 West elevation (left) and east elevation (right).

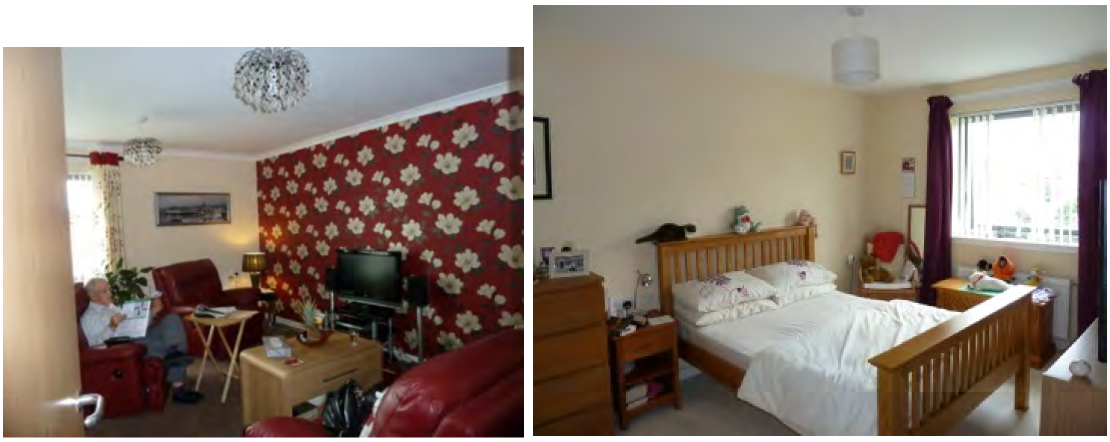

Figure 16: BB1 Living room (left) and master bedroom (right)

Dwelling BC1:

Single storey, 2 bed/ 4 person end terrace house.
Timber kit construction.
Space heating is provided by a gas fired boiler with water heating provided by a mix of gas and solar assisted means.
Ventilation is provided by natural ventilation via background trickle vents, openable windows and intermittent mechanical extract fans to 'wet' spaces.

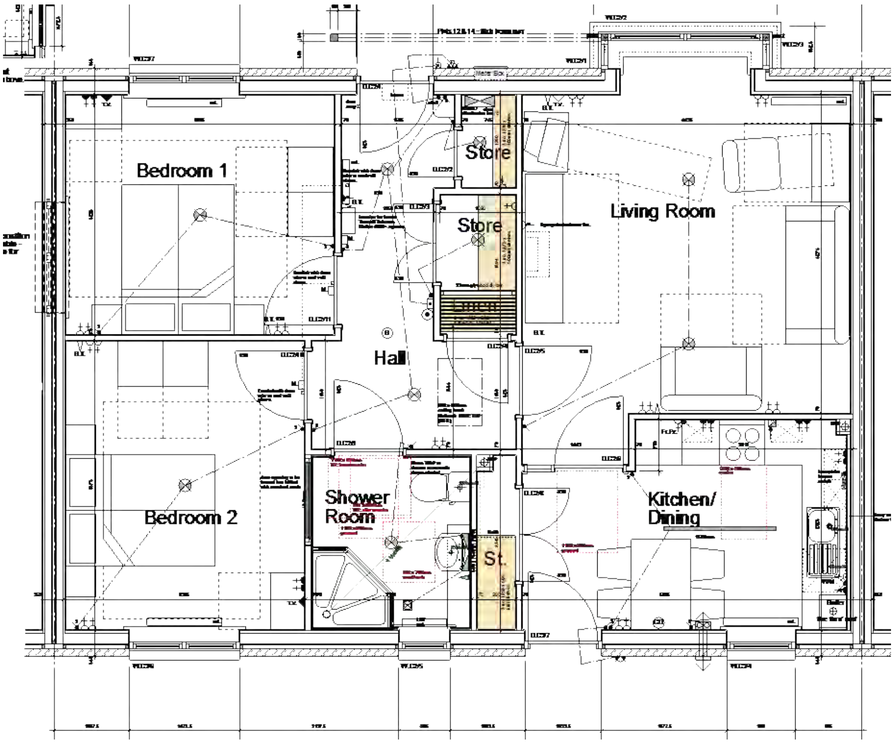

Figure 17: Typical floor plans cottage flat

Figure 18: BC1 North elevation (left) and south elevation (right).

Figure 19: BC1 Living room (left) and master bedroom (right).

Overall:

The dwellings were designed with the backstop ventilation rate in Scottish Building regulations of 10 $m^2/m^3.h$ @ 50 Pa. and no specific elements of airtightness were included.

Figure 20: South facing trellis and planting

The provision of the landscape to the courtyard was protected by removing it from the main contract; this space is successful for the occupants. The trellis for planting to screen the south facades is also now maturing.

Very few contentious issues were encountered during the construction process. The principle issues are discussed in the relevant sections. These include the change in specification to the vapour permeable construction (Section 3); issues of insulation in the loft and thermal weaknesses at openings (Section 3); and the Solar Thermal system (Section 6).

2.2. Procurement and contract

The project inception was in November 2005. An Outline Planning Application was lodged in August 2006 and was granted in October 2006. An application for Planning Permission was lodged in June 2008 and granted in October 2008. Following development of the working drawings and receipt of a Building Warrant in December 2009, competitive tenders were invited. The successful tenderer was Ashleigh Construction and their tender was accepted in January 2009. The site start date was 1st March 2010 and the date of completion was 20th December 2010. The contract was a traditional procurement using SBCC 2008. The contract period was 42 weeks. The work was completed on programme and to time.

2.3. Design Changes

There were no substantial design changes during the project. HSHA are an experienced developer of housing for older people and both the brief and the design intentions were clear and understood. There was a change to the specification of the vapour permeable construction during the contract. The contractor did not install the BSK Building Paper on the inside of the wall, but instead another layer of the external breather membrane, the Glidevale Protect 'TF200 Thermo', the effects of this are discussed in Section 3. During construction it became apparent that there was insufficient space on the roof of BB1 for two solar panels, as a result of which a single panel was installed, the implications of this are discussed below and in Section 6.

2.4. SAP review

The original and revised SAP sheets are contained in Appendix A. The tables below summarise and compare these with the measured performance. The original SAP calculations were reviewed as part of the project. There were no major changes of specification between the designed SAP calculations and the as-built construction, the exception being an alteration to the as-built vapour permeable construction. However, the original SAP sheets included the Solar Thermal panel on BB1 of 4.68m^2, but as this size could not be accommodated, a smaller panel of 2.34m^2 (with a different orientation) is located on the roof of this flat. Table 2 shows the differences between as-design and as-predicted SAP.

	As-built		**As-designed**	
House Number	**SAP Rating**	**Improvement on TER**	**SAP Rating**	**Improvement on TER**
BA1	B87	17.41%	B86	12.60%
BB1	B85	13.06%	B86	14.77%
BC1	B85	16.22%	B85	11.84%

Table 2: Comparison of Design and As-Built SAP

The as-built figures take into account measured U-values which were marginally higher (worse) than design values, but also improved air-permeability (above default back-stop values), which improve predicted performance. It also takes into account the smaller Solar Thermal panel in BB1. In general the differences in SAP scores are minimal, with a very slight improvement in BA1 primarily due to airtightness and a very slight drop in BB1 due to the smaller solar panel.

However, the table below compared the as-designed SAP with actual performance, and in this case large differences are apparent. It should be noted that SAP does not include some use (such as appliances), however Table 2 makes comparisons with specific elements of SAP including primary energy for space and water heating.

BA1			
	SAP	**Actual**	**Difference**
GIFA (m^2)	93.1		
Primary Energy (kWh/m^2)	99.0	114.1	115%
Solar HW production (total kWh)	1119.0	1298.0	116%
Hot Water consumption (total kWh)	2188.0	1900.0	87%
Space heating consumption (total kWh)	4518.0	7564.0	167%
Space heating consumption (kWh/m^2)	48.5	81.3	167%
Space heating proportion of total loads	49%	71%	

Table 3: BA1 Comparison of SAP and actual consumption

BB1			
	SAP	**Actual**	**Difference**
GIFA (m^2)	75.8		
Primary Energy (kWh/m^2)	114.0	142.1	125%
Solar HW production (total kWh)	1119.0	794.0	71%
Hot Water consumption (total kWh)	2188.0	571.0	26%
Space heating consumption (total kWh)	3891.0	9126.8	235%
Space heating consumption (kWh/m^2)	51.3	120.4	235%
Space heating proportion of total loads	45%	85%	

Table 4: BB1 Comparison of SAP and actual consumption

BC1			
	SAP	**Actual**	**Difference**
GIFA (m^2)	75.4		
Primary Energy (kWh/m^2)	123.0	199.0	162%
Solar HW production (total kWh)	1021.0	422.0	41%
Hot Water consumption (total kWh)	1962.0	1462.0	75%
Space heating consumption (total kWh)	5030.0	13226.0	263%
Space heating consumption (kWh/m^2)	66.7	175.3	263%
Space heating proportion of total loads	54%	88%	

Table 5: BC1 Comparison of SAP and actual consumption

Comparing SAP figures, particularly space heating loads, it is clear that the actual energy consumption exceeds that of SAP. Comparing SAP with actual primary energy consumption shows use of 115%, 125% and 162% respectively. Within these figures some elements are of note, in particular the smaller than expected hot water use, but higher space heating requirement. In this case the SAP calculation does not account for obvious and predictable occupancy factors, which in this case will be older people, with more continuous occupancy, which is likely to lead to higher temperatures for longer periods. In the case of hot water use there is a tendency for older people to have a lower hot water demand. It is also very apparent that the proportion of the space heating loads is much higher in use than in SAP.

There is a clear difference in the Solar Thermal hot water production. In BA1 this exceeds the prediction, but in BB1 it is much smaller, due to a smaller panel size (discussed in Section 6), and the production in BC1 is very poor, which also leads to increased gas use for hot water heating – however demand temperatures are an important context here.

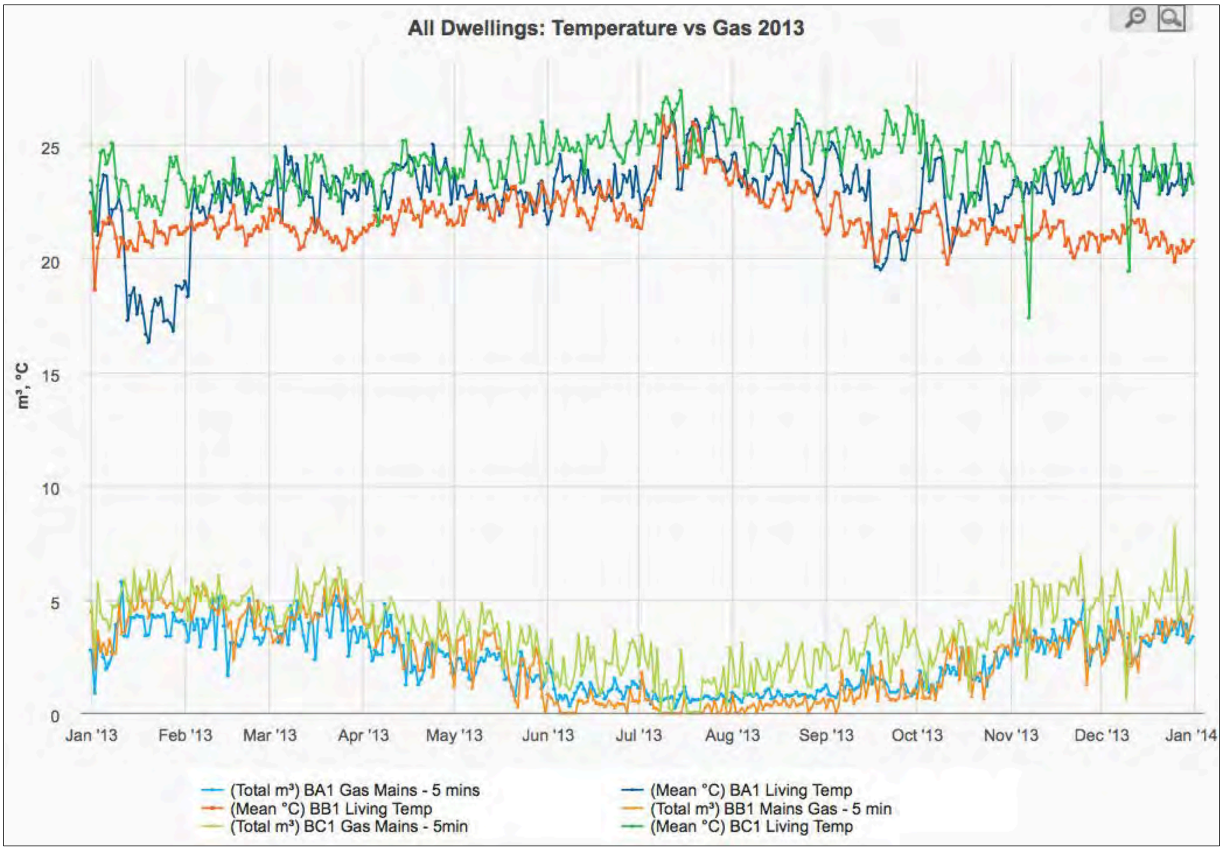

Figure 21: Annual living room temperatures and annual gas use (m3)

Demand temperature is discussed in more detail in Section 7; however it is apparent that much higher internal temperatures are being achieved in BC1, which has the highest gas consumption (Figure 21). Temperature alone does not account for differences in consumption between BA1 and BB1, but these have different construction (single story block construction vs 2 storey terrace timber frame) and ventilation regimes (Figure 24). The achieved values can be compared with the adjusted living room temperature in SAP, which are 19.23 for both BA1 and BB1; and 19.11 for BC1. However the fabric performance of BB1 is poorer (see Section 3), the house operates a more liberal ventilation regime (discussed in Section 7), and has less solar thermal input.

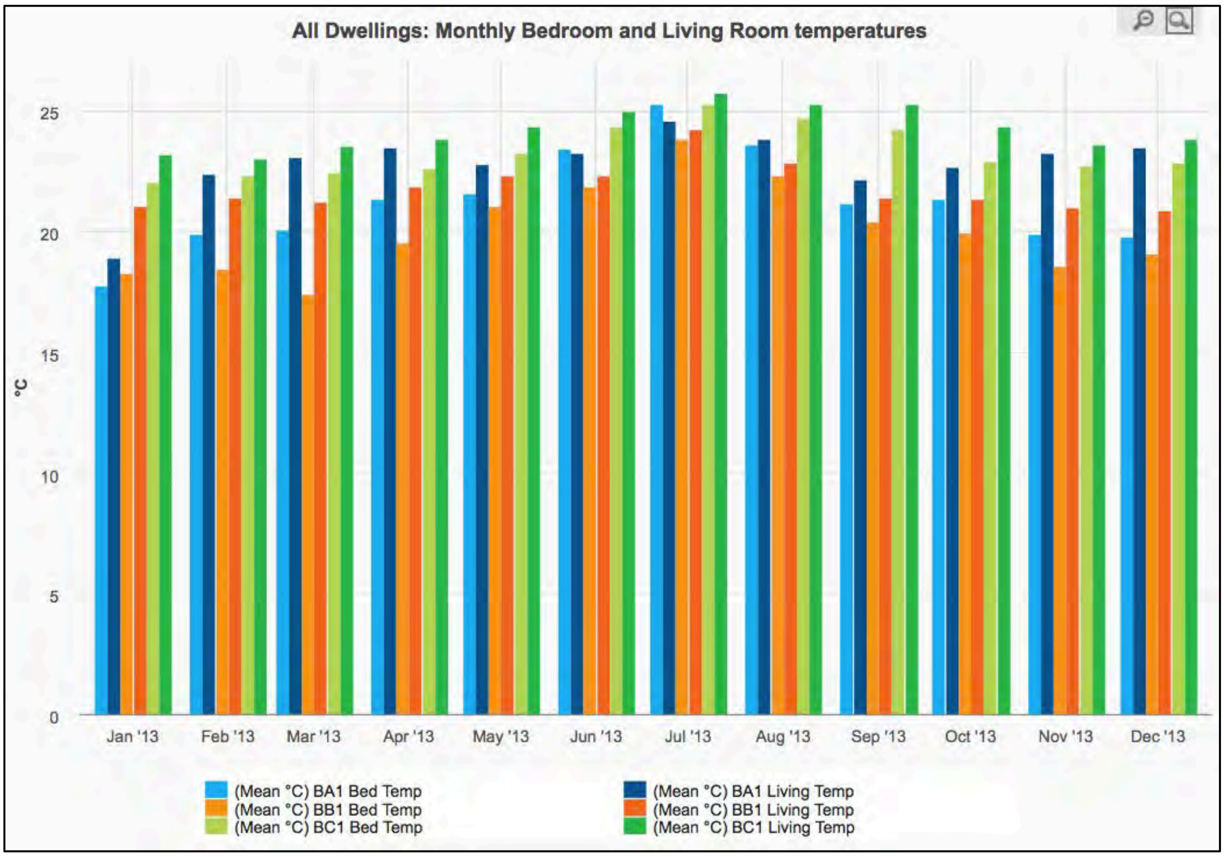

Figure 22: Monthly temperatures in Living rooms and Bedrooms

It is important to note that SAP is intended as a comparative, not a predictive tool and so a comparison may be made between the relative performances of the dwellings. Although the order of performance is similar, with BA1 using the least and BC1 using the most, the difference of actual consumption is much greater. Using SAP, BB1 is expected to use 15% more energy and BC1 would use 24% more. However in actual consumption terms BB1 is using 25% more and BC1 is using 75% more.

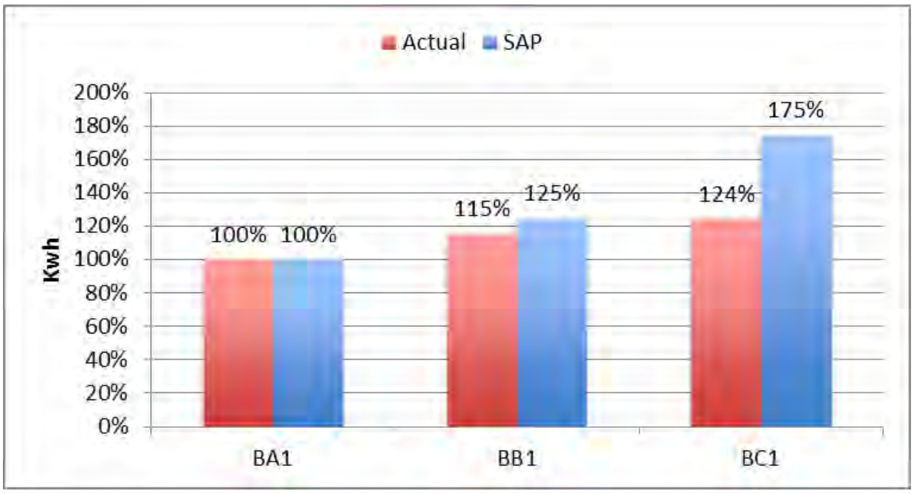

Figure 23: Comparison of proportional difference between the dwellings using SAP and monitored performance

Whilst some issues were identified in the fabric performance, and these are discussed in Section 3, the key sources of additional energy consumption are the increased rates of occupancy and demand temperatures, particularly in BC1, and the underperformance of the Solar Thermal systems.

2.5. Conclusions and key findings for this section

- The overall construction closely matches the design intention, with little variations. Some issues of performance (such as missing insulation) are described in the following fabric testing sections.

- The need for the reduced size of the solar collector on BB1 only became apparent during construction and was not factored into the design SAP.

- The inclusion of the solar thermal system is the result of a policy by the HSHA board, rather than an analysis of the needs and benefits in this particular development.

- Backstop ventilation rates were assumed in SAP, which will differ in as-built construction.

- SAP values should not be used as the basis for an estimate for actual energy consumption without a sensitivity analysis that takes into account likely and predictable patterns of occupation.

- There is some suggestion that the SAP tail is wagging the energy use dog in respect of the selection of measures, and that this exercise occurs at design stages and is not followed through into construction and use. There may be a tendency for measures to be selected at design stages based on the impacts that they have on the SAP score rather than their intended or actual benefit.

- The over reliance on SAP may be stifling innovation in design and development in that it is difficult to justify the procurement of elements that do not have a benefit in SAP. In this case the use of the vapour permeable construction does not affect SAP; even though control of moisture may lower ventilation requirements. Architects may feel forced into design decisions to achieve certain SAP scores.

- In the absence of this BPE project the SAP sheets would not normally have been reviewed or updated post design stage.

- Comparative SAP results of the tested buildings highlights how differences in fabric performance can have a limited difference on overall rating and that SAP scores may be overly skewed toward the importance of technologies and not a ‘fabric first’ approach. Greater weight should be given to fabric issues over systems.

- The rigid process for recording SAP data for TSB is limiting for projects which were assessed using varying versions of SAP.

- As an energy only tool, SAP does not allow for other important quantitative elements (for example ventilation rates for good IAQ) or qualitative effects (thermal comfort due to thermal mass).

- The space heating consumption is substantially higher that indicated by SAP. Overall primary energy is closer as it is balanced to some degree by lower hot water consumption.

- A more comprehensive modelling tool would be required to make a more accurate assessment of actual performance and running costs, and effects of different measures, taking into account the likely occupancy and patterns of demand of this type of occupancy.

3. Fabric testing (methodology approach)

3.1. U-Values

In-situ U-Value testing was undertaken in the properties, the report on this procedure is contain in Appendix H. The methodology used for all testing and analysis is based on the procedures set out in ISO 9869:1994 and Hukseflux HFP01/ HFP03 manual version 1014 and TRSYS01 manual version 0810, both of which describe thermal resistance testing procedures in accordance with ISO 9869, ASTM C1046 and ASTM 1155 standards.

In the development a standard roof construction is used throughout but two varied wall construction approaches are present: a vapour permeable timber kit used on the terraced houses; and a more acoustically robust masonry approach used for flatted dwellings. The approach of this testing element has, therefore, been to test the 3 no. construction elements of: a) Typical cold roof; b) Vapour permeable timber kit walling and; c) Masonry walling. The results of these tests are summarised below:

CONSTRUCTION ELEMENT	FULL SAMPLE PERIOD	ANALYSIS SAMPLE DURATION	DESIGN U-VALUE	MEASURED U-VALUE	% VARIATION
BB1 External Wall (Block)	21.10.13 @ 12.00 - 15.11.13@ 11.10	240 hours	0.19W/m^{2}K	0.26W/m^{2}K	**26.5**
BC1 External Wall (Timber)	31.01.14 @ 12.00 - 21.02.14 @ 11.50	480 hours	0.19W/m^{2}K	0.198W/m^{2}K	**4%**
BC1 Roof	31.01.14 @ 12.00 - 21.02.14 @ 11.50	480 hours	0.12W/m^{2}K	0.59W/m^{2}K	**491%**

Table 6: In-situ measured U-values

The value for the block wall is well below the design values and places the element below current technical standards (2014) which give a baseline value of 0.25 Wm^{2}K. There are no obvious constructional defects which would account for this and no particular anomalies were identified in the thermographic survey. Beyond a poorer that expected performance other possible explanations include: test error; differences between assumed and actual k-values for the specified materials; and possible thermal dynamic effects of the block.

The results for the timber construction are good, and go some way to validating the test procedure. The detailed drawings for the wall construction noted a design performance of 0.24 W/m^{2}K but a recalculation of this construction identified its potential U-value to be 0.19 W/m^{2}K. Compared to this the measured value of 0.198 W/m^{2}K, this can therefore be seen to be a very good result, although as identified in the previous section this has relatively little impact on the SAP result.

With respect to the roof construction the performance is obviously poor in relative terms. The quality of data derived from the tests and the validity of the analysis process suggest that the result is correct within the range of accepted errors. This level of variation therefore identifies a construction issue, which demanded further investigation.

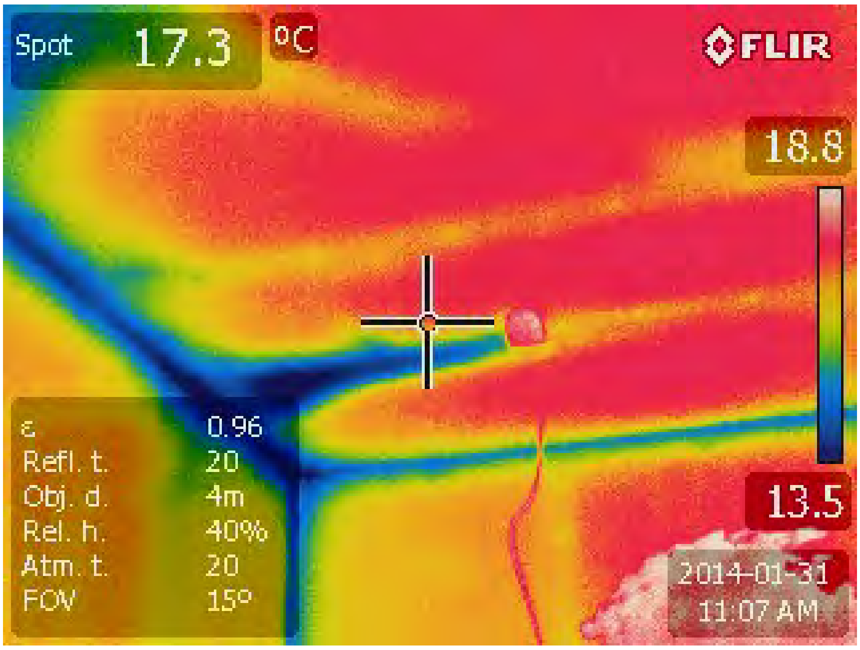

Figure 24: The image shows the flux plate and temperature sensor located at a cold element of the roof construction

Examination of the thermographic survey images identified a significant cold spot in the ceiling construction terminating at the flux plate location. It is presumed that this issue is caused by missing or ill-fitting perimeter insulation and it is clear that this will have impacted on the data recorded for the roof construction. The U-value derived is, therefore, not representative of the majority of the roof construction (the warmer areas to the right of the image and generally away from the perimeter) but it is very useful in quantifying the effect and impact on performance of the construction issues identified by the thermographic survey. What this identifies is that whilst the straightforward construction (for example as seen in the details) may be performing to a reasonable level, there are many areas where junctions and other construction elements – in this case the trusses - are resulting in some thermal bridging.

The conduction of the U-value tests was challenging in this project. It was by far the most disruptive to occupants, requiring the installation of equipment for lengthy periods. In several cases the equipment was dislodged during the tests, the availability of sockets, and access for external measurements was also restricted. Ensuring reasonable weather conditions further restricted the periods during which the tests could be conducted. Whilst some tests could be rescheduled, changes in the occupants health prevented further testing.

There is clearly a case for undertaking U-value testing prior to full occupancy. This would ensure that there were no restrictions on the placement of sensors, internal conditions can be controlled, and effects on decoration and finishes are reduced. It would also allow any defects identified, in this case the insulation, to be addressed prior to occupancy.

3.2. Thermography

A thermographic study was also undertaken as part of the project, the test reports are located in Appendix G. Internal and external images (both infrared and digital camera) were taken in all subject dwellings on Friday 31st January between 11.00 and 13.00 hours. Testing was undertaken in accordance with the requirements of TSB monitoring protocol, BRE IP 1/06 and BSRIA 39/2011.

The prevailing conditions at the time of testing were:

Weather: Overcast (surfaces had been free from direct solar radiation for > 2 hours)

Ext. Temp: 4^{o}C
Ext. RH: 79%

Int. Temp: circa 20^{o}C to 22^{o}C in all dwellings
Int. RH: circa 40% in all dwellings

Outwith the confines of the courtyard development a significant wind was prevalent at the time of testing which may have created limitations in identifying instances of external heat loss. The general fabric construction generally appears to be of good quality with few obvious defects affecting thermal integrity. There was no evidence of slumping of the cellulose insulation, which had been a concern; however further testing over time is required to verify this. It is clear that openings are a clear source of thermal weakness, and thermal weakness at door and window frames were noted in all of the properties.

Thermal weakness at openings seems to be endemic across the sector. Whilst heat losses at these points are defined as ‘normal’ they identify a need to improve detailing, construction, and specification of external doors to reduce this thermal weakness.

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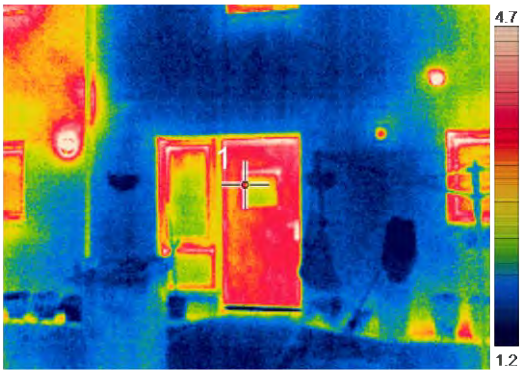


IR_1038.JPG

MEASUREMENTS	°C
Spot 1	3.0

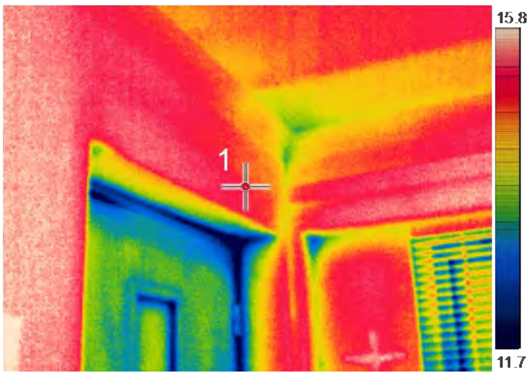
2014/01/31 12:42:51

DC_1039.JPG

PARAMETERS	
Emissivity	0.97
Refl. temp.	20.00 °C
Distance	12.00 m
Relative humidity	79 %
Atmospheric temperature	4.00 °C
Transmission	0.90

Figure 25: Rear elevation of BA1.

2014/01/31 12:43:58



IR_1048.JPG

MEASUREMENTS	°C
Spot 1	14.9

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DC_1049.JPG

PARAMETERS	
Emissivity	0.96
Refl. temp.	20.00 °C
Distance	2.00 m
Relative humidity	40 %
Atmospheric temperature	22.00 °C
Transmission	0.90

Figure 26: Thermal weakness at BA1 doors and windows.

Insulation at wall head/ eaves conditions and around perimeters generally was found to be problematic due to the practical difficulty of installing insulation over the wallplate. This was found to be an issue in all three test houses and prompted a review of an industry wide 'standard' detail.

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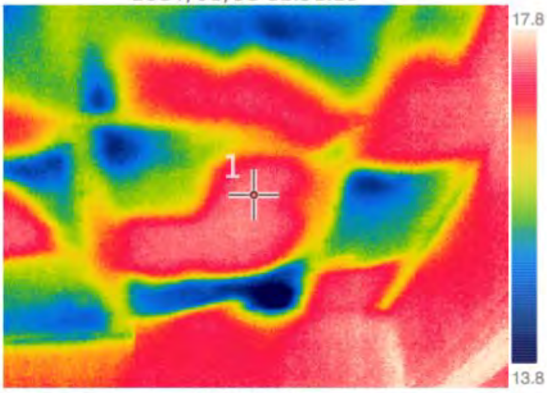

IR_1092.JPG

MEASUREMENTS	°C
Spot 1	17.5

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DC_1093.JPG

PARAMETERS	
Emissivity	0.96
Refl. temp.	20.00 °C
Distance	2.00 m
Relative humidity	40 %
Atmospheric temperature	22.00 °C
Transmission	0.90

Figure 27: Missing insulation at ceiling.

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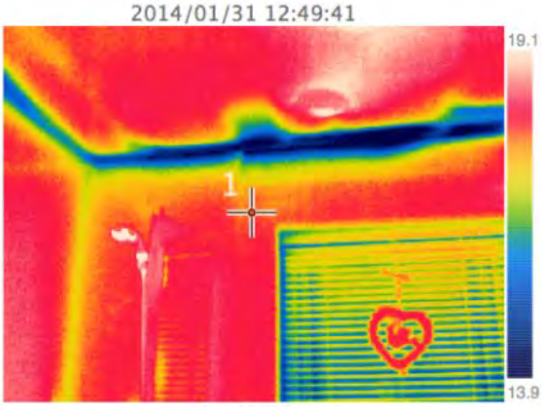

IR_1078.JPG

MEASUREMENTS	°C
Spot 1	17.8

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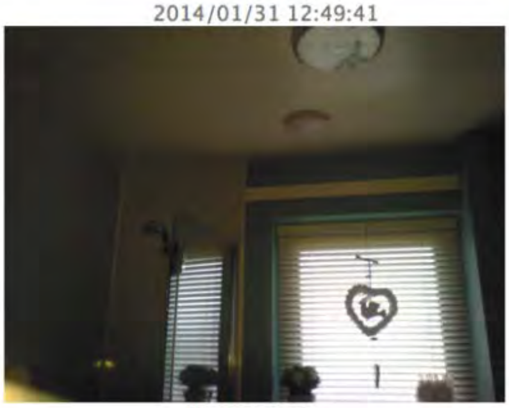


DC_1079.JPG

PARAMETERS	
Emissivity	0.96
Refl. temp.	20.00 °C
Distance	2.00 m
Relative humidity	40 %
Atmospheric temperature	22.00 °C
Transmission	0.90

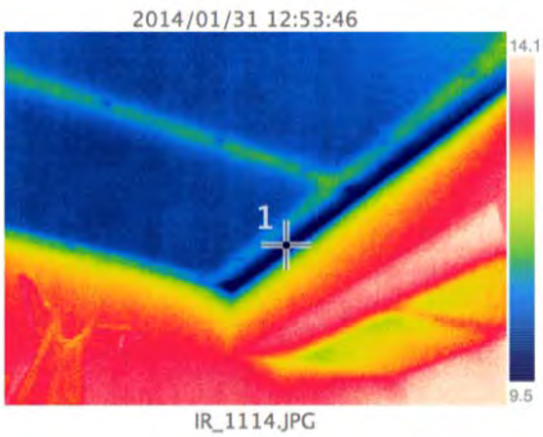
Figure 28: Missing insulation at eaves.

MEASUREMENTS	°C
Spot 1	14.9

PARAMETERS	
Emissivity	0.96
Refl. temp.	20.00 °C
Distance	3.00 m
Relative humidity	40 %
Atmospheric temperature	22.00 °C
Transmission	0.90

Figure 29: Missing insulation at eaves.

A specific issue was observed in the ceiling of the dressing room at BA1. In this case it would appear that insulation had been omitted. The very shallow pitch of the roof here is such that insulation cannot easily be installed from within the roofspace and would need to be placed during construction prior to the installation of linings.



MEASUREMENTS	°C
Spot 1	9.5

PARAMETERS	
Emissivity	0.96
Refl. temp.	20.00 °C
Distance	2.00 m
Relative humidity	40 %
Atmospheric temperature	22.00 °C
Transmission	0.90

Figure 30: Missing insulation in BA1 dressing room.

The ceilings in all the dressing rooms were inspected by the contractor and their report found that insulation had been omitted in BB1, this was the only one that was defective. As a result of this survey, remedial work was undertaken to fit insulation in the ceiling of the affected room.

The issue of bridging at the eaves has been addressed in this project. The original eaves detail is shown in Figure 31. It would appear that the insulation was not installed as shown and/or that air is managing to bypass the insulation and cool the surfaces of the ceiling plasterboard leading to greater heat loss, higher fuel bills and an increased risk of condensation forming on these surfaces.

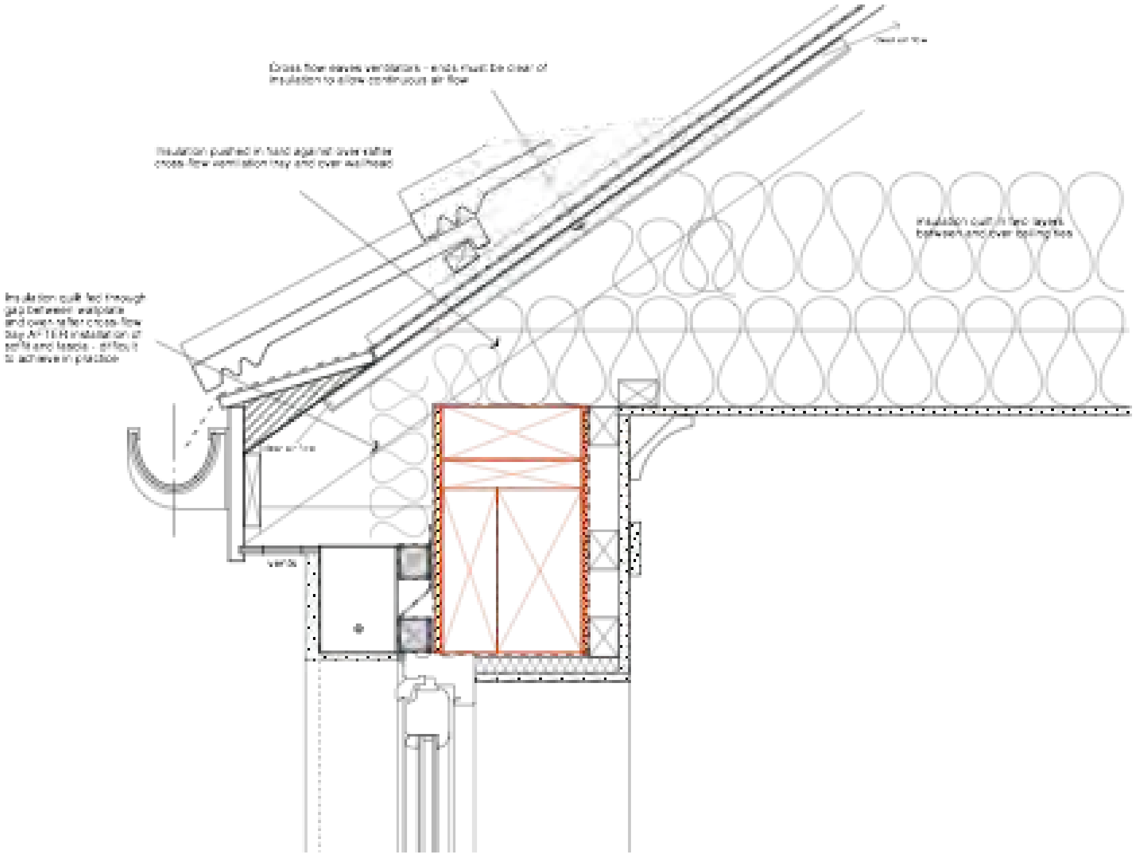


Figure 31: Original BA1 standard eaves detail

Analysis of this problem raised the practical difficulty of placing insulation in roof spaces, particularly at eaves. This has now been addressed by the architects who have amended their standard details and the revised detail is shown in Figure 32.

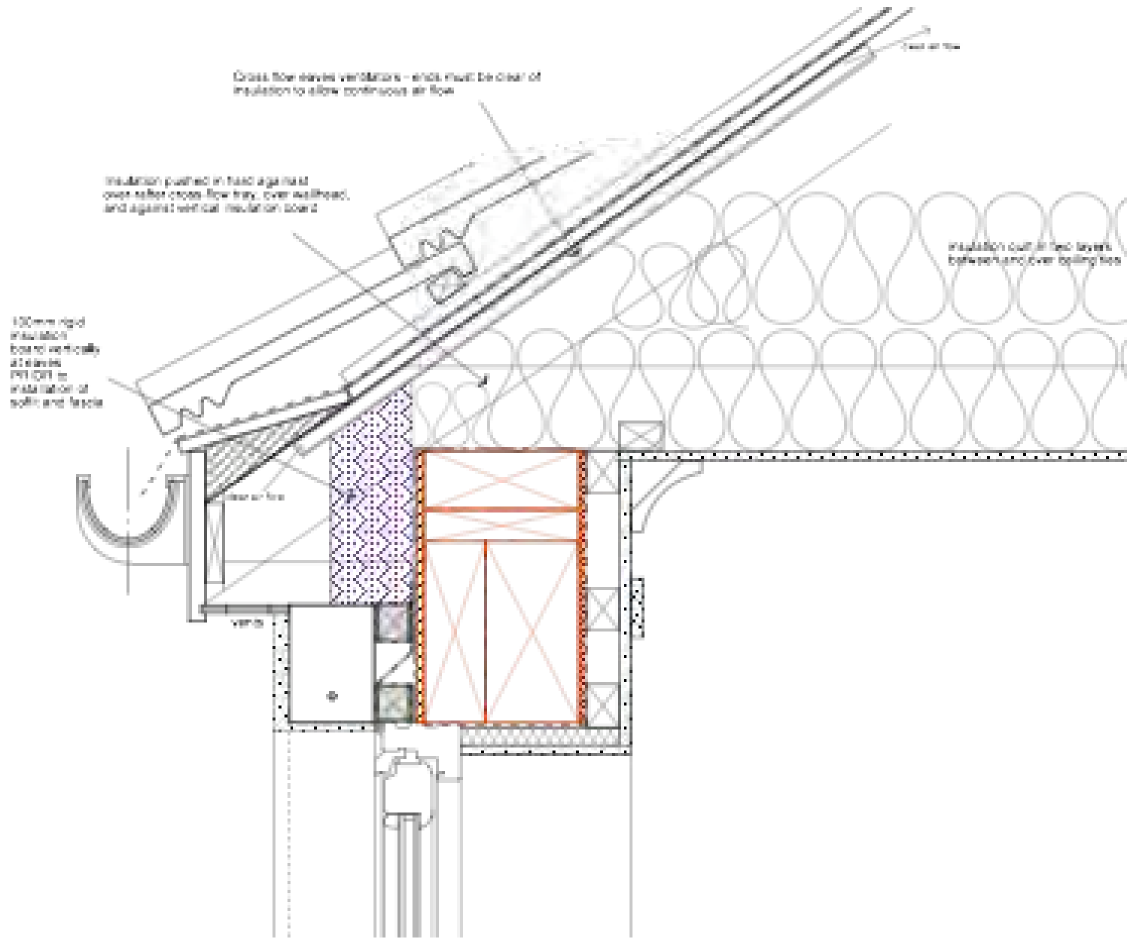


Figure 32: Revised eaves detail

This shows the specification of a rigid board beyond the head binder. This allows the insulation to be pushed up against the board with a view to achieving a continuous insulation layer, rather than the industry-wide "standard" timber frame detail, which relies upon the operatives pushing the quilt over the wall plate, which has proved to be impractical on site. This detail is now being used on all future projects

3.3. Air Tightness testing

Two sets of airtightness tests were conducted; the first on 19 October 2012 and the second on 30 July 2014 and the results of these are contained in Appendix C2. The results of these tests are summarised below:

	Oct 2012	July 2014	% difference
	$m^3/h/m^2$	$m^3/h/m^2$	
BA1	7.273	5.32	73%
BB1	9.109	6.65	73%

	Oct 2012	July 2014	% difference
BC1	7.287	4.63	64%

Table 7: Summary air tightness testing results

The measured values are well within the Scottish Building Regulations requirement of 10 $m^3/h/m^2$, however a figure of 4.63 $m^3/h/m^2$ would take air permeability below a threshold of 5 $m^3/h/m^2$ below which guidance on the standards recommends the use of mechanical ventilation systems (but is above the level at which MVHR would be effective).

The relatively good performance of the timber frame without a vapour barrier is also an important finding for this project. This demonstrates that good levels of airtightness can be achieved without vapour barriers. The airtightness of the block construction is poorer, however, in all cases the major points of air leakage occurred at service penetrations in the kitchens and bathrooms, which raises a question about the relative airtightness of particular rooms and spaces in relation to maintaining good indoor air quality; this is discussed further in Section 7.

Of further note is that the 2014 tests have produced higher levels of airtightness than the initial tests. There had been a general assumption that levels would have deteriorated over time. However, some remedial measures had been undertaken in the properties, including improvements in insulation, which will have improved matters.

3.4. Breathing wall

A key component of the environmental strategy and resultant construction is the use of a vapour permeable construction of the walls in the timber framed houses. This construction involves replacing the conventional – vapour impermeable – outer sheathing with a vapour permeable sheathing (‘Panelvent’, a medium density fibreboard), which allows day-to-day levels of moisture in the construction to escape safely. The permeable outer sheathing is complemented with a relatively vapour-tight internal sheathing (‘Paneline’, a type of hardboard) and hygroscopic insulation that in this case is recycled cellulose fibres known as ‘Warmcel’. To add further resistance to vapour movement through the wall (without preventing it altogether) a layer of BSK 410 Building Paper was specified inside the Paneline. The construction detail is shown below.

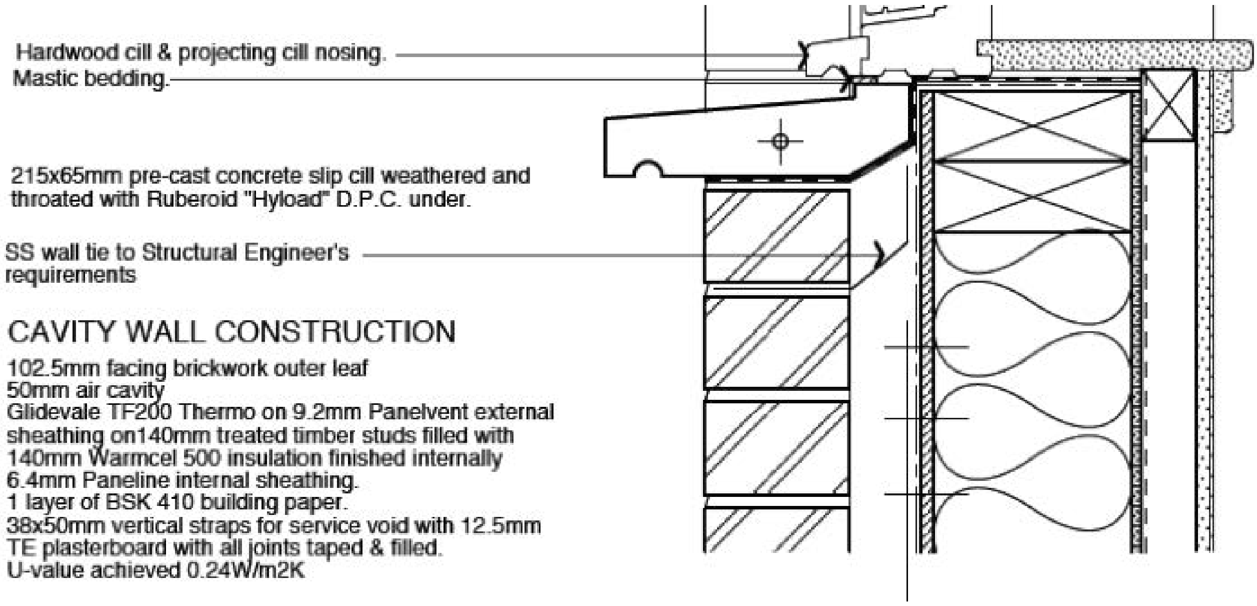


Figure 33: Original external wall construction detail

The table below is taken from the original U-value and Condensation Risk Analysis, showing the vapour resistivity and resistance of the various components of the wall construction.

Construction	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m^2K/W)	Vapour Resistivity (MNs/gm)	Vapour Resistance (MNs/g)
Outside surface resistance	-	-	0.040	-	-
Brick, Medium wt external	102.5	0.752	0.136	0.00	0.00
Ventilated Cavity	50.0	-	0.000	-	0.00
Glidevale TF200 Thermo	0.5	0.001	0.670	1000.00	0.50
Panelvent 9.2mm.	9.2	0.080	0.115	159.78	1.47
Warmcel® 500 (15% Timber Frame)	140.0	0.040	3.500	9.30	1.30
Paneline 6.4mm	6.4	0.080	0.080	159.84	1.02
BSK 410 - Building Paper (VCL)	-	-	-	-	42.00
Service Cavity	38.0	-		0.100	-	0.00
Plasterboard	12.5	0.167	0.075	45.00	0.56
Inside surface resistance	-	-	0.130	-	-

Table 8: Original U-Value and condensation risk analysis

The graph below displays the results of the condensation risk analysis, which indicates no risk of condensation within the construction. It is possible to see however that this is largely related to the large drop in vapour pressure across the vapour control layer, the BSK 410 Building Paper (layer 8 in the diagram).

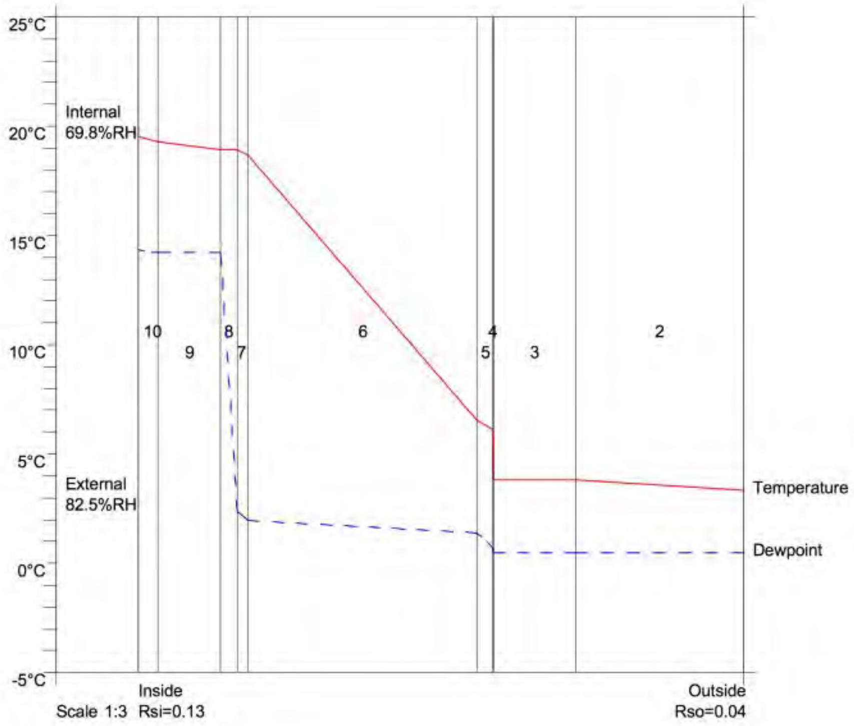


Figure 34: Original condensation risk analysis

An issue that was encountered on site was that the Contractors did not install the BSK Building Paper on the inside of the wall, but instead another layer of the external breather membrane, the Glidevale Protect 'TF200 Thermo'. In theory that means that there is insufficient resistance to vapour entering the construction which could lead to excess moisture build-up in the wall and increased risk of decay.

In the first instance, the Architects commissioned another condensation risk analysis with the installed construction noted, shown in Table 9.

Construction	Thickness (mm)	Thermal Conductivity (W/mK)	Thermal Resistance (m²K/W)	Vapour Resistivity (MNs/gm)	Vapour Resistance (MNs/g)
Outside surface resistance	-	-	0.040	-	-
Brick, Medium wt external	102.5	0.752	0.136	0.00	0.00
Ventilated Cavity	50.0	-	0.770	-	0.00
Glidevale TF200 Thermo	0.5	0.000	0.000	1000.00	0.50
Panelvent 9.2mm	9.2	0.080	0.115	159.78	1.47
Warmcel® 500 (15% Timber Frame)	140.0	0.040	3.500	9.30	1.30
Paneline 6.4mm	6.4	0.080	0.080	159.84	1.02
Glidevale TF200 Thermo	0.5	0.000	0.000	1000.00	0.50
Service Cavity	25.0	-	0.670	-	0.00
Plasterboard	12.5	0.167	0.075	45.00	0.56
Inside surface resistance	-	-	0.130	-	-

Table 9: Revised U-value and condensation risk analysis

A revised graph (Figure 35) was produced which continued to show no risk of condensation within the construction. However, to be on safe side, the Architect instructed the Contractor to provide a remedy and it was agreed that the Contractor would coat the plasterboard internally with a sealant to provide additional resistance to vapour from the inside.

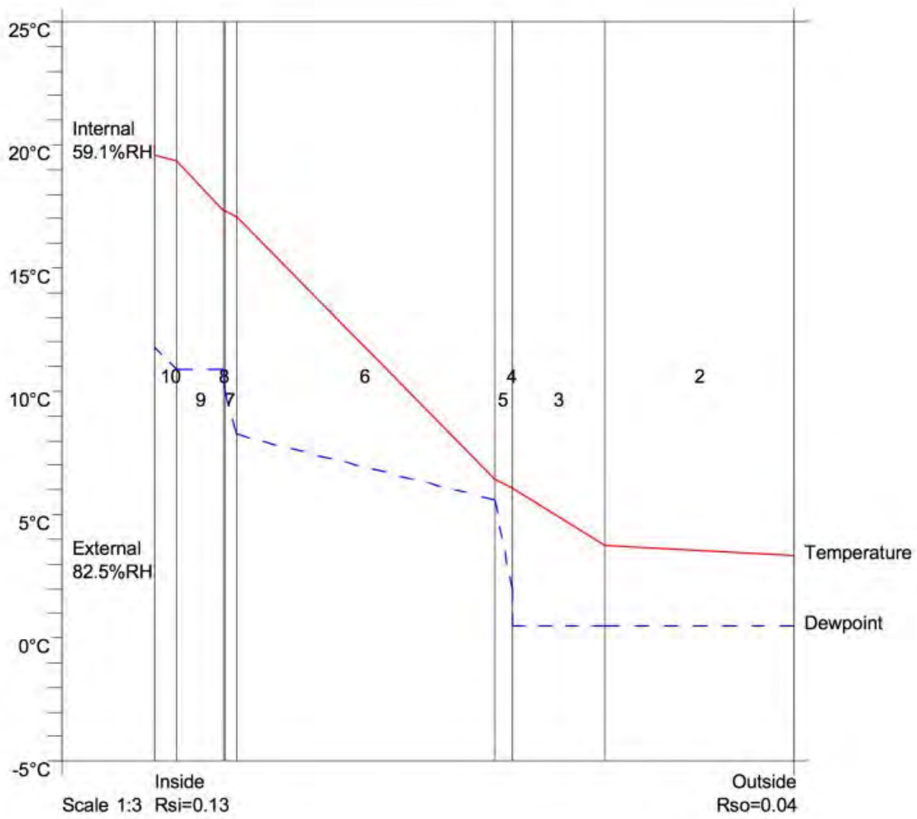


Figure 35: Revised condensation risk analysis

The revised instruction was as follows: "18.1.1 In accordance with the contractor's proposals to achieve the requisite level of the vapour barrier following the deviation from the specified material on site, external walls of timber frame construction to receive two coats of Gyproc Drywall Sealer. Note:- this work is to be at no cost to the contract. This is solely a record of the incorporation of the contractor's proposal in respect of the vapour barrier."

The interstitial conditions have been monitored over the course of the project and Figure 36 and Figure 37 show conditions in the wall and the adjacent living room over a typical month (February 2013). It is apparent that, as might be expected, temperatures are lower within the wall, and humidity levels are higher; however at no point has dew point been reached.

Comparing the living room and interstitial RH demonstrates that interstitial moisture levels are a function of the internal conditions. Spikes in moisture levels are reflected in the interstitial conditions - of interest is that RH levels decline slowly after peak conditions, indicating some hygroscopic buffering effect. In this example, humidity spikes are the result of social events held in the room.

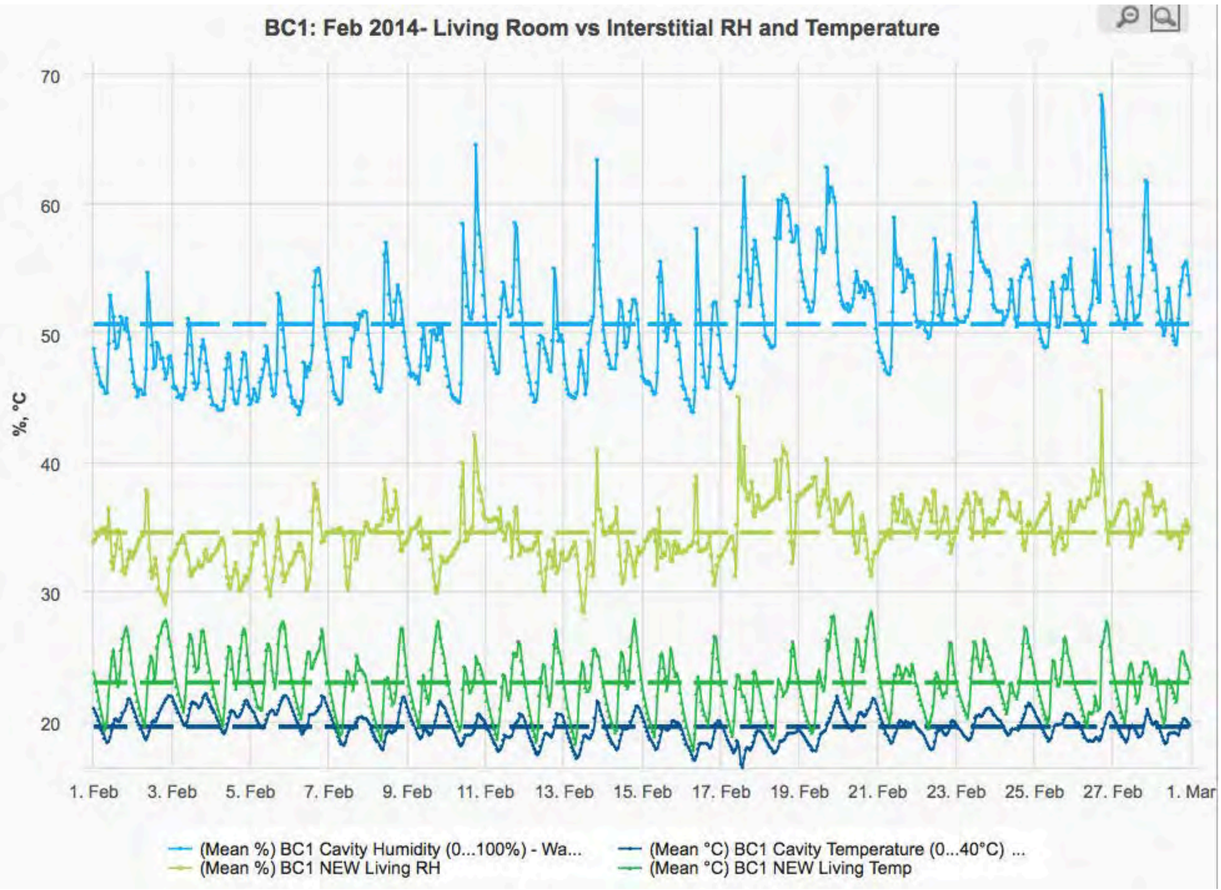


Figure 36: BC1, February 2014. Living room RH and temperature vs interstitial RH and temperature

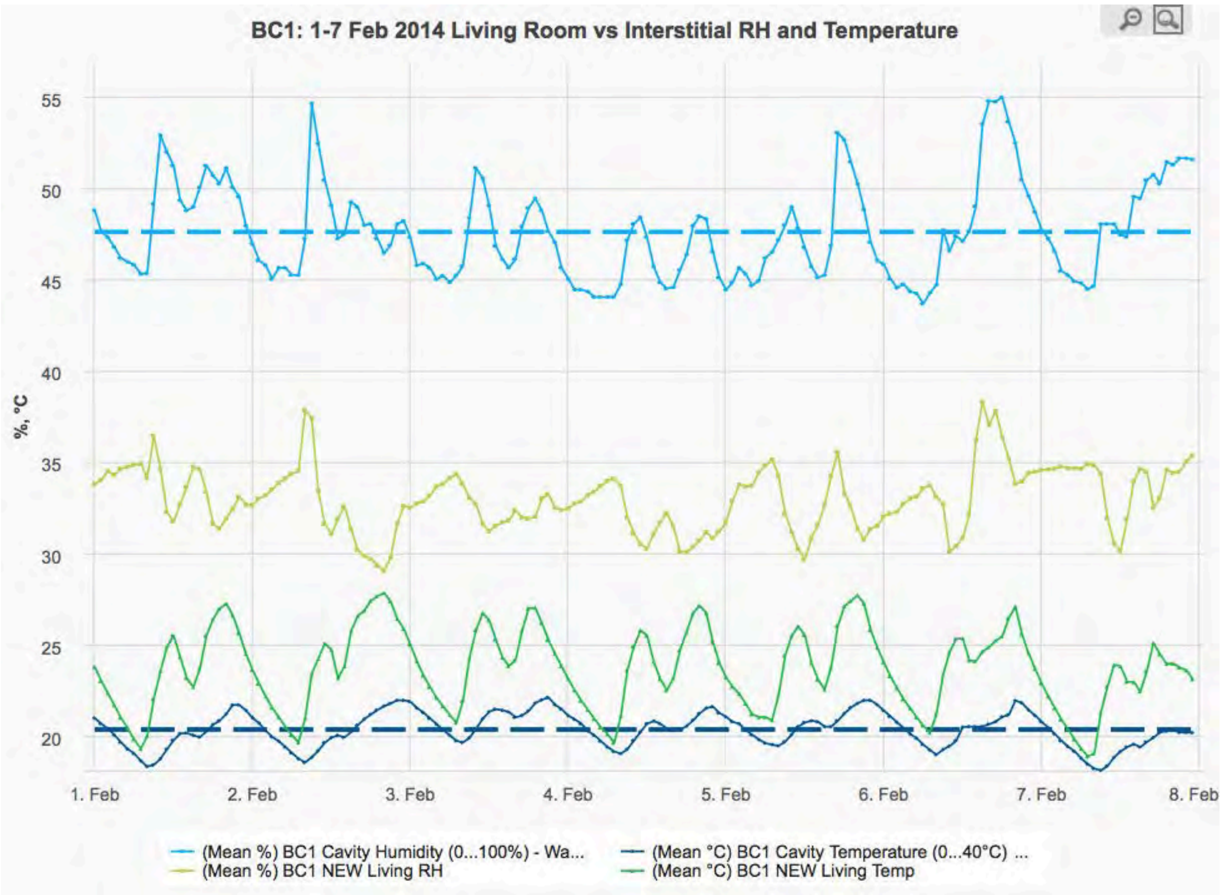


Figure 37: BC1, 1 – 7 February 2014. Living room RH and temperature vs interstitial RH and temperature

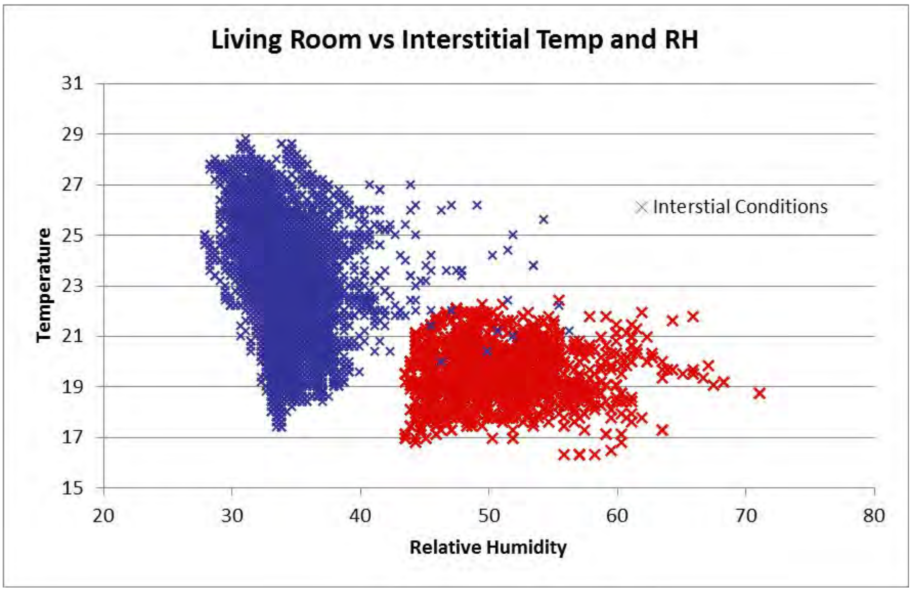


Figure 38: BC1, February 2014, comparison of living room RH and temperature vs interstitial RH and temperature.

The scatter plot of temperature and RH in the living room and wall is shown in Figure 38. As can be seen the temperature range is lower, and RH is generally higher but would appear to be no cause for concern. Whether this construction is having beneficial effects on the internal conditions is discussed in Section 7.

3.5. Conclusions and key findings for this section

- In general the fabric performance of the dwellings was good and exceeded the design values, although the design values tended toward backstop values. However particular weakness were identified, including missing and misplaced insulation in the roofs, and elements of thermal bridging in construction. Some of this may be ascribed to workmanship, but the issue of 'buildability' - the ability for a designed detail to actually be physically constructed - was also observed.

- Measured U-values were poorer than anticipated with the exception of the timber frame wall. The exception of the ceiling construction was clear, but revealed the problems associated with elements of non-standard construction

- At this stage there was no evidence of 'slumping' in the cellulose insulation, nor does the intermediate floor junction provide a significant cold bridge, however, this does represent another area of 'non-standard' construction which will perform less well than a designed wall build-up.

- Difficulty with access has meant that follow up testing of replaced insulation has not been possible within the timescale of the project. A testing regime for various elements, including U-value and thermography might be more beneficial prior to occupancy, as the tests would be less restricted and remedial measures could be re-tested.

- Thermographic images found the construction fabric for both dwellings to be generally good quality with few obvious or unexpected weak spots identified.

- The study was able to identify clear deficiencies in the placement of insulation, particularly in the roofs. This has led to remedial works, and the amendment of a standard detail to avoid this problem.

- As a general observation, the proportion of construction which is 'normal' (i.e. standard build-up_ as opposed to 'special' (i.e. at corners, junctions with opening, floors, roofs etc.) is quite small and attention to the design of junctions is therefore critical.

- Thermal weaknesses at openings, due to frame placement and the nature of the frames themselves are defined as ‘normal’. Whilst overall heat loss from these elements may be small, they may be avoidable with more thorough detailing.

- The measured U-value of the block wall was much poorer than expected. Whilst some caution should be exercised in respect of a single in-situ test, this may be contributing to the higher energy consumption (with lower demand temperatures) seen in BB1.

- The general levels of airtightness are good, well within the backstop requirements. The exact causes for increases in airtightness are not known. Certainly some remedial measures such as insulation may have improved matters, but not to the extent seen here. This does raise a question about the veracity of testing - the two tests were undertaken by a different contractor, but both were conducted to ATTMA standards.

- Weaknesses in air permeability due to service penetrations were found in all properties. This may suggest that greater attention should be paid to these areas in terms of improving airtightness requirements, rather than forms of external wall and roof construction.

- The relatively ‘leakiness’ of kitchens and bathrooms calls into question the general airtightness of particular rooms in the dwelling - which may therefore be much tighter - and this question was raised in parallel research involving these houses, which looked at ventilation rates in bedrooms, discussed in Section 7.

- There had been some speculation that drying of the timber might lead to shrinking and cracking, but the evidence suggests that there may be some expansion and tightening. It is possible to envisage a situation where a low wood moisture content in a factory condition would change over time on a building on site. This could be examined in future projects by testing the wood moisture equivalent of the frame and other materials in the factory and over time on site.

- From the monitoring to date there does not appear to be any significant problems with interstitial moisture in the vapour permeable construction. In future projects it would be beneficial to place interstitial sensors during construction to allow some degree of condition monitoring in areas where some risk might be anticipated.

4. Key findings from the design and delivery team walkthrough

4.1 Interview Findings

Interviews were conducted with the project's client and architects, the transcripts of these are in Appendix J. As the dwellings had been occupied for some time, and a number of visits made to the houses for equipment installation and client interviews, a walk-through was not undertaken formally. However, both the client and the architect had attended on site during these processes and made observations on the project. Key personnel from the contractor were also invited for interview, but both the site foreman and contract manager have moved to other posts. This is common situation in construction projects, where team members, who may have excellent insight at the point of delivery, leave the organisation. Not only does this mean that organisations have little or no institutional memory, its also makes tracing design and contract decision back 'upstream' very difficult. This was certainly the case for key personnel on site such as the plumbers who fitted the Solar Thermal systems.

It was clear that as well as important technical agendas, including 'designing for varying needs' and a low energy/affordability ambition, there were significant qualitative requirements for the design, including: a nice living environment; safe and protected external spaces; and good space standards.

There was no specific target for energy set, although an informal goal was 20% better than the current Scottish Building Regulations (2009) and, simply to get as low as possible for the overall budget. The Board of HSHA has mandated that Solar Thermal systems were to be included on all suitable developments, paid for from HSHA, with all benefits going to the residents. There was no additional funding available for energy savings measures. Health was a key design driver, which led to the use of vapour permeable construction to reduce RH levels.

Robert Potter and Partners (RPP) were appointed on a traditional basis as architect and contract administrator. They have on-going projects with HSHA, and a good working relationship exists between the client and architect, this has extended to this BPE project in which both the client and architect have been actively involved.

A Quantity Surveyor and Structural Engineer were also appointed. There was no specific M&E engineer, these works being done as a performance specification by RPP and undertaken as a Contractor Design by the main contractor Ashleigh; plumbing and electrical works were sub-contracted. The Mark Group designed, installed and arranged grants for the solar thermal system and RPP ensured that Mark Group were responsible for all aspects due to a previous project in which there were problems due to sub-contract work. None of the contractors or sub-contractors were available to participate in the BPE project.

There were very few design changes during the course of the contract, the only one of significance being the use of TF200 breather membrane (discussed in the construction review) and was described as a smooth process. Some issues have arisen in the course of the project, particularly with the solar thermal system in BA1, in which a defect was identified prior to the BPE project commencing. It had always been the intention to locate the solar thermal tanks in the attic space. The implications of this are described later.

The architect did not have any specific role in the handover process for this project, but this is now recognised as an issue and use is being made of itect did not have on both this project and future projects. Whilst there are some HSHA handover processes, these were not specific to the houses. The contractor was required to provide a welcome pack but this is a generalised collection of various manuals. Issues with tenants understanding of the programmers were identified, which has resulted in repairs calls. MEARU undertook research on behalf of Scottish Government Building Standard Directorate in 2011, which developed the concept of Quick Start guides [1], and this research is being used to produce occupant guidance on future projects. A further issue identified is that the maintenance contract is with Scottish Gas who were sending out different operatives for the boiler and solar thermal system, neither of whom adequately understood the systems.

4.2 Lessons learned

In terms of lessons learned, in general the houses are used as expected and designed, although there are some anomalies. For example not all of the residents are retired and there are some instances when (older) children visit and stay in the homes. The courtyard has a good feel to it and works as a social space. The landscaping was taken out of the main contract to protect it, a lesson learnt from previous projects.

Section 7 discusses several problems associated with the Solar Thermal systems, including commissioning and maintenance issues and the reduction in panel size on BA1. Both the architect and client had experienced problems with active solar thermal systems before, and problems with post completion understanding of the system and its maintenance were identified.

There are on-going issues and discussions about the solar thermal system and both the architect and client were concerned about the complexity and knowledge base of sub-

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[1] http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards/publications/pubresearch/researchsustainability/reslcarb

contractors especially for maintenance. The systems have had to be checked several times after debris was found in the system at BA1 and there has been a leak in BC1 which resulted in damage to the ceiling.

The use of Solar Thermal systems is now a requirement by the board of HSHA and the monitoring also showed that the output - in a fully functional system - could meet design expectations. A larger question arises about the appropriateness and benefits of the system in houses with this type of tenure and relatively low hot water use, and the relative costs for maintenance and repair of such systems, particularly where this requires different operatives.

4.3 Conclusions and key findings for this section

- The project has benefitted from a good working relationship between the architect and client. The aspirations were for a balance of targets, to include both quantitative (energy use, barrier free) and qualitative (good space, healthily environments).

- Both the architect and client were familiar with Building Performance issues prior to the project and the client in particular has been proactive in trying to develop BPE and has insights from previous monitoring undertaken by MEARU.

- The use of a fabric-first approach has been beneficial, especially in the light of the difficulties with the solar thermal system, but it felt that these are overshadowed in regulation and SAP by active measures.

- There would appear to be insufficient knowledge and expertise within the construction industry for active systems. This is ironic given that Solar Thermal is one of the most mature renewable technologies, but is perhaps a function of specialist systems becoming mainstream.

- The heating system was a contractor-designed element to meet specified performance criteria. There is only an informal post-contract debrief process, and a more formal process may allow lessons learned during the build process to be captured and more widely disseminated.

- There can be a lack of control over fragmented and detailed elements, for example the choice of controls and sub-contracted elements. In current projects RPP have more detailed performance requirements and specifications for controls and active elements.

- Both the architect and client are content that the vapour permeable construction has not led to any clear risk of interstitial moisture. Its potential benefits are discussed in Section 7.

- Better handover processes are required. A lack of adequate understanding of systems and controls led to both unnecessary maintenance call-outs and increased energy consumption. Future projects intend to make use of simpler Quickstart guides rather than large documents, but work is also needed to ensure that HSHA staff are adequately briefed about systems and technologies in the houses.

- Guides need adequate information to be gathered at design and construction phases to produce as-built information. A more informed handover process is needed, which may need to be staged, including both pre-occupation knowledge and follow up visits.

- A system to capture insights and knowledge from key personal on site could be valuable, both in terms of a particular project, but also for informing future projects.

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

5.1. Overall Findings

A BUS Questionnaire was undertaken in November 2013, with MEARU researchers going door-to-door, with most returns being made by collection on 28th November 2013. The reporting from the study is contained in Appendix D. In total 9 returns were received (60%). The study was undertaken across the development. It should be noted that the responses are from a variety of house types.

Full analysis of this process is available via:

http://portal.busmethodology.org.uk/Upload/Analysis/ichljgnr.hgv/index.html [Accessed: 11/12/14]

Copies of the supporting documentation are provided in Appendix D: BUS.

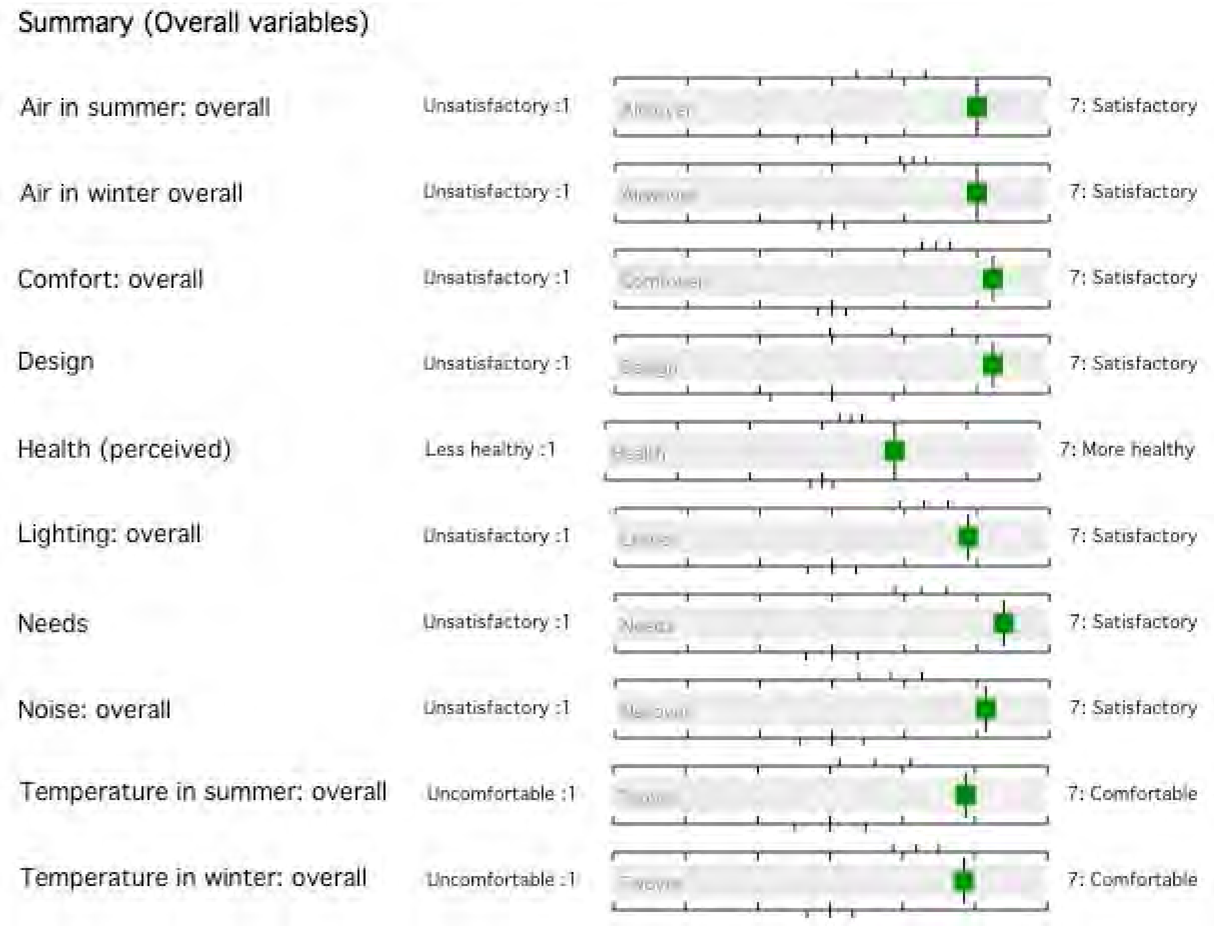


Figure 39: Summary of overall BUS quantitative variables.

The summary of the analysis shows that against the main variables the perception of the development at Barrhead is tending towards the more positive side of the analysis spectrum. It should be noted, however, that what appears positive in this output (to the right of the scale) is actually a 'Satisfactory' condition and, therefore, could be seen to be neutral rather than positive. The context of the slightly lower Health perception is that this is a development for older residents and health issues are therefore likely to be more relevant.

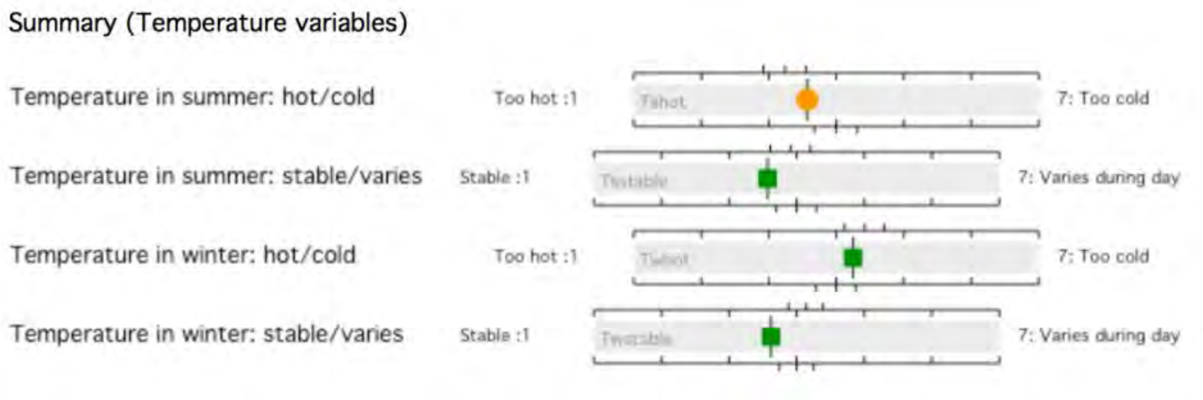


Figure 40: BUS temperature survey.

The temperature profile only identifies a moderate issue relative to some overheating in the summer; temperatures are discussed in more detail in Section 7. However, given the context of older occupants and continuous occupation, temperatures at reasonable comfort levels were observed throughout the monitoring period, but periods of high temperatures are apparent during summer months.

The suggestion that there is no significant under-heating is a positive outcome for the project given the housing demography and the fact the fuel poverty and winter heating are very real problems in the Scottish context.

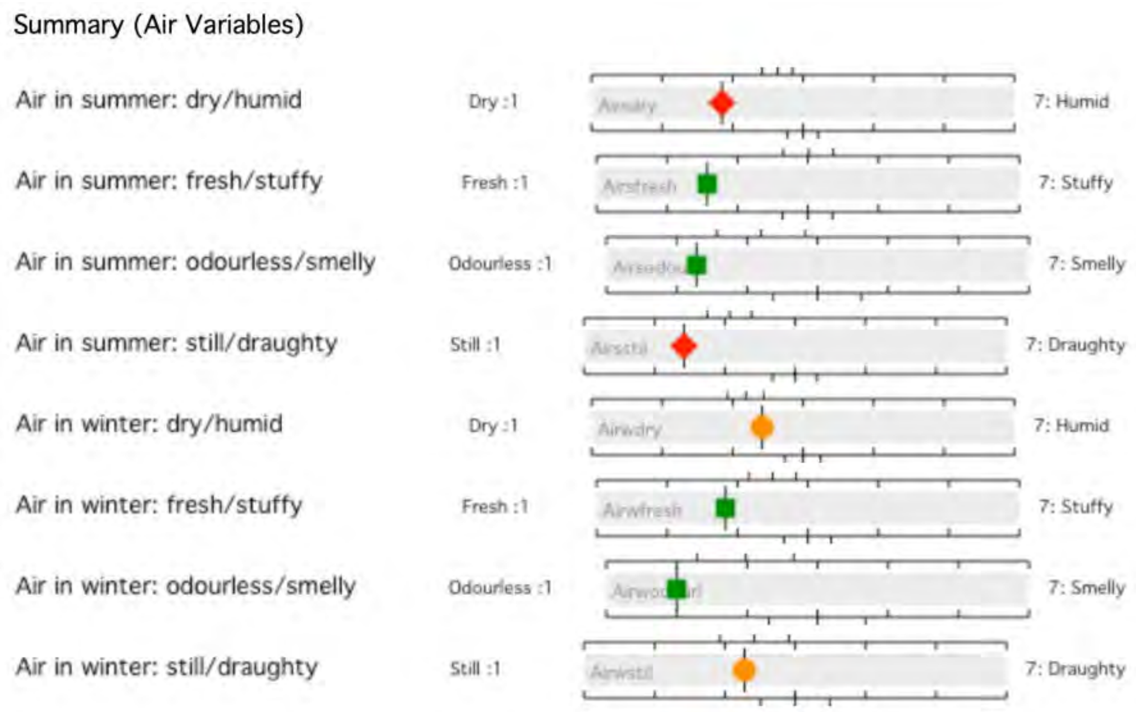


Figure 41: BUS air quality summary.

The most significant outcomes relative to air quality relate to perceived moisture content and air movement both in summer. While the air being still is recorded as a negative outcome it was interesting to note during the survey process that some residents identified with this parameter as a positive condition; i.e. draughty is a bad state therefore the semantic opposite (dry) is positive. This perception may have skewed this result to appear negative when the residents were actually reporting something that they perceived to be a good aspect of performance.

Notwithstanding this, alongside the slight perception of summer overheating it would seem that in this season comfort conditions are poorer than during the rest of the year.

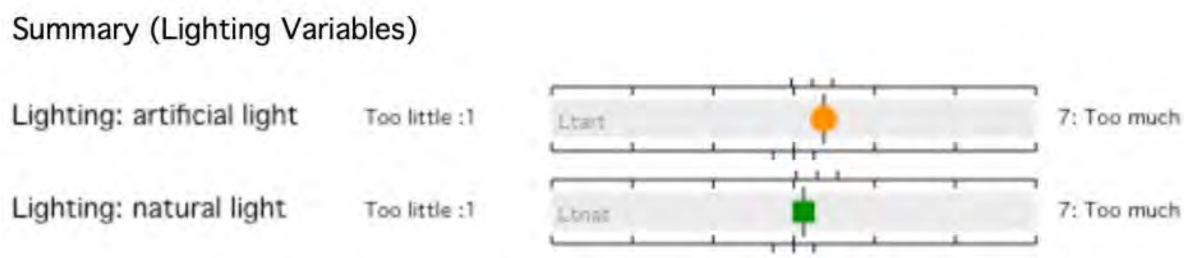


Figure 42: BUS lighting summary.

The outcome for natural light is clearly a positive one and suggests that window openings and sizes have been well considered to the needs of the occupants, this is relevant to the overall aim of the design which sought to maximise natural lighting and sunlight. This is a particularly important condition as access to natural light is of great importance to those, such as the elderly, who spend a lot of time indoors and potentially lead largely sedentary lifestyles. It is unclear from the analysis as to what the slight excess of artificial light actually relates to, especially as there is no recorded commentary to support this.

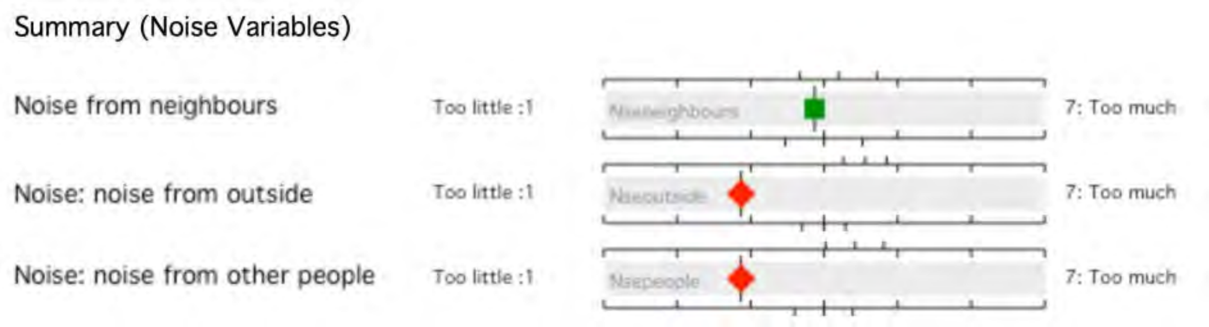


Figure 43: BUS noise summary.

When undertaking the survey in relation to noise it was clear that the respondents struggled with the concept of there being too little noise particularly as this is deemed to be a negative condition. Several residents reported that the houses were well acoustically separated from the exterior but saw this as a positive aspect and as such were confused by the phrasing of this question. However an issue which is emerging is that with higher levels of insulation, air-tightness and double glazing, external noise is reducing. Whilst this may be seen as a positive outcome, in the context of housing for older people, there may be implications for social isolation and in other housing types, perception of internal noise.

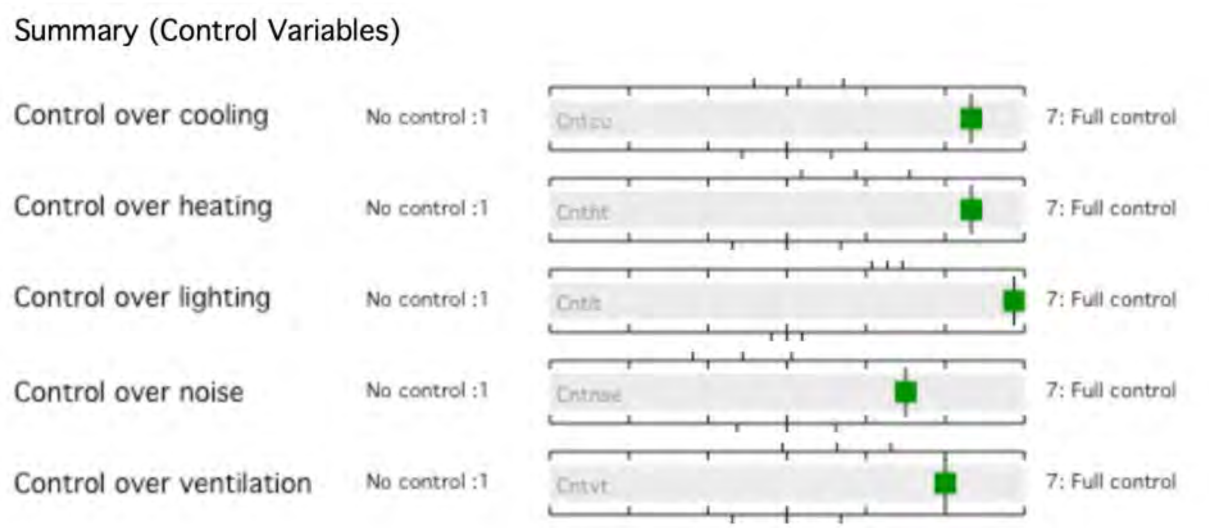


Figure 44: BUS control summary.

The majority of residents reported that they could exercise very good levels of control over all aspects of the dwelling. An analysis of the systems and controls used in the development shows that this has not always been the case and suggests that there may be a disconnection between the residents' perception of correctly commanding systems and the reality of using them in an optimised manner. This suggests a place for improved education and providing the occupants with a better understanding of how all systems work well and how performance can be maximised.

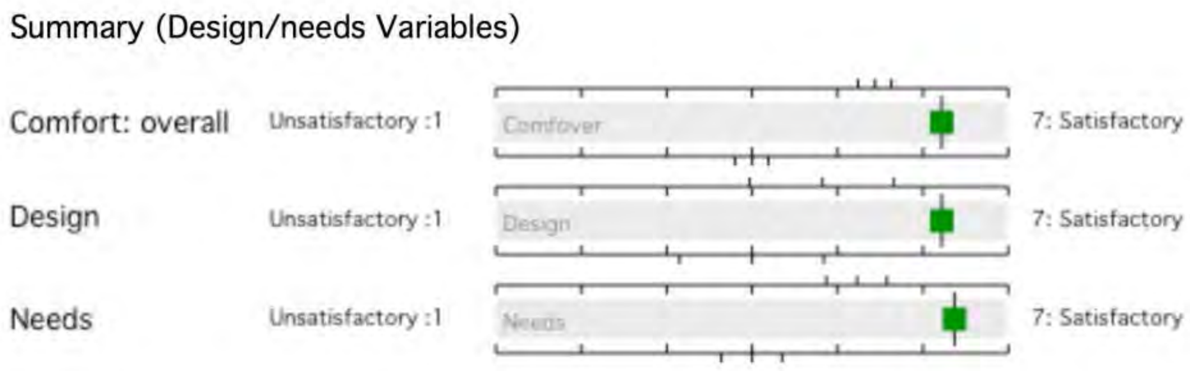


Figure 45: BUS design summary.

The summary for overall design presents a positive outcome for the design team and Housing Association but again it is slightly confusing as the positive end of the scale is actually representative of a neutral condition.

5.2. Semi-structured Interviews with Occupants

A better understanding of occupants' perceptions and insights from the project were gained through a series of semi-structured interviews, and surveys gathering information about occupancy habits and preferences. The complete versions of these are contained in Appendix J.

Semi-structured interviews took place with the occupants throughout the day of 13th May 2013 at each of the participating properties. These interviews were recorded and the key elements are summarised in bullet point form for each property. This section aims to combine information from each of the properties to review the complaints and praises of the development to determine if there are common themes occurring. Each dwelling is normally occupied during the day by two adults in their retirement years.

Demonstration of systems

The occupants of each of the dwellings revealed they had not been shown round their property prior to, or on handover of the building to them. Although, one occupant had received a tour of the show house with the same floor plan as their home while their house was still under construction. None of the six tenants had received a system demonstration, one occupant described that “we had to find it out for ourselves...we just worked out what worked best for us by trial and error ” and another added “we ended up getting someone in to set the heating to our desired settings”. One occupant highlighted that they moved in in February and “the installer of the heating system installer had been organised to come to provide a heating demonstration but the weather was bad and they didn’t turn up – it was snowing quite heavily at the time.” But no re-arrangement of appointment was made by the housing association.

User Manuals

All households had been provided with “big” manuals for operation of the building and setting of the systems, however they all had reported them to be too technical and “only useful to an engineer”. But all interviewees responded differently when asked what would have been useful to them. One would prefer a “simple booklet with straightforward guidance” another requires handholding “someone to show how it all worked” and the final occupant required information “to show the solar heating” mechanics. The user manuals were too technical and incomplete.

Storage

One occupant commented that they were required to dispose of many of their belongings before moving in, but even when doing so the couple had found that the property was still lacking in storage for items such as a golf trolley, golf bag and clubs and fishing equipment. While another dwelling occupant commented on the lack of space in the kitchen for a tumble dryer, which they have needed to locate in the second bedroom. The third set of occupants in the two-storey dwelling were delighted with the storage space, especially the walk-in wardrobe off the master bedroom.

Problems or Issues

There were many issues and problems discussed, one of the households termed their home “the Friday afternoon house, you know the builders were in a hurry to get away on the Friday afternoon”. But a common comment was in relation to the Solar Thermal panels. There were reports that there wasn’t any power to the installation for the first few months and despite this all households were unsure as to whether they were operating.

A further issue was that a blockage in the hot water pipework was found to be caused by “polystyrene [that] looked as though it was from packaging material... a good handful came out” of the pipework. This caused low hot water temperatures and hot water had to be heated by the gas boiler or electrical immerser for two years (prior to this project). The delay in identifying the problem was due to the lack of certification by the gas engineer who came to inspect the boiler. It was found that an engineer trained in gas boiler systems was not trained to inspect Solar Thermal systems and vice versa. It took many visits and two years for two engineers to be sent to the property.

The occupants of a further property have had a leak from pipework in their solar thermal system which has caused considerable damage to the living room ceiling. They point out that the hot water calorifier is located in the loft space on a plinth. The location of this has made a large area of the loft space inaccessible, as they found when the leak occurred and were unable to access the area in the loft to mop away the water.

The occupants of the third property claim that there is one Solar Thermal panel heating their hot water, whilst every other dwelling has two panels of the same size. They are concerned that their one panel is not adequately sized for their hot water needs.

Another problem identified was a leaking valve, spraying water behind a shower wall and a separate occurrence of a nail through plastic pipes. On both occasions the shower tray and all wall finishes needed to be stripped off to repair the leaks. The level of workmanship for the repairs has not been satisfactory to the residents.

In the flatted dwelling the hall radiator has been placed near the front door in the vestibule, the room thermostat for the heating system is in the hall on the opposite side of the vestibule door. The occupants have found that the vestibule door needs to be wedged open when operating the heating system otherwise the temperature in the hall does not reach a high enough temperature to shut off the heating system, resulting in warm rooms elsewhere in the property.

Placement of radiators, plug sockets, telephone points, light switches, a toilet, rattling extract fan and lack of bathroom window caused irritation to some of the residents. The displays on heating programmers are too small, trickle vents cause draughts, faulty window mechanisms and the bedrooms in the flatted dwelling are reported to be cold during the winter. Overheating occurs in the living room of one dwelling which could result from a combination of the high heating set point and the large television in the room.

On the positive side all residents liked their new homes, the location, the courtyard outlook and the way sun moves around the dwellings during the day. Two occupants in separate dwellings had commented on the lack of dust and the ease of keeping their respective homes clean. One householder commented on the relatively low cost for energy, but this household reportedly heats their house for two hours each day.

Maintenance

There were mixed views in relation to maintenance support. Those that had finally had their problems repaired generally state that the maintenance is good, while another household waiting for repairs are generally dissatisfied with the service provided. The third household states that "the maintenance service isn't bad, the response time depends on what the problem is".

Conclusion

Generally the occupants are satisfied with their homes, the location, orientation and the outlook over a green. However there is a common concern over the Solar Thermal systems and questions over whether they are working. After two years occupation only one of the households knew how to set the heating programmer, but admitted that they had only learnt how to do this recently. However this is at odds with the survey response, which indicates 'full control' of the heating.

There have been a number of defects and annoyances with the housing such as: leaking pipework, debris in pipework, faulty windows, gaps beneath doors, ill-placed light switches and light fittings, questions over whether extract fans are necessary in rooms where there are windows, telephone points with no adjacent power sockets, radiator placement issues, occurrence of overheating in a living room and reports that two bedrooms have been found difficult to heat during the winter. The maintenance provided by the landlord appears be simple to organise but it takes time to detect and repair the faults.

5.3. Occupant Diaries

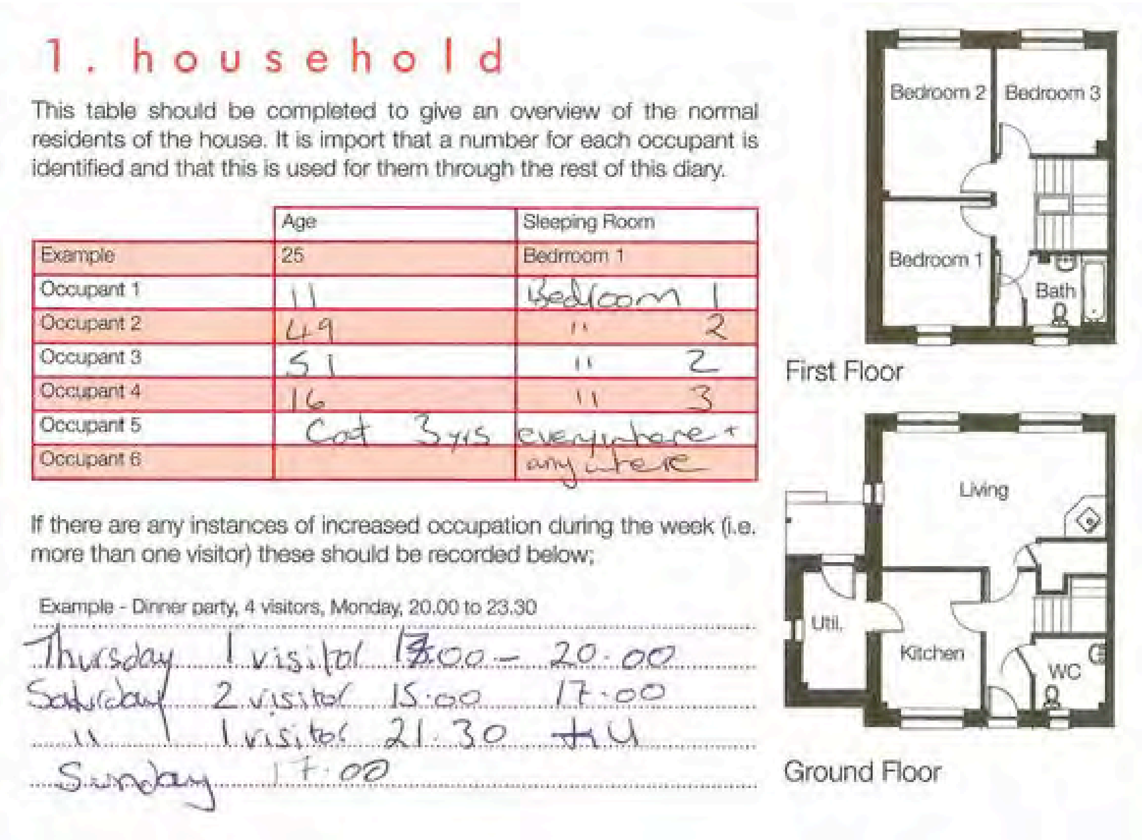
The aim of the diaries was to gather fine grain data on occupancy and activity patterns in the dwellings, and to analyse these against the environmental and energy performance data. The diaries were undertaken across all MEARU TSB projects over 24 hours a day over one winter week, Monday 3rd – Sunday 9th February 2014; and one summer week June 30th to July 6th 2014.

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. 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.

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 normal residents of the house. It is import that a number for each occupant is identified and that this is used for them through the rest of this diary.

	Age	Sleeping Room
Example	25	Bedroom 1
Occupant 1	11	Bedroom 1
Occupant 2	49	" 2
Occupant 3	51	" 2
Occupant 4	16	" 3
Occupant 5	Cat 3yrs	everywhere +
Occupant 6		anywhere

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

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

Thursday 1 visitor 18:00 – 20:00

Saturday 2 visitor 15:00 17:00

" 1 visitor 21:30 till

Sunday 17:00

Figure 46: Occupant Diaries: occupants and visitors were all noted throughout the week.

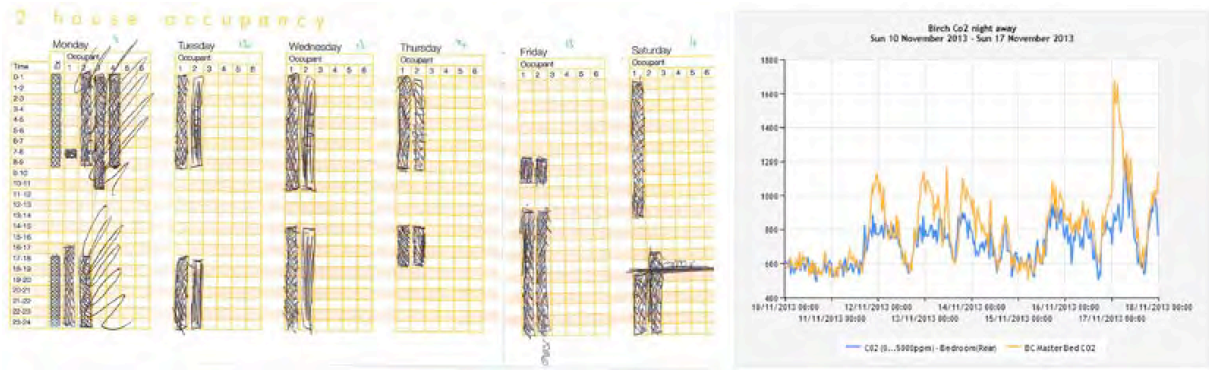


Figure 47: Occupant Diaries: nights away can be clearly seen as night-time reductions in CO_2 levels in bedrooms.

5.4. 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 are 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 16 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. 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 HA who reported that it was not a user friendly document and has limited value when compared with in-house surveys.

5.5 Conclusions and key findings for this section

- Notwithstanding the possible methodological shortcomings, the overall picture is of a high quality environment, with high levels of satisfaction.

- Notwithstanding comments on the methodology, a consistent level of satisfaction is apparent amongst the occupants across a range of measures.

- However, the interviews identified a number of problems, in particular the Solar Thermal systems, and controls.

- Improvements are needed to refine the methodology to take account of small sample sizes and granularity between difference types of dwellings.

- Refinements in the methodology are required to ensure appropriate semantic differentials for domestic users, and take into account effects of prior experience.

- To be a more widespread tool in housing, consideration is needed as to the costs of delivery, and the presentation of outputs from the studies.

- The project was subject to an ethical consent process and participants were required to give consent, this is an important aspect of domestic projects, not adequately addressed in the guidance for project execution.

- Talking to the residents directly through interviews and conversation elicited a great deal of useful information and insight. This is a finding repeated in other projects that, treating participants with respect and gaining their trust is a crucial aspect of domestic BPE.

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

6.1. Heating and Hot water system

The dwellings have spacing heating provided by a conventional high efficiency gas boiler supplying radiators, with a hot water tank for domestic hot water also fed from a solar system. The active systems in the dwellings were commissioned prior to this BPE project and the information on commissioning is contained in Appendix E. The installation of heat flow meters on the solar thermal system meant that these systems were re-commissioned at the start of the BPE project, but re-commissioning sheets were not provided at that point. The schematic for this is shown in Figure 48.

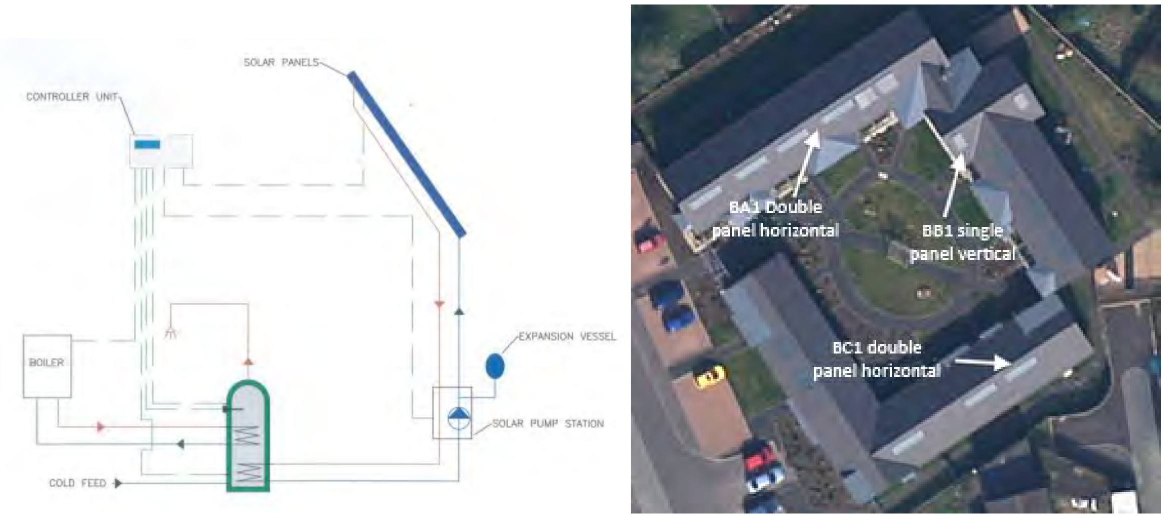


Figure 48: Solar Thermal schematic (left), aerial photograph showing solar panels (right).

The solar water heating system was installed by the Mark Group as a domestic sub-contractor to the main contractor. Plumber work generally was undertaken by James Frew. The installed system is a Worcester Bosch Greenstar 30CDi ‘regular’ (i.e. not a combination) boiler, with a 30kW output, located in the kitchen. The solar thermal system is a Worcester Bosch FKC-1S flat plate collector with 2 No. 2.34 m^2 collectors (total 4.68 m^2) on the south facing slope of the roof, both of which supply a Range Tribune Indirect HW cylinder located in the cold loft space. It became apparent during construction that there was insufficient space on the roof of BB1 and so only one panel (of 2.34 m^2) was installed there.

Figure 49: Boiler located in the kitchen (left); programmer located below the boiler (right) - note access to programmer (blocked by the location of Microwave oven).

The choice of system was largely due to a desire to have a ‘conventional’ wet heating system that would be familiar to occupants, supported by a solar thermal system as a requirement from HSHA. It is not clear how the boiler sizes were determined, but it is assumed to be from the Heal Loss Parameter and in a worst case Delta T (24 ^{o}C), which indicated a maximum output of 27kW. However, sizing for the worst-case scenario does mean that for the vast majority of the time the boiler is oversized for the heat demand.

Controls are a programmer, thermostat located in the hall and Thermostatically Controlled Radiator Valves (TRV) located on the radiators. The control panel for the solar thermal system is located in the loft, which means that the occupants cannot access it.

There were problems identified with the users’ understanding and knowledge of the controls, this is also discussed in Section 5. The controls are very standard to wet central heating systems, but it was apparent that users were having some difficulty understanding and using these. There was no specific handover process for controls and they are basic digital units that users find hard to understand. They have been located in spaces, which are difficult to access (see Figure 49) and this combined with the size of the screen and information is likely to be a challenge for users with poor eyesight.

The lack of understanding led to early problems with control of the heating which led to a number of service call-outs, which turned out to be controls issues. Further guidance was provided to occupants at this time, and through the project "Quickstart Guides' have been produced which will be introduce in winter 2014 (Draft copies are contained in Appendix C4). As the controls for the solar thermal system are located in the loft, users have no access to them. Users would not be expected to interact with these, but access to readings may be useful to assist with diagnosis of faults. It is certainly the case that their location there hampers access for routine and emergency maintenance.

The use of the solar thermal system meant that combi boilers could not be used and that space was therefore required for the hot water storage cylinder. A design decision was made to place these in the attic spaces, primarily to save space in the dwelling and to maintain space and storage provision.

An 'accepted wisdom' for hot water systems is that any heat lost remains beneficial to the dwelling if it remains within the thermal envelope. However in the context of contemporary low energy dwellings such loss from the system will reduce the efficiency of the hot water system and may contribute to unwanted heating. This is particularly the case with a solar thermal system when the majority of gains occur in the summer. These problems are avoided with the cylinder being located in the loft, however, this will result in system losses during cold weather. It will also result in losses due to unused hot water demand when hot water produced from the boiler is not used. In this installation a standard 50mm spray foam jacket is present, which is standard for an internal installation, and whilst pipework is insulated this is not to either a high specification or a high standard of workmanship (see Figure 50). System efficiency would be improved by increasing the thickness but also the continuity of insulation. It is not clear from the SAP how heat losses from the system are accounted for.

During the course of the works, it became apparent that there was uncertainty as to the exact responsibilities of the Mark Group and the contractor's electrician in relation to the interface between the electrical installation and the solar water system. These were resolved but a legacy of this included finding during the monitoring that the cylinder thermostat in BC1 had not been properly connected, resulting in the solar water system not functioning. This was resolved early in the project and the resident was delighted to find that they were subsequently receiving "free" hot water rather than, as previously, using the system boiler. However there was a subsequent leak from this cylinder and the positioning of it meant that this resulted in damage to the ceiling. It was found during the repair of this that a container cannot be placed under the unit, which hampered drain down and led to further damage. Problems were also identified in BA1 at the start of the BPE project were polystyrene debris was blocking the pump.

Figure 50: Left: Water damage due to a leak from the Solar Thermal system. Right: Cylinder located in the loft

Difficulties arose on site as a result of poor co-ordination/ working relationship between the main contractor's plumbing and heating subcontractor (Frews) and the installer of the solar thermal hot water installation (Mark Group). An issue which created particular difficulties was that of who fitted and/or supplied thermostats, who cut out any holes in the hot water cylinder and who sets or calibrates the system once installed.

Problems also arose with the annual maintenance of solar thermal installation as a result of the Scottish Gas service engineers not being conversant with the operation of the solar thermal hot water installation.

The operation of the solar thermal controls appears to have proved a challenge for both Scottish Gas engineers and others who attended call outs. Where system failures have arisen it has usually been Worcester Bosch the manufacturer of the equipment who has resolved any problems involving recalibration/resetting the system.

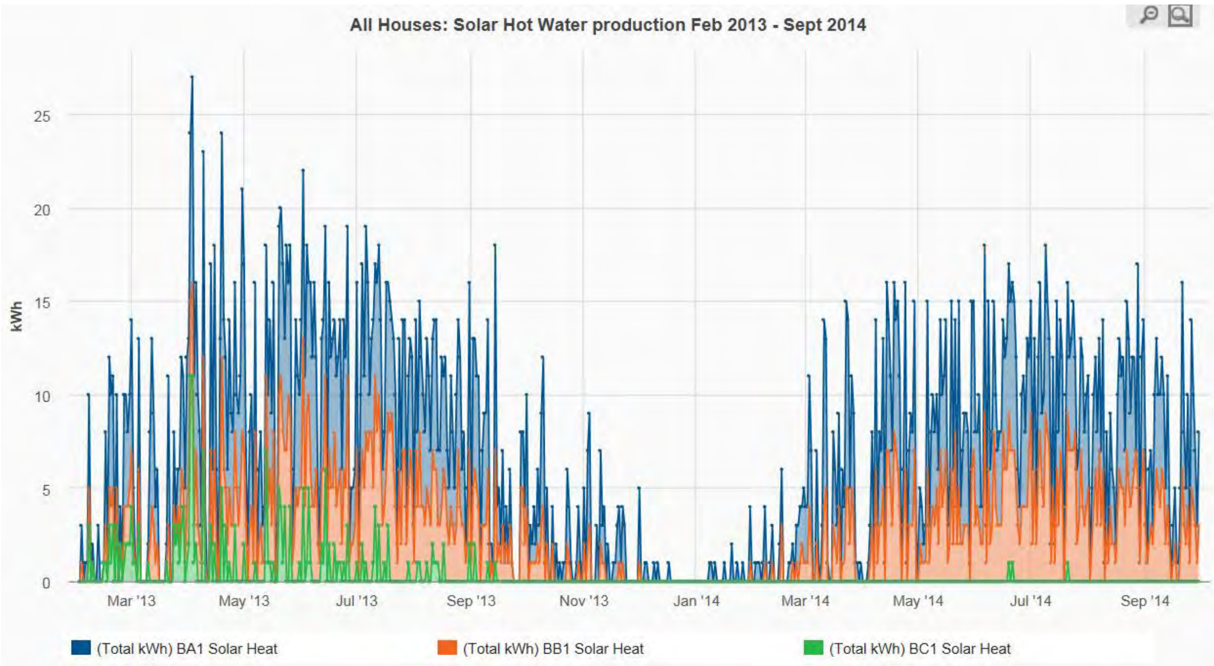


Figure 51: All houses, solar hot water production Feb 2013 - Sep 2014.

The overall output of the solar thermal systems is shown above. There are several features to note. In spring 2013 there was output from the system in BC1 but this was intermittent and corresponded with difficulties including the leak from the system. Output appears to ceased in the winter of 2013, and did not pick up again in summer 2014. The output from BC1 was been consistently poor throughout the period.

The reasons for this have yet to be fully established. At the time of writing the solar thermal maintenance contractors are claiming the system is functional and the error is due to a leak from the monitoring heat flow meter, but this is disputed by the plumber who fitted these. Comparing summer gas use of the houses to see if there is greater gas use in BC1 strongly suggests that there is defect.

Additionally, when monitoring started it was not known that the panel size in BB1 was smaller. The panel cannot easily be seen from the courtyard and the roof plan showed two (separated) panels, the commissioning sheets indicate that all of the panels are the same size. It was only when possible underperformance was reported that it was found that there was a single panel for each of the upper and lower floor flats. At this point the disparity in performance between BA1 and BB1 became clearer.

The effects of these issues on energy performance are discussed in Section 7.

6.2. Mechanical Ventilation

A related area of investigation in these dwellings concerned extract ventilation. Testing in other dwellings by MEARU had identified deficiencies in the extract provision and some issues with dampness in the bathroom and shower rooms had been reported and so the testing regime was extended to the dwellings in this project. Volume flow rates were measured in-situ using a volume flow meter and accessories detailed below. All measurements were undertaken in accordance with HM Government 'Domestic Ventilation Compliance Guide', 2010 edition with 2011 amendments. Observator Instruments - Automatic volume flow meter with pressure compensation Type: Diff Automatic, Cert No: UK08111MN, Calibrated: 20th June 2013 and light extension hood, Type: AT-242, Cert No: UK08111MN, Calibrated: 20th June 2013. The apparatus used allows values to be derived using the "Unconditional Method" of measurement. The powered flow hood eliminates back pressure and places no additional restrictions on fans under test; therefore results displayed on the equipment can be taken as correct without any further need to apply pressure drop correction factors. The results of these tests in the context of other MEARU BPE projects are shown below.

Dwelling	Fan Location	Manufacturer	Avg Measured extract rate (l/s)	Design extract rate (l/s)	Pass/Fail Measurement test
IA1	Kitchen	Manrose	25.60	60	Fail
	Utility	Manrose	29.40	30	Pass
	Shower	Not known	7.50	15	Fail
	Bathroom	Vent Axia	7.50	15	Fail
IA2	Kitchen	Manrose	34.50	60	Fail
	Utility	Manrose	31.90	30	Pass
	Shower	Vent Axia	3.70	15	Fail
	Bathroom	Vent Axia	4.60	15	Fail
IB1	WC	Passivent	3.20	7	n/a
	Bathroom	Passivent	4.90	15	n/a
IB2	WC	Passivent	5.20	7	n/a
	Bathroom	Passivent	4.00	15	n/a
	Kitchen	Not known	62.60	30	Pass
IC1	Kitchen	Passivent	5.80	60	n/a
	Bathroom	Passivent	7.30	15	n/a
IC2	Kitchen	Passivent	8.50	60	n/a
	Bathroom	Passivent	5.90	15	n/a
ID2	Kitchen	Icon Air Flow	26.10	60	Fail
	Bathroom	Primeline	6.90	15	Fail
BC1	Bathroom	Airflow Icon	11.83	15	Fail
	Kitchen	Airflow Icon	64.27	60	Pass
BB1	Bathroom	Mentis	17.30	15	Pass
	Kitchen	Airflow Icon	71.87	60	Pass
BA1	WC	Airflow Icon	12.40	15	Fail
	Bathroom	Airflow Icon	2.80	15	Fail
	Kitchen	Airflow Icon	0.00	60	Fail
GB3	Bathroom	Xpelair	9.20	15	Fail
	Kitchen	Vent Axia	32.57	60	Fail
GB1	Bathroom	Vent Axia	11.13	15	Fail
	Kitchen	Vent Axia	41.43	60	Fail
GB2	Kitchen	Vent Axia	30.10	60	Fail
	Bathroom	Vent Axia	16.30	15	Pass

Figure 52: Mechanical ventilation testing.

The results show that 26 out of 31 fans tested were underperforming and that 71% were failing the design performance criteria. In this project 4 out of 7 are underperforming. This is a cause for concern on several levels. Firstly, it impacts on moisture extraction from these spaces and particular issues were apparent in the bathrooms. Secondly, in the context of modern airtight dwellings, extract ventilation is an important component as a mechanism to draw air through the house, also failure to do this effectively could have negative consequences. These fans have now been replaced.

6.3. Conclusions and key findings for this section

- Gas central heating systems are now a familiar technology in contemporary housing. On-going costs (for example annual maintenance) have become accepted and built into cost and maintenance plans. Where other active systems are used, costs and impacts of maintenance (for example, ease of access) must be considered.

- As energy demands due to fabric and ventilation losses reduced, the need for smaller, efficient systems increases. In some cases systems are sized to meet hot water demand, or worst case scenarios (which ignore other heat gains), which can lead to oversizing of the space heating provision.

- The heating system controls were not well understood by the occupants. There was no information provided on these at handover and occupants had to adapt their behaviour and use.

- Greater consideration is needed of the integration of heating and ventilation systems.

- ‘Fit and forget’ approaches are high risk - in the event of failure they can result in additional costs to occupants. Systems need to have interfaces that that can both monitor and communicate their performance. The lack of information available from the solar thermal systems (the temperature gauges being in the loft) means that occupants have no way of knowing whether these are working or not, nor engaging with and optimising their use of the technology and resulting cost/energy savings.

- Retrofit of monitoring devices is difficult and expensive. It would be better if such devices are either built into the system or fitted at the time of installation.

- The location of the solar thermal system in the loft has both pros and cons. Advantages are that it does not take up useful space in the home; pipework may be easier to install and access if not built into the fabric of the building; incidental gains which may contribute to overheating are avoided. Disadvantages are that access to the system to control and maintain it is difficult; heat loss from the system (for example solar gains during the day, or water pre-heating) will be higher; a potential heat source for a drying space in the dwelling is lost; and the controls are not accessible.

- Location of the hot water cylinder in the heated volume of the house is, on balance, desirable, but careful attention to insulation, including an increase in specification, is needed to ensure that unwanted heat gain does not occur, summer gains can be ventilated and that solar gains are retained.

- The solar thermal systems have made a contribution to the hot water demands of the houses (which are generally low - family housing demands would be greater). However the financial value of this is relative small (approximately £45 p.a), but not all of this was utilised in the dwellings. Given this occupancy type, with relatively low hot water demands, direct systems may be more effective.

- Consider relabeling solar thermal hot water systems as solar assist as tenants have an expectation that they will be getting and are always entitled to free hot water.

- The overall efficiency and costs of maintenance may be such that for houses such as this, and with this type of managed occupancy, communal systems may be more effective.

- Controls tend to be specified by cost, rather than effectiveness or usability. During the project users improved their knowledge of controls and there is evidence emerging from on-going monitoring that this is reducing energy use.

7. Monitoring methods and findings

This chapter discusses the selection of metering and monitoring methods adopted for the project, 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 each house type.

7.1. Overview of monitoring and metering

A plan for monitoring and metering the energy consumption and environmental conditions of the three houses was developed at the start of the project by MEARU. MEARU entered into detailed discussions with equipment suppliers regarding appropriate range and specification of the equipment required to gather data in accordance with the TSB Guide for project execution.

Due to the length and varied locations of the BPE monitoring projects, a system that gathers data wirelessly locally and transmits data over GRPS (General Packet Radio Service) networks to a central server was designed with suppliers. The use of wireless data systems in domestic situations is preferable to wired systems (previously Eletek and Gemini loggers had been used) as it makes sensor placement far less restrictive by removing the need to be adjacent to power sockets. The selection of placement enables robustness, as there is less risk of the equipment being accidentally unplugged. Data is transmitted live to an off-site repository, to provide better security, minimise data loss and reduce the need for access to the houses and disruption to occupants. This in turn enables remote access through an online portal for data outputs and analysis.

The equipment suppliers selected for this project were T-Mac Ltd. for sub-metering and environmental monitoring, and ORSIS Ltd. for fiscal gas and electrical metering, both of whom have provided monitoring on previous projects including Bloom Court (TSB BPE project) also owned by HSHA.

T-Mac supplied a wireless solar and battery powered temperature, relative humidity (RH) and Carbon Dioxide sensor (CO_2), which was used to monitor the environmental conditions. This was used in conjunction with solar powered contact sensors to monitor window opening. This data is transmitted wirelessly to a central t-mac unit, which is hard-wired via a fused spur to the meter board in the utilities cupboard. At the meter board up to six electrical sub-circuits are monitored via CT clamps, which are also connected back to the t-mac unit.

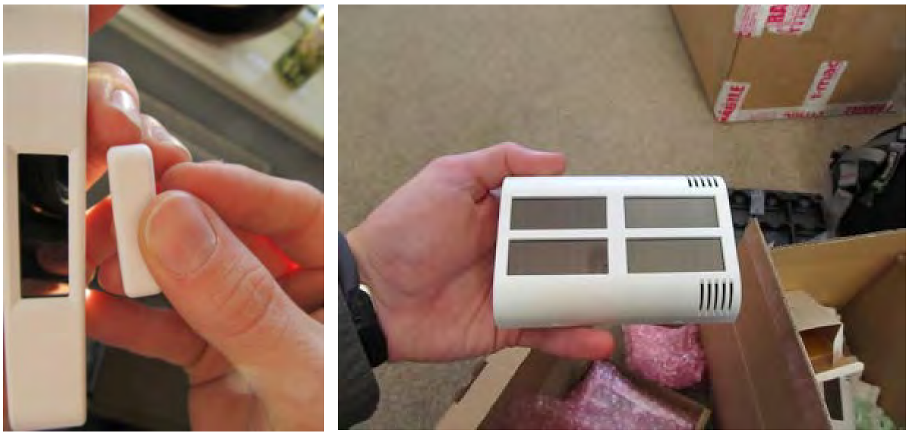


Figure 53: Window contact sensors (left) and combined CO_2, temperature and RH sensor (right).

Figure 54: Window contact sensors in-situ (left) and combined CO_2, temperature and RH sensor in-situ (right) , next to CO_2 sensor.

Heat flow meters were plumbed into hot water systems and used to monitor hot water use through pulse output. In these houses the output from the Solar Thermal system was monitored, along with domestic hot water consumption. At the time of project inception T-Mac did not have the capability to meter fiscal energy, this was undertaken by Orsis, who carried out the site survey and installation of pulse counters to the existing gas and electricity fiscal meters. A Global System for Mobile (GSM) communication link was used; data was collected wirelessly and transmitted to the ORSIS data portal, where is it streamed to the T-Mac site for collation and analysis. This also had the advantage of providing a backup source of energy data.

A site visit was commissioned by MEARU and representatives from T-Mac attended site on September 2012 and series of further discussions were made to refine the project requirements. As installation costs were higher than originally intended, the on-site weather station was replaced by local weather data feeds provided by T-Mac.

Monitoring equipment installation was undertaken on 28/11/12, and commissioning and testing was carried out by T-Mac on site on 10/12/12. The need to install a fused spur and to extend the sub-circuit tails to accommodate CT clamps required the attendance of an electrician, and a plumber was needed to install the heat flow meters on the solar thermal and hot water pipework.

Figure 55: Installation of T-Mac unit in meter cupboard.

A wireless interstitial sensor was inserted into the vapour permeable construction at BA1 and BC1 to measure temperature and relative humidity interstitially. This required that a hole be drilled to a depth of approximately 200mm and a duct probe inserted to measure temperature and RH at the end point.

Figure 56: Interstitial sensor.

The areas and variables monitored in each house are summarised below:

	BA1		**BB1**		**BC1**
	Mid-Terr 2 storey house		Upper floor flat		End Cottage Flat
	Mains Gas		Mains Gas		Mains Gas
	Mains Electricity		Mains Electricity		Mains Electricity
	6no. Electrical Sub-circuits:		**6no. Electrical Sub-circuits:**		**5no. Electrical Sub-circuits:**
Not Monitored	*Monitored*	*Not Monitored*	*Monitored*	*Not Monitored*	*Monitored*
Solar	Cooker	Water Heater	Sockets	Water Heater	Sockets
Door Bell	Downstairs sockets	Door bell	Cooker	Cooker	Cooker
Smoke Alarm	Downstairs lights	Smoke Alarm	Kitchen sockets	Kitchen	Kitchen sockets
Water Heater	Upstairs sockets	Central Heating	Lighting 1	Lights	Lighting 1
Lighting 2	Upstairs lights		Lighting 2	Lights	Lighting 2
			Central Heating Power	Central Heating	Central Heating Power
	Hot water		**Hot water**		**Hot water**
	Domestic Hot water consumption		Domestic Hot water consumption		Domestic Hot water consumption
	Solar Thermal Hot water production		Solar Thermal Hot water production		Solar Thermal Hot water production
	Environmental conditions		**Environmental conditions**		**Environmental conditions**
	Deg C, CO_2 and RH Living room		Deg C, CO_2 and RH Living room		Deg C, CO_2 and RH Living room
	Deg C, CO_2 and RH Mater Bedroom		Deg C, CO_2 and RH Master Bedroom		Deg C, CO_2 and RH Master Bedroom
	Deg C, CO_2 and RH Kitchen		Deg C, CO_2 and RH Kitchen		Deg C, CO_2 and RH Kitchen
	Window contact sensors Living Room		Window contact sensors Living Room		Window contact sensors Living Room
	Window contact sensors Master Bedroom		Window contact sensors Master Bedroom		Window contact sensors Master Bedroom
	Window contact sensors Kitchen		Window contact sensors Kitchen		Window contact sensors Kitchen

Table 10: Summary of metered data by house.

Not all of the sub-circuits were monitored, for two reasons. Primarily, there was very limited space in the consumer unit in which the CT clamps were fitted. The tails for the sub-circuits had to be extended to provide enough accessible cable on to which the clamp could be placed. The bulk of these clamps meant that only 5 or 6 clamps could be placed whilst allowing the consumer unit to be closed for safety. The second reason was an attempt to provide some consistency between what was being metered in the different properties. A judgement was made on site about which circuits were appropriate to measure.

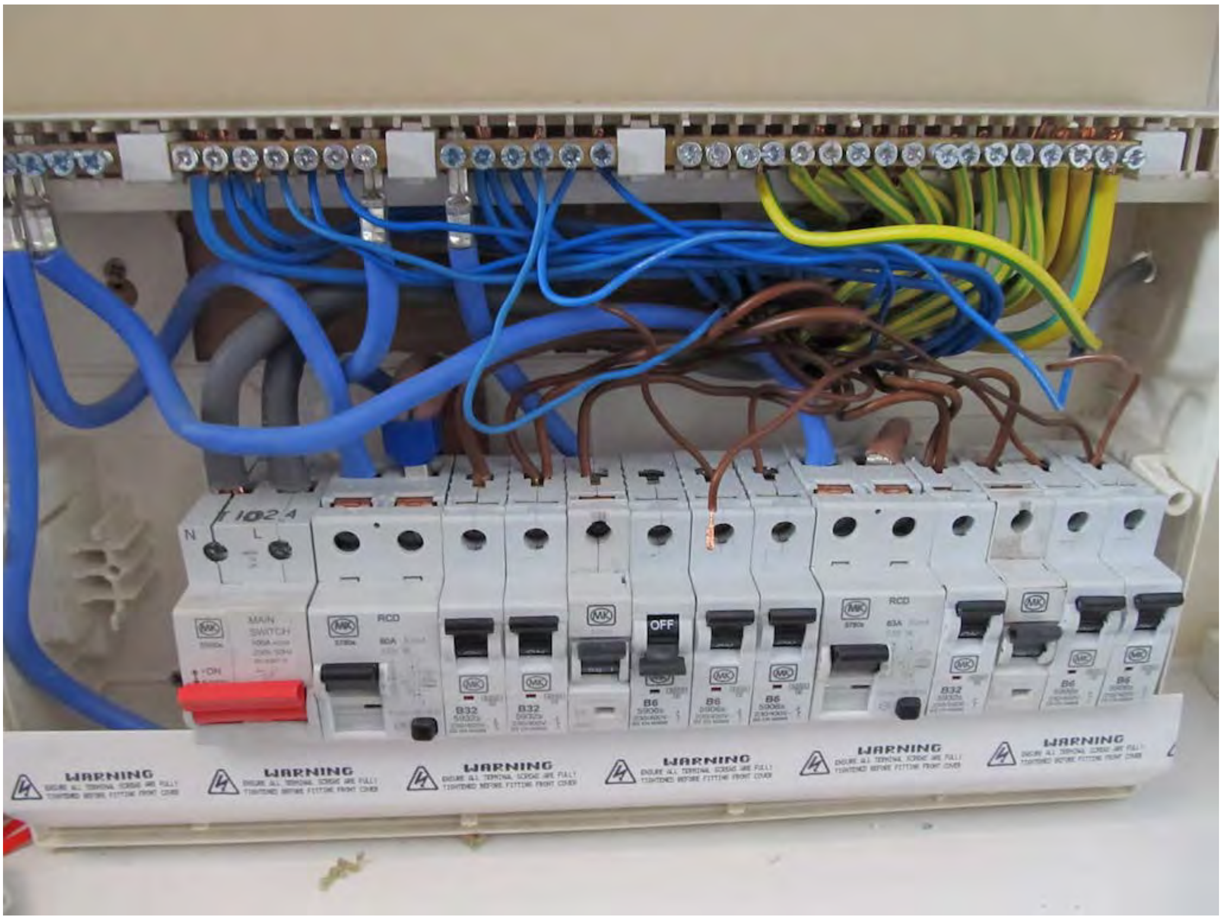


Figure 57: Inside a consumer unit showing the amount of cabling and tails for sub-circuits being extended.

There is some inconsistency in the naming of sub-circuits, with some items labelled as 'sockets' and some as 'ring main' for example. It is not clear why BA1 has a separate sub-circuit for solar whilst the other houses do not, and it is further assumed that in BB1 and BC1 the solar loads are contained in the central heating circuits. Although the water heating circuit (an immersion heater for the hot water cylinder) could be a high load item, given that water heating is provided by the gas boiler and supplemented by the solar thermal system, regular consumption here was not anticipated and so this circuit was not metered. Similarly, doorbell and smoke circuits were considered to be low use and were also omitted.

In general monitoring has been effective, with both the internal and GSM signal strength being good. The effectiveness of monitoring in this project this is largely a result of the lessons learned from other MEARU TSB funded BPE projects, resulting in improved specification of equipment and engagement with equipment suppliers. For this project, T-Mac revised their working methods. These steps included a more detailed site survey to accurately measure signal strength in the houses, and to identify locations for equipment; consumer units, space available for CT clamps and heat flow meters. Where possible, site surveys were undertaken in conjunction with an electrician and plumber to optimise equipment installation and positioning. MEARU identified some cases where the domestic electrician was unfamiliar with the equipment and wiring required; this lead to extended time on site during installation.

This approach to monitoring was relatively new and presented both advantages and disadvantages. It was apparent that the monitoring requirement of the TSB programme is very intensive. In many ways this was an experimental setup, required due to the remote nature of the sites, sensitivities of the occupants and large dataset that was required. It also became clear during the course of the project that monitoring domestic environments was unfamiliar territory for T-Mac.

Particular issues arose concerning the reliability and veracity of data on the reporting portals, which required constant checking and verification. It was apparent that there were quite different expectations about the on-site commissioning processes. MEARU's expectation was that the commissioning process would check that: a) the equipment was working and communicating correctly and that; b) it was reporting meaningful results, however this was not always the case and resulted in significant amounts of effort in checking and correspondence to rectify missing and erroneous data. To address these problems a tracker system was established to identify and correct problematic data where possible. Overall this was a huge learning curve and was substantially more time-consuming than anticipated.

When compared with equipment used previously, the system overall was cost effective. The capital costs are lower, but installation costs are higher, requiring a minimum of two days for site survey and commissioning. As fewer site visits are required, maintenance costs are lower than the hosting costs, taking into account labour and travel costs for site visits. Notwithstanding the limitations of the portal system (discussed below) analysis costs are also lower. Data can be accessed and visualised quickly, although there is limited control on the formatting and scale of images produced. However data can be visually isolated for export and further analysis and formatting. The need to include sub-metering and heat flow metering was a significant additional cost, both in terms of equipment to do this (sub-metering clamps and heat flow meters), but also the requirement for site attendance of an electrician and plumber and in the case of the latter, re-commissioning of wet systems.

Equipment Problems

In overall terms the system has provided the data required, albeit with some limitations. The sensors have, by and large, worked over the two year period. There were early concerns that the battery and small on-board PV would not be sufficient, but these were unfounded. Early problems were experienced on a different site due to GSM signal issues were avoided here through the commissioning of a site-survey my t-mac.

Whilst overall the system has great merit, in practice there have been a significant number of frustrations. The main problems have been the frequency of data intervals. Although all data is recorded at 5 minute intervals, the specification of the sensors was they would only ‘wake’ and send a signal when one of the monitoring parameters changed or every 15 minutes, but examination of data seemed to indicate that this period might be longer. Updates were made to rectify this, but it would appear that some granularity is missing for some sensors. Whilst site surveys, specification of equipment and commissioning were all instructed, it took significant periods of time and effort to resolve data issues. It would seem that the commissioning undertook to identify that the sensors were sending data, not that this data was appropriate to the element being monitored. Some of the differences between main and sub-metered loads (discussed in section 7.3) may be due to the CT clamps not having sufficient resolution for very low loads and small power requirements. This is currently being investigated with a view to identifying clamps that can be installed here for on-going monitoring.

Analysis of monitored data

Access to the data is through a series of online portals. At the beginning of the project there were two elements to the Config portal (Figure 58), an energy analysis portal (Figure 59) and a Showcasing portal (Figure 60). The portal allows the selection and inspection of monitored data, and also the section of monitored elements and time periods, which can be viewed visually and downloaded. Whilst this provides rapid visual access to data, there are limitations in the formatting of the data. Nevertheless, it provides a rapid way of accessing and sharing data online. Whilst data ranges and data could be quickly selected and collated, visualisation of data was limited. A key facility was the use of this portal to identify data sets and export these for analysis in excel.

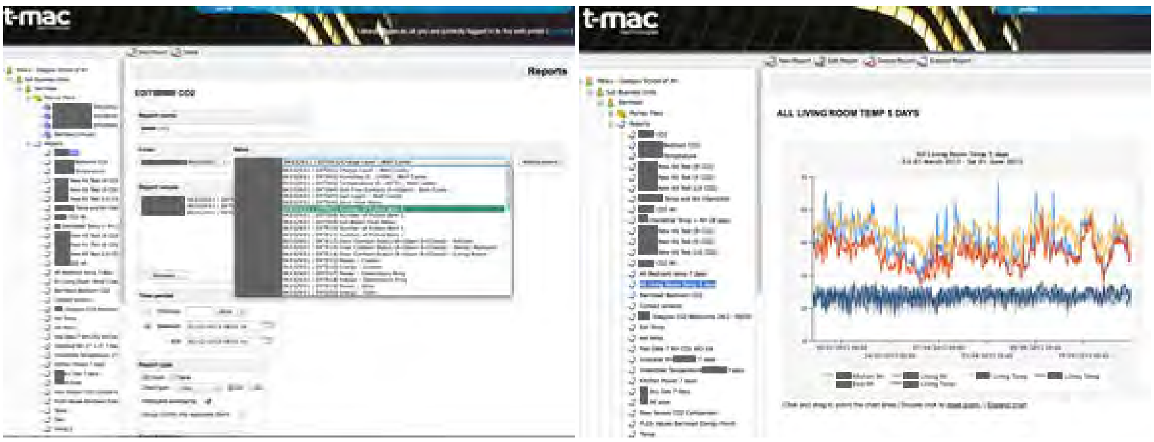


Figure 58: Examples of data access in the t-mac Config portal.

The Energy Analysis portal provided a more visually sophisticated access to energy data. It allows complex selection of time periods, aggregation (yearly, monthly, weekly, daily, 60, 30, 15 and 5 minute data intervals) and varying forms of graphical display (graphs, charts and export to .csv.) The principle shortcomings of this were that it did not host environmental data and that reports generated could not be saved.

Figure 59: Examples of data access in the Energy Analysis portal.

The most disappointing element was the Energy Showcasing portal. This had been identified as being a site where householders could access their own data. At the time of commissioning this was not available, and when it did come online it was clear that this did not produce useful data for domestic projects. Limitations on access meant that households could not see their own data without seeing other properties, and the interface was geared up for non-domestic buildings. As a result of this data was exported and collated into a summary feedback sheet that was provided for occupants.

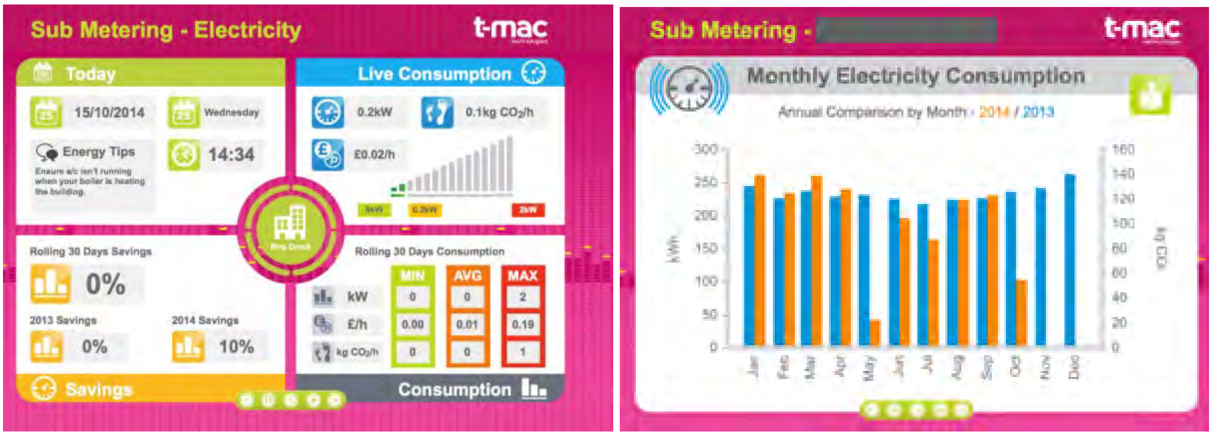


Figure 60: Energy showcasing portal.

Whilst the portals have been very useful for accessing data, it has been a constant battle to ensure that the correct data is being made available. For example one particular shortfall is that weather sensors originally supplied never worked externally and so weather 'feeds' were purchased. However, for significant periods these presented unusable data. This is now being resolved in the reporting portal, but has limited the quantity of external weather data available for comparison during the internal monitoring period.

Monitoring and sensor development through BPE

In August 2013 MEARU met with senior management at T-Mac to discuss the overall performance as a result of which a number of improvements were made. One of the facilities promised at the meeting was access to a new reporting portal. In the event this access was not provided until June 2014, but the access to data in this portal is much improved. This portable allows complex selection of data, including both environmental and energy data, varying (and multiple) date and time period selection. Data points are easily named, varying graph types are supported (including line, bar, scatter and donut) and 2 axis graphs can be produced. Some analytical tools are provided for mean, max, min and trend. Very complex data can be easily selected and visualized, with several export options. At the time of writing the system remains in beta, and some critical functions are not yet available, for example gas is not yet converted to kWh, and there is limited access to sub-metered electrical data.

A complete dataset is available for a 24-month TSB BPE monitoring period (See Appendix …). This data monitoring is continuing in order to resolve both outstanding monitoring issues and to collect data on behalf of the project. The overall energy performance and consumption is described in the following section.

7.2. Overall Energy Consumption

Two years' worth of data is available for overall electrical and gas consumption, solar hot water production, domestic hot water consumption, and sub-metered electrical consumption for up to 6 sub-circuits in the dwellings. The overall patterns of consumption are shown in the Figures below. The raw data for this monitoring period and variables is contained in Appendix I.

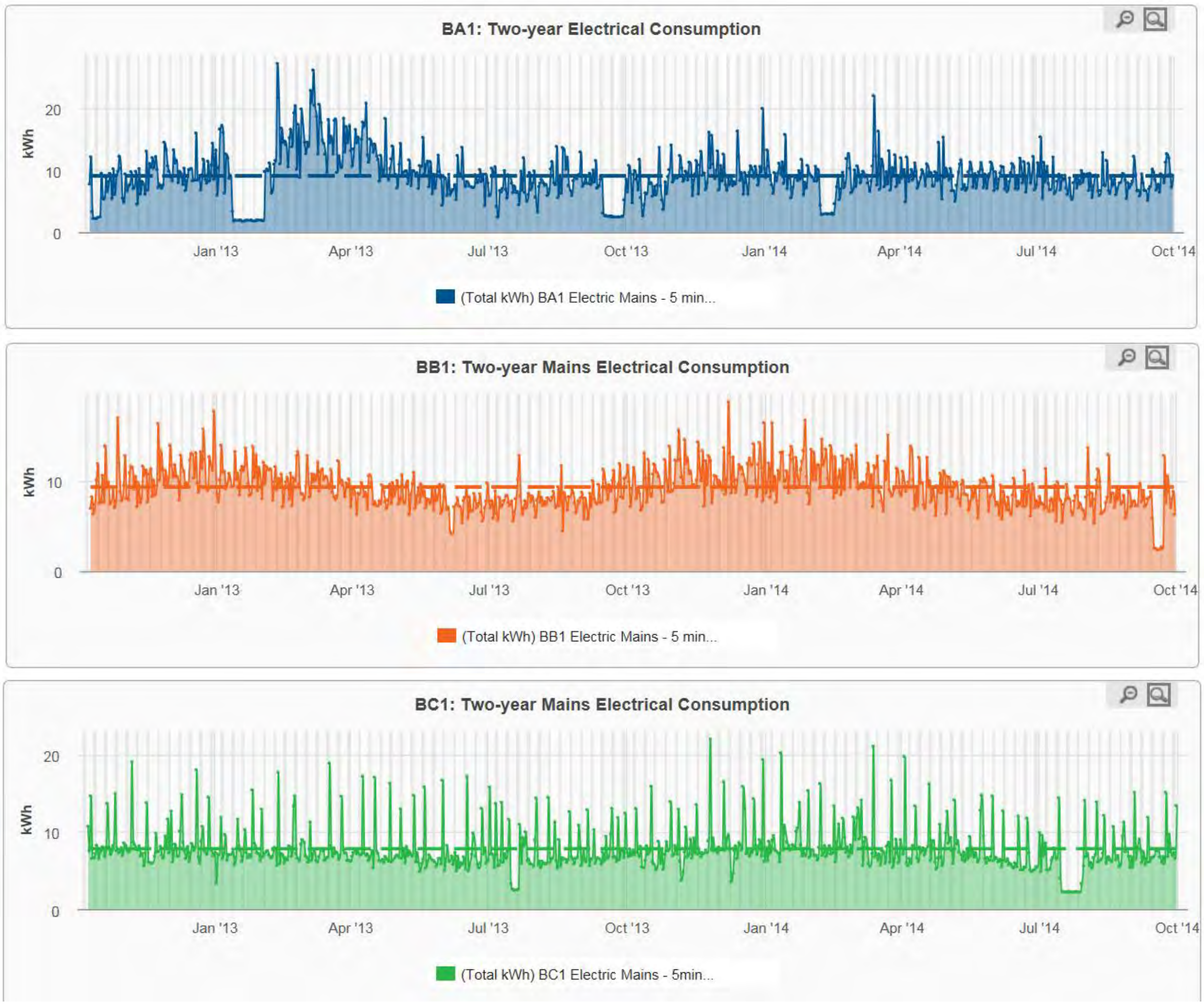


Figure 61: Two-year mains electrical consumption across all three dwellings.

Examining the overall pattern of consumption in all three dwellings suggests that there is a consistent pattern of energy consumption throughout the year. BB1 shows some seasonal range, with increased consumption in the winter, indicating greater use of artificial lighting. Periods where the house is vacant are very clear for BA1; the presence of standby loads is apparent and this is discussed in more detail below.

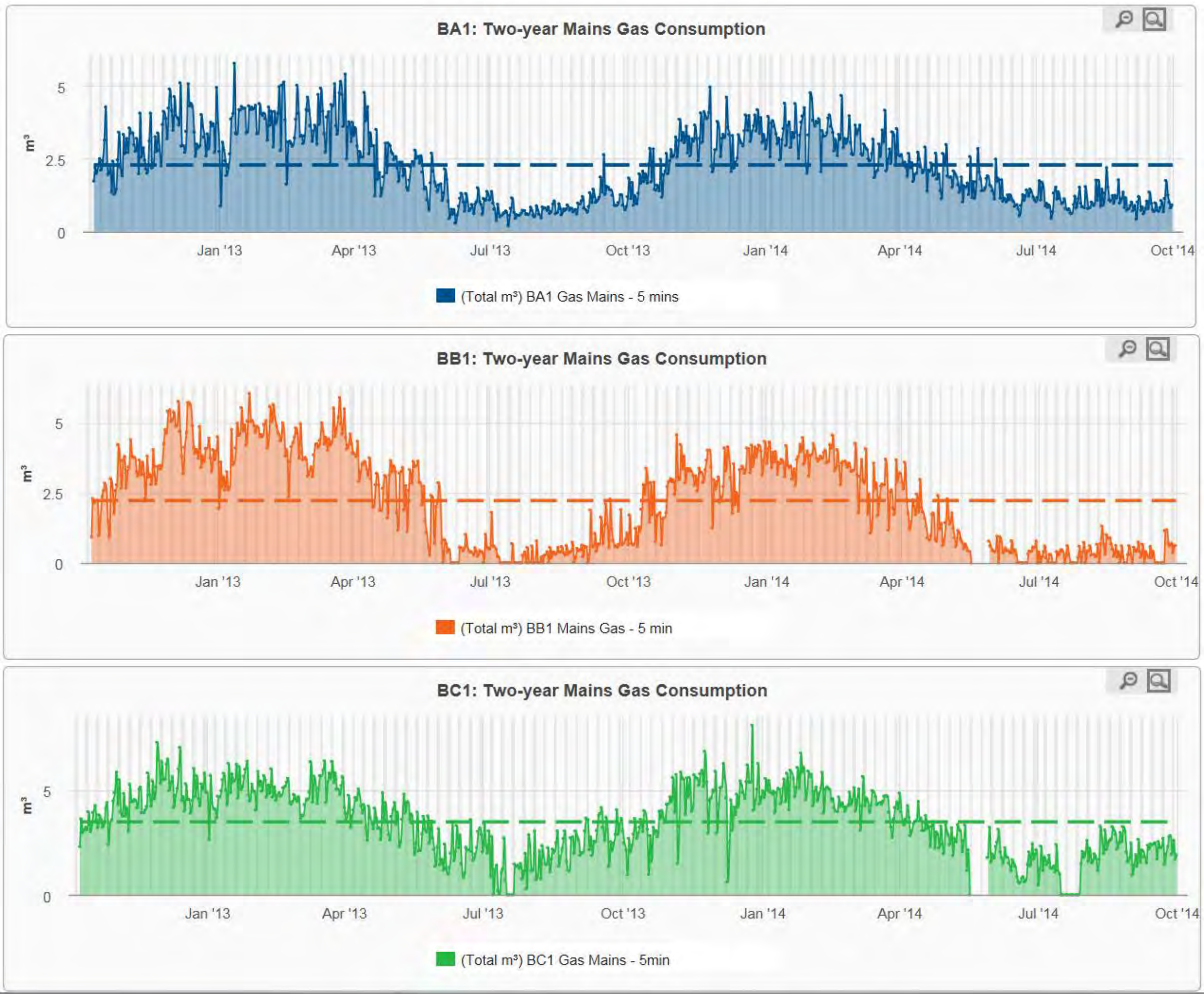


Figure 62: Two-year mains gas consumption across all three dwellings.

Patterns of annual gas consumption are clear in all three dwellings with increased demand over the winter periods. As discussed in Section 2, consumption is notably higher in BC1 and it is interesting to note relatively high consumption during the summer months. This is due to problems with the Solar Thermal collectors, but also a tendency to keep the heating on throughout the year and difference in demand temperatures, this will be discussed in more detail in following sections.

BA1 also has marginally higher gas consumption in summer, this is due to gas use for cooking, with both a gas hob and oven. In the case of BA1 and BB1, consumption in 2014 appears to be reduced over 2013. However, correlating consumption against degree-days reveals this to be primarily due to warmer weather in 2013 as shown in Figure 63. This figure also shows the additional consumption in BC1.

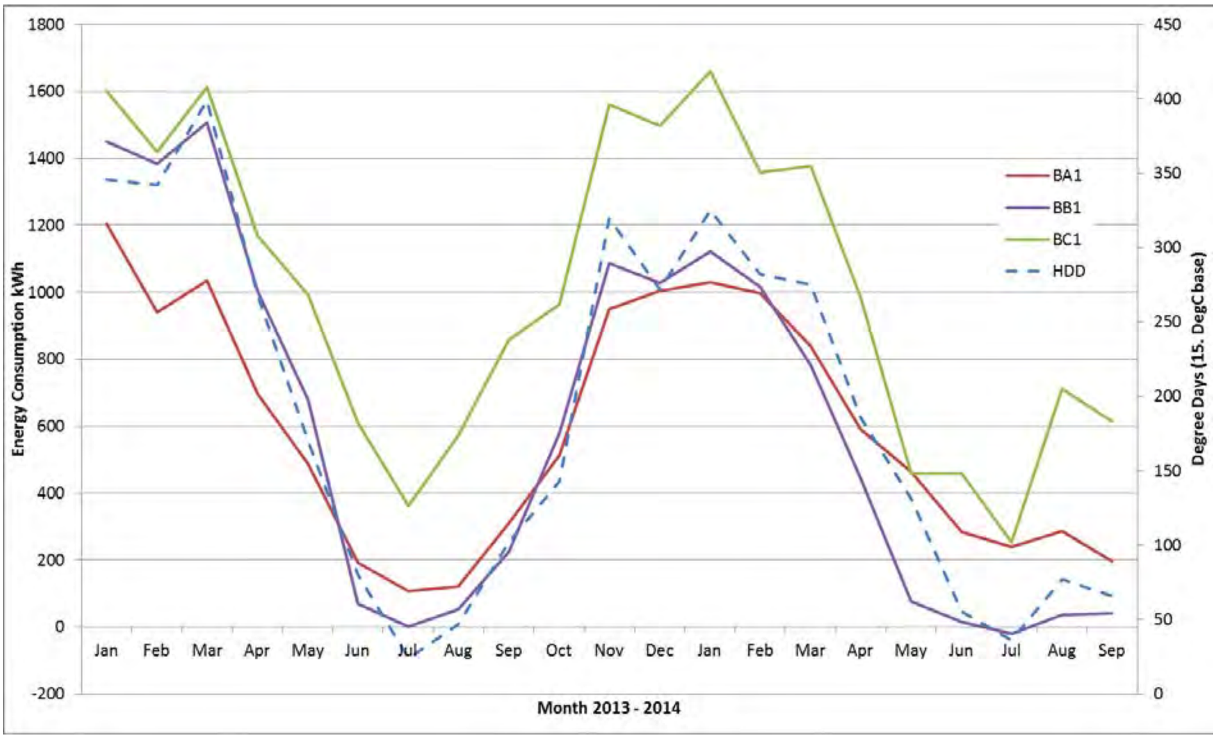


Figure 63: Comparison of space heating energy consumption against degree days 2013 – 2014.

Plotting the energy consumption against degree days shows an improved performance for BA1. Looking at the consumption of this house against degree-day data indicates that the dwelling uses less energy during the winter than the others. This house has the most effective solar orientation with a 2-story elevation; contain both the living room and the master bedroom, facing south.

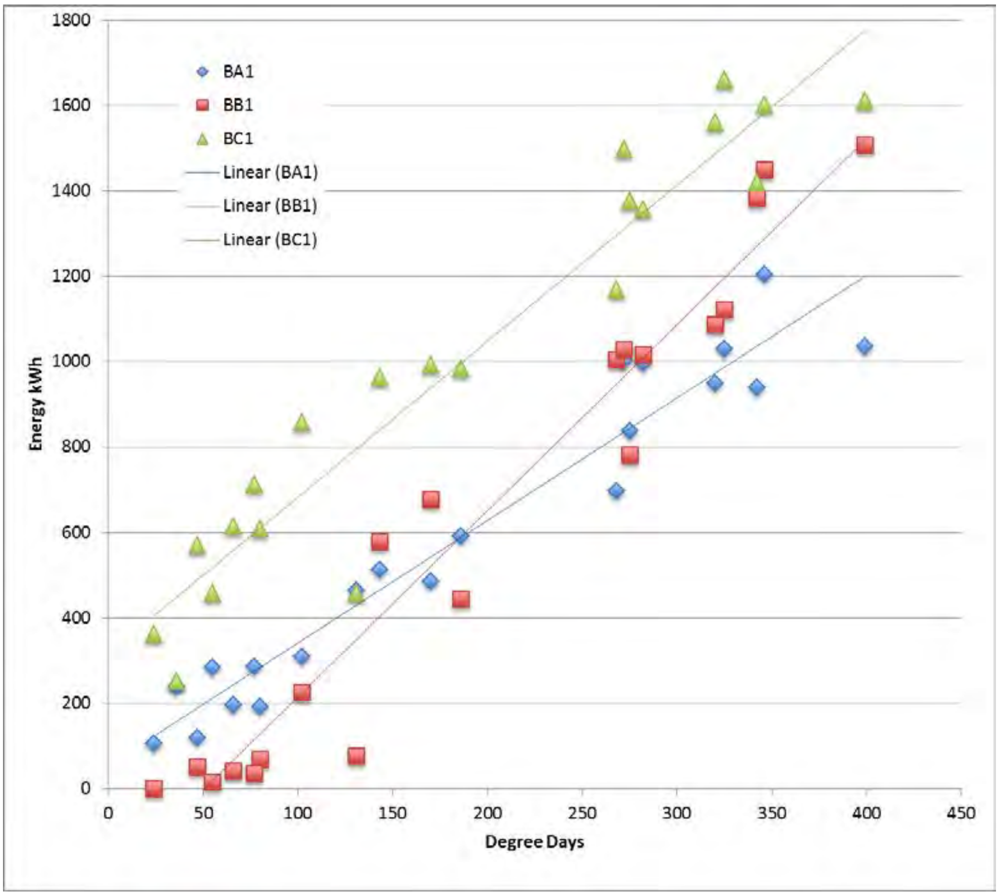


Figure 64: Scatter plot and performance line of energy consumption against degree-days.

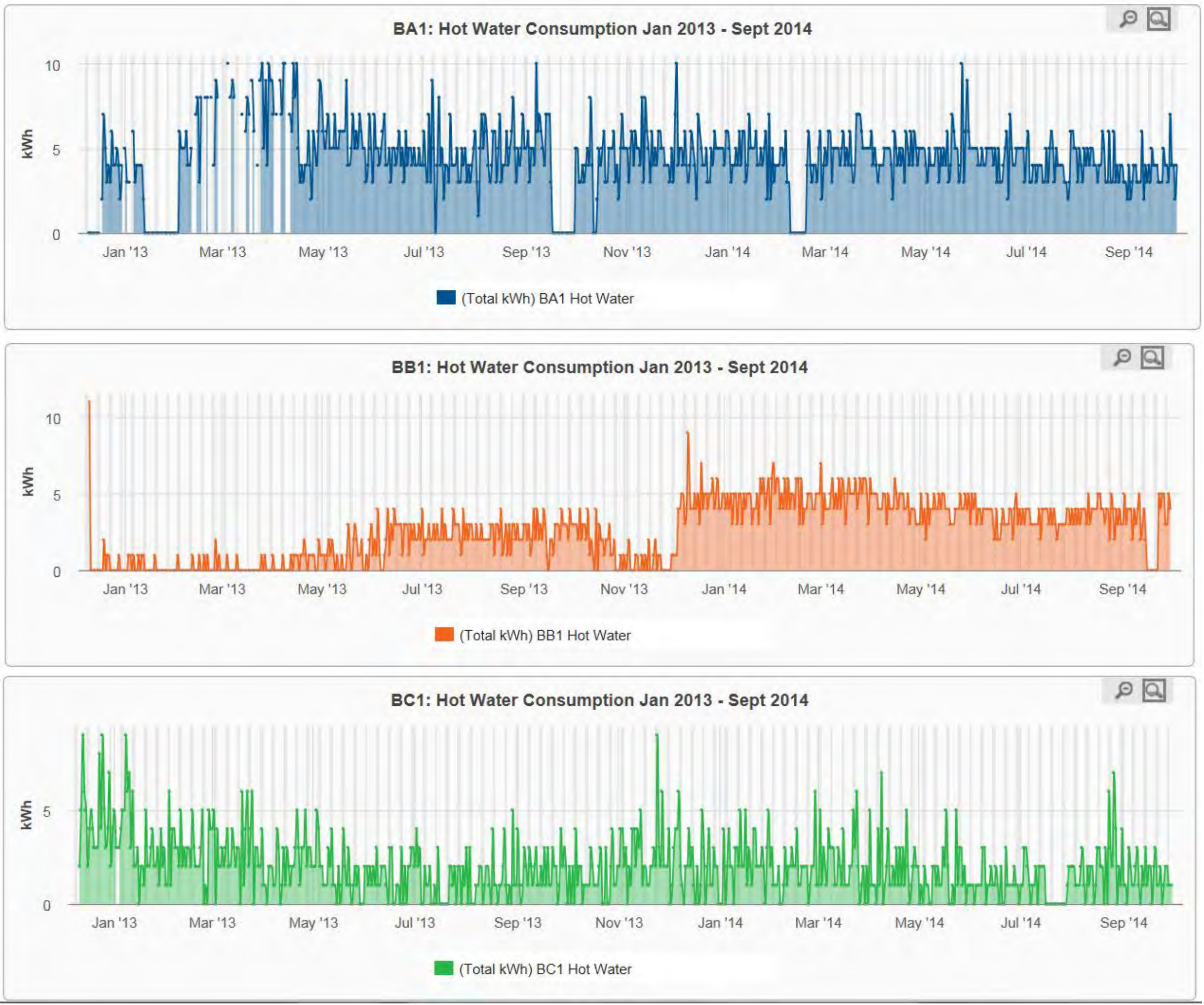


Figure 65: Hot water consumption Jan 2013 – October 2014.

Figure 65 shows the two-year pattern of hot water consumption. Whilst consumption for BC1 is consistent (and high) throughout the period, it varies for the other properties. Of note is the high consumption in BA1 after a period of absence in January 2013. This correlates with the electrical consumption at the same time, and is thought to be due to extended amounts of laundering being conducted following a long holiday. The very low hot water consumption in BB1 appears to be coincident with works to the heating and hot water systems and is due to the heat flow meter being disconnected.

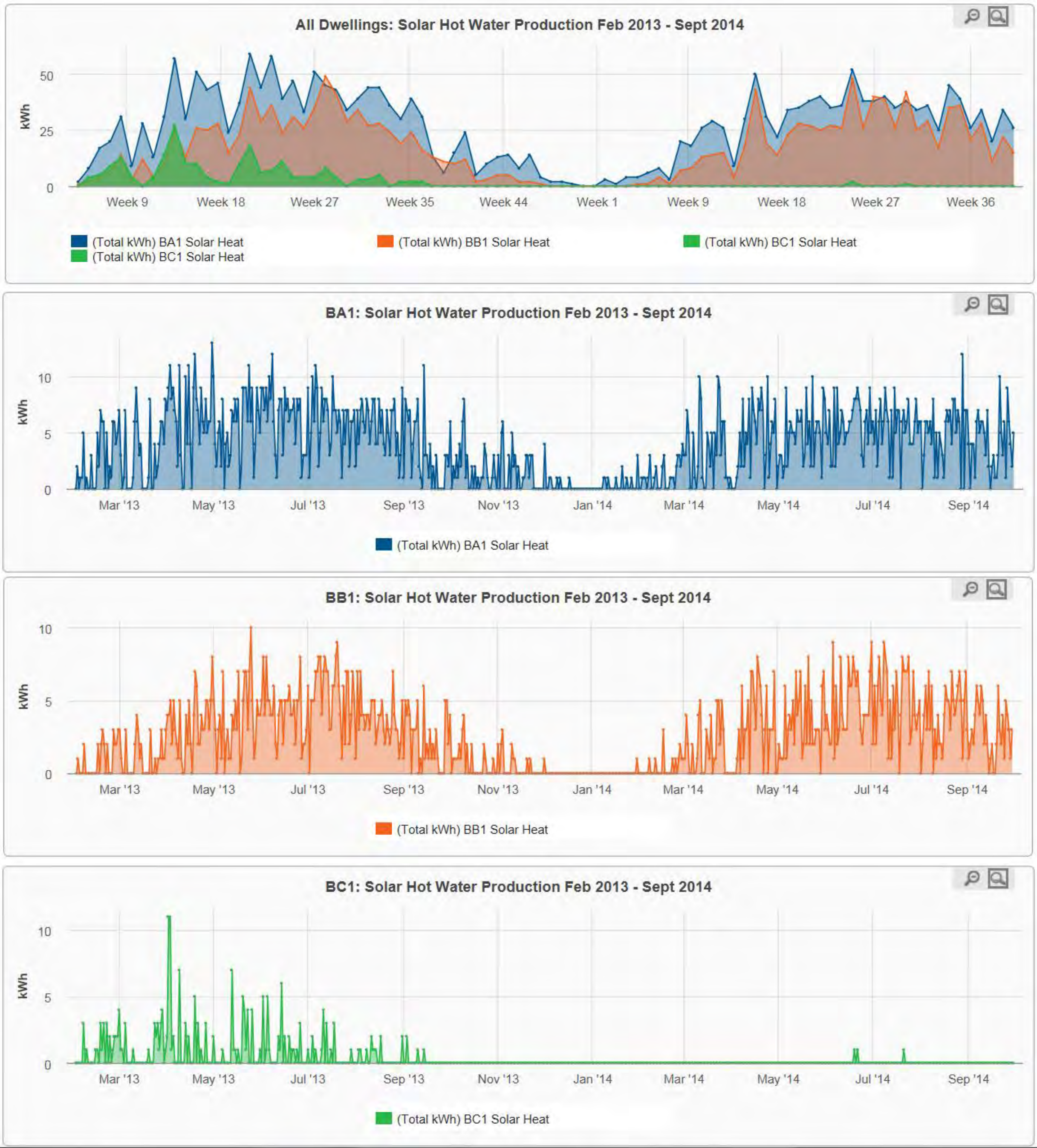


Figure 66: Solar hot water production Jan 2013 – October 2014.

Figure 66 shows the 2 year annual output from the solar hot water heating system, which clearly is seasonal in nature. Of interest is the period of time – between March and November – during which some contribution is made. This is important in the context of Scotland, where there is a general assumption that solar strategies, especially on the West Coast, may be less effective. There is clearly an issue with consumption in BC1 and this is discussed in more detail below.

The summary energy consumption was discussed in Section 2 in the SAP review. Figure 67 shows the total energy consumption for the houses and Figure 68 breaks this down into monthly consumptions. As with previous discussion, it is evident that BC1 with high demand temperatures is the highest energy consumer. BB1 is second highest – although demand temperatures are lower here, the poor fabric performance, reduced solar thermal production and more liberal ventilation regime (see Section 7.5) are through to be the main contributory factors.

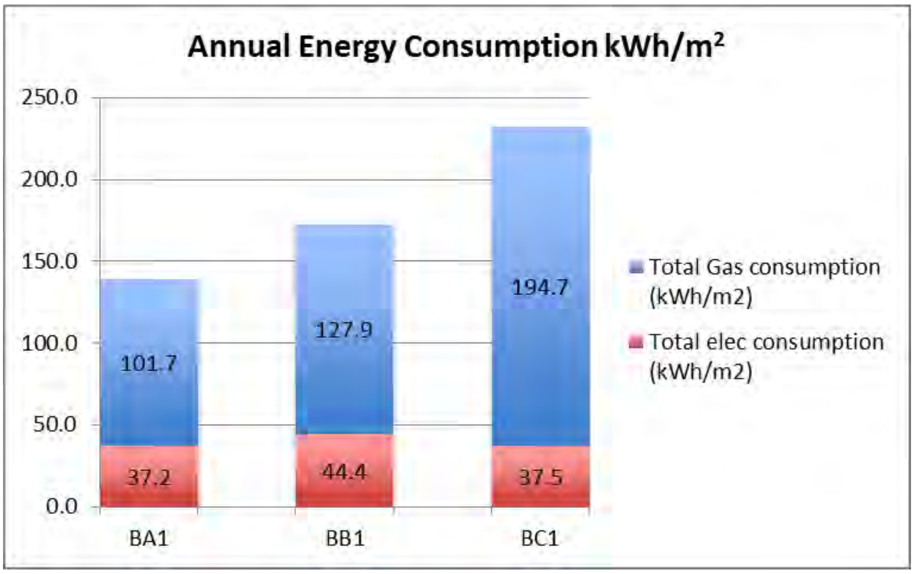


Figure 67: Overall energy consumption by dwelling.

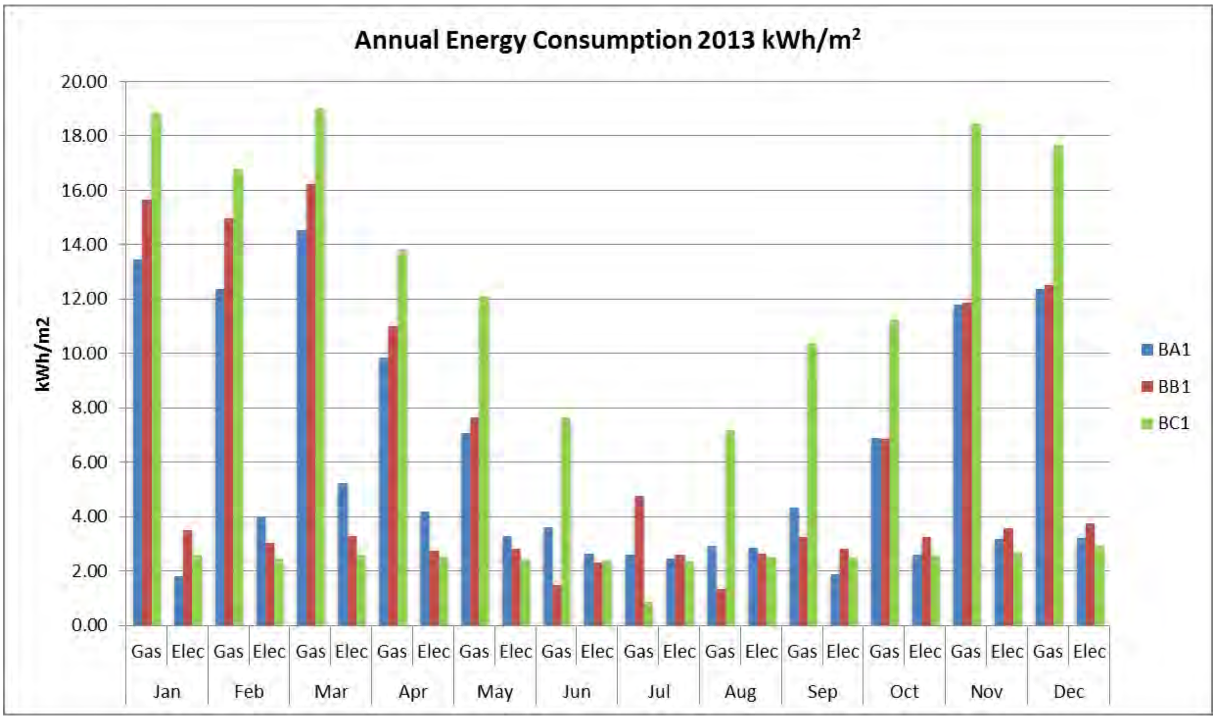


Figure 68: All Dwellings: Annual Energy Consumption (kWh/m^2) by month, 2013.

A DomEARM analysis has been undertaken and the sheets are contained in Appendix B. The data is based on 2013. As the project started in Autumn 2012 there is not yet 2 years worth of clear data, and some data losses were experienced in early 2014. The DomEARM analysis has been used to compare this consumption against benchmarks, this is shown in the following figures.

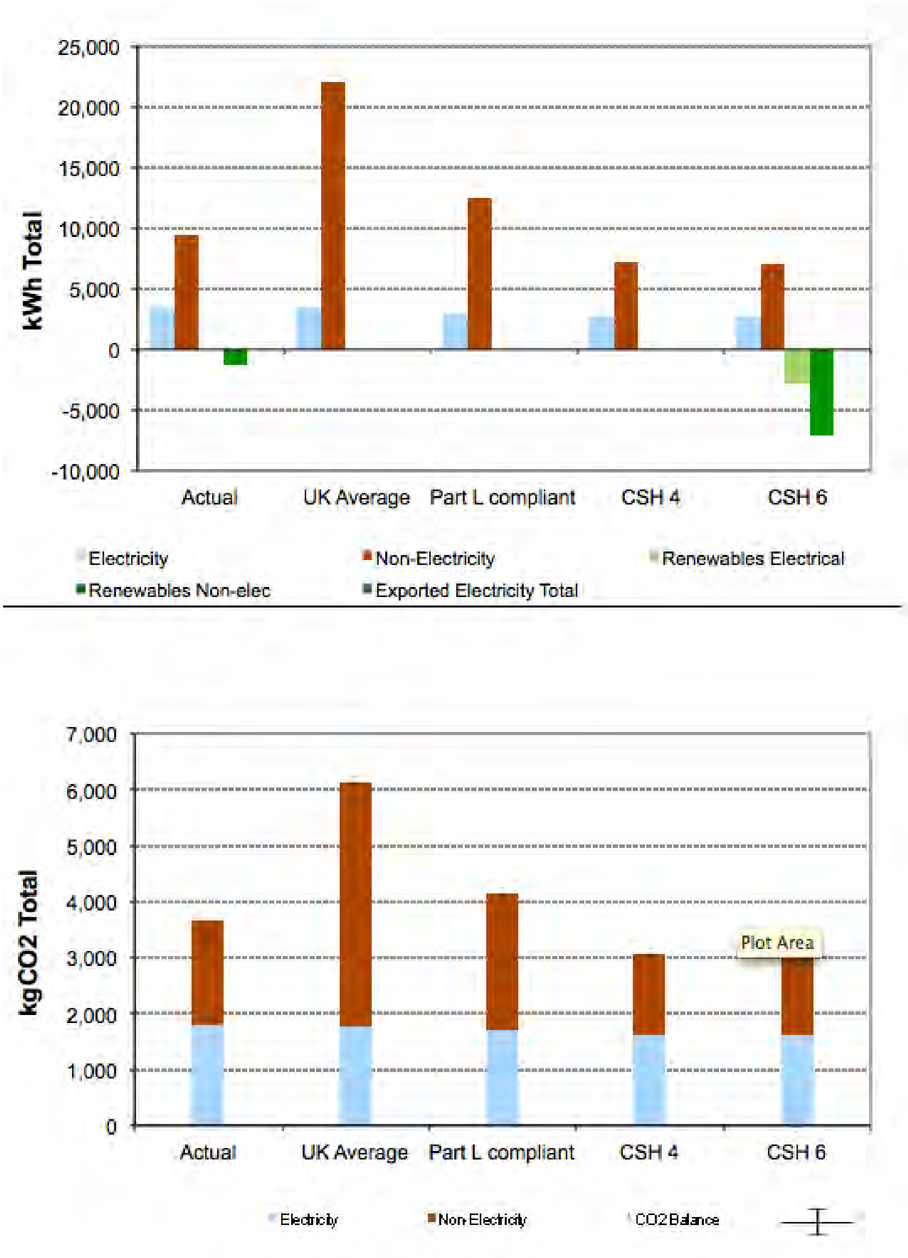
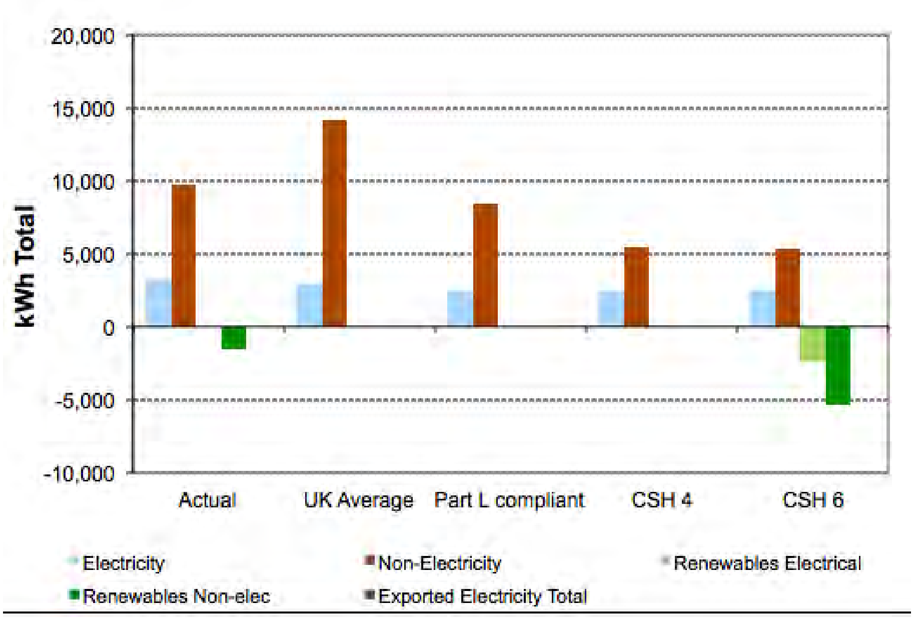


Figure 69: BA1 DomEARM comparison of actual energy use against benchmarks



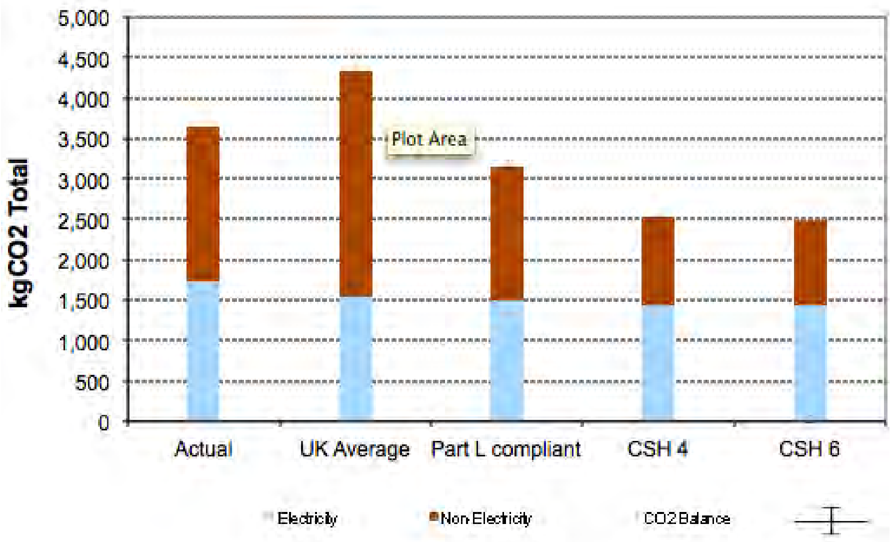
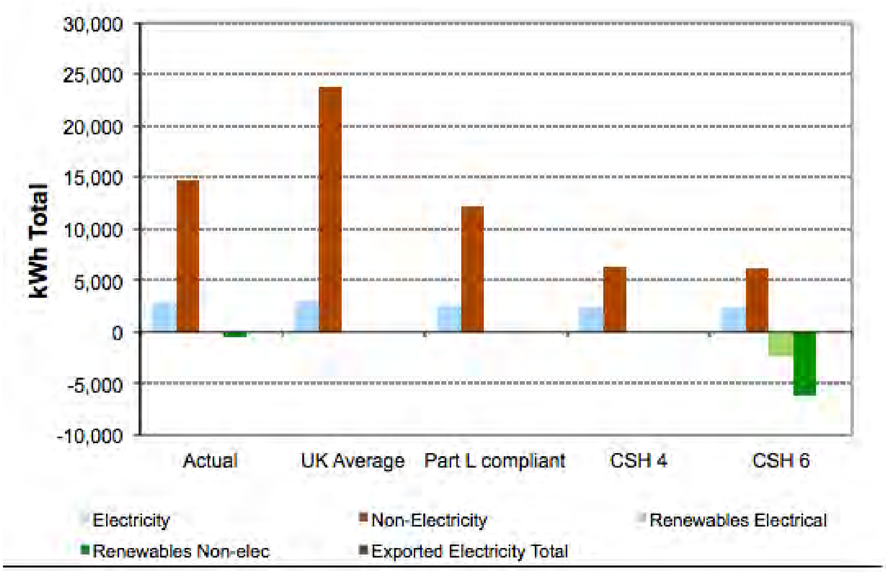


Figure 70: BB1 DomEARM comparison of actual energy use against benchmarks



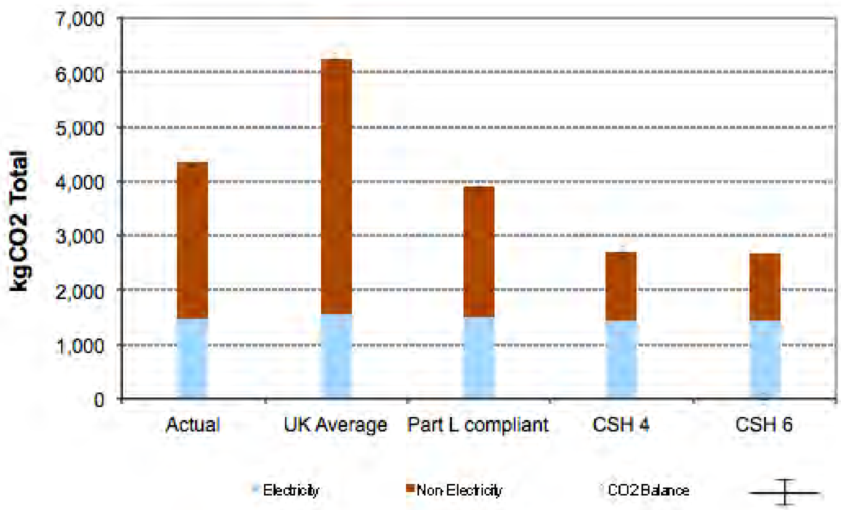


Figure 71: BC1 DomEARM comparison of actual energy use against benchmarks

This comparison of DomEarm data indicates that overall energy consumption for space and water heating is higher than benchmarks for current Part L compliance with the exception of BA1. These results are indicative of the performance gaps between expected and actual consumption, there may be several factors, which are contributing to this shortfall. These include: continued occupancy and higher demand temperatures in housing for older people; reduced contribution from the solar thermal systems; poorer fabric performance, especially in relation to insulation and openings; lack of control over heating systems.

It should be noted that the benchmarks are based on idealised, rather than actual measured data. Thus the Part L compliance is based on a calculated consumption rather than benchmarks of actual consumption of Part L houses. The DomEARM tool does not have benchmarks for Scottish Building Regulations: Section 6 Energy.

General electricity use is broadly in line with benchmark figures; in this case use BB1 has higher use. Breakdown on sub-metered data for electrical use is discussed in the following section.

7.3. Sub-metered energy

The measured sub-metered data for the properties is summarised below. There are two sources of sub-metered data: measured data taken on site (refer to section 7.2 for detail), and the DomEARM audit. In practice it has not been possible to combine these data sets as there are a number of uncertainties and mismatches. The three key areas identified for this are:

1. Variations between the named sub-circuits of the three houses and the sub-categories in DomEARM. These are a result of differences in sub-circuit and circuit labelling between dwellings and BPE projects; uncertainty as to supply circuits for elements such as the solar thermal system; combined circuits for prevent identification of separate kitchen appliances from other consumer electronics.

2. Some loads are very small leading to a discrepancy between the main electrical consumption and the sub-metered data. As the CT clamps in use can only detect loads of over 1 kW to generate a pulse, small loads may be unregistered. As the only solution offered was to pay for new clamps to be fitted this could not be afforded either in cost of time in the current project, but will be addressed in on-going monitoring to try to resolve the issue.

3. Mismatches in data indicate a number of unmetered sub-circuits. The lack of comparative circuits makes it difficult to identify where differences will be occurring. An obvious suspect would be the use of immersion heaters, although this was not reported, further enquiry is needed. The other possibility is that some spurs have been linked to unmetered circuits. Whilst in BC1 sub-metered loads exactly match the main electrical consumption and goes some way to verifying the functionality of the metering system, mismatches are apparent in BA1 and BB1. In these dwellings up to 33 – 45% of the sub-metered electrical load unaccounted for.

The second source of data for sub-metered energy is the DomEARM audit. A detailed audit of electrical appliances was undertaken in all the properties and this was used to generate a Level 3 analysis including estimates of electrical appliances. The following figures summarise the annual and monthly consumption from measured data between January – December 2013, and also show the results of the Level 3 analysis.

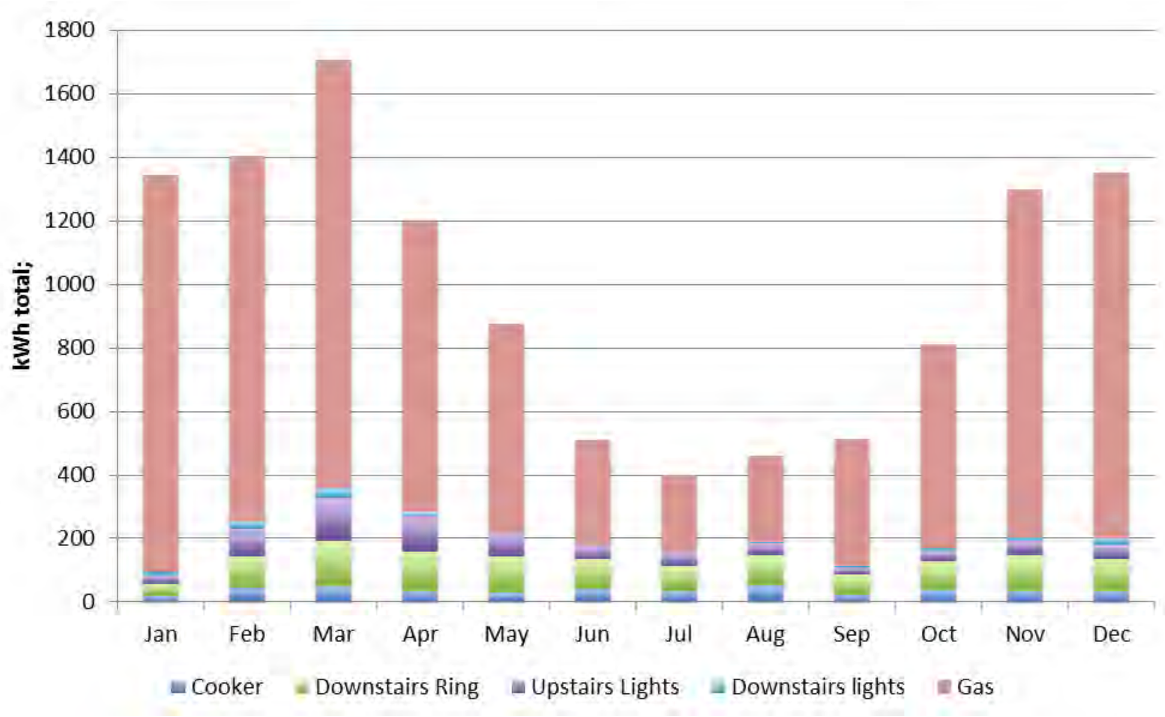


Figure 72: BA1 2013 Annual Monthly sub-metered energy use kWh

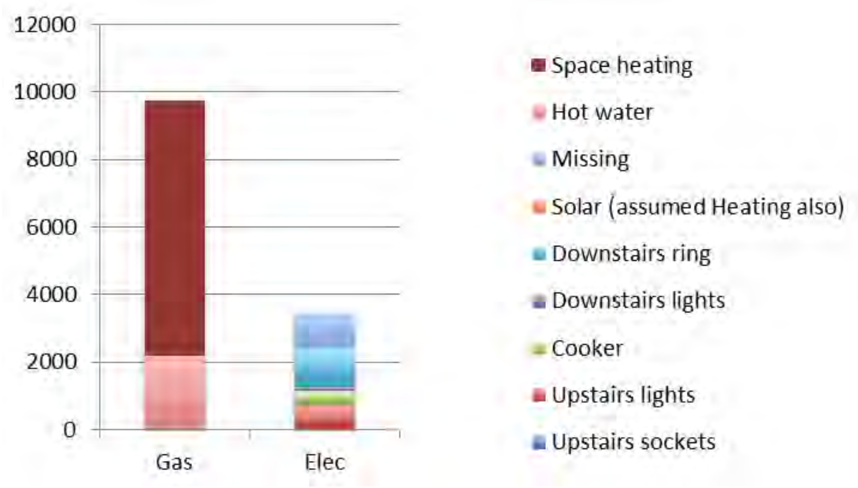


Figure 73: BA1 2013 Annual breakdown of measured energy consumption

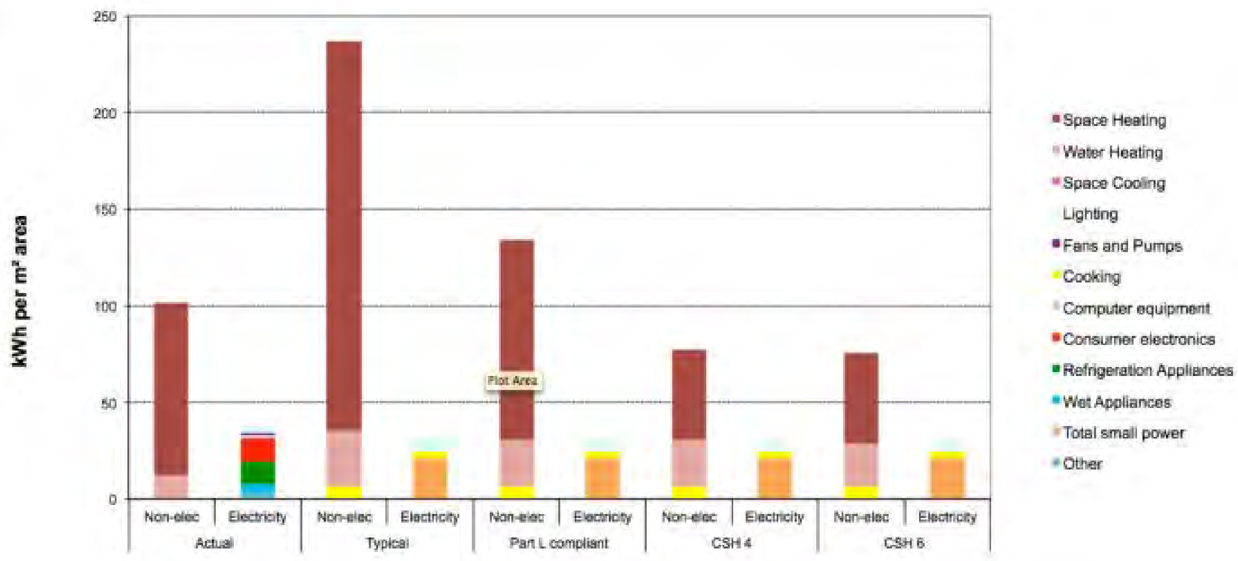


Figure 74: BA1 Level 3 DomEARM estimate of energy consumption

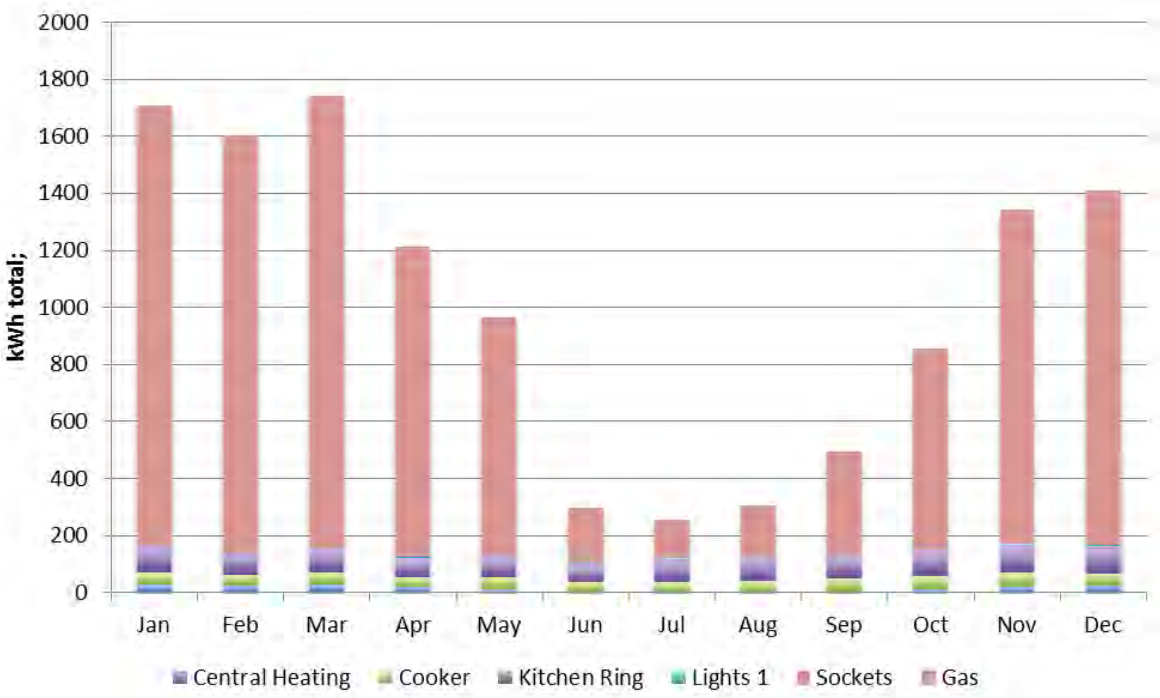


Figure 75: BB1 2013 Annual Monthly sub-metered energy use kWh

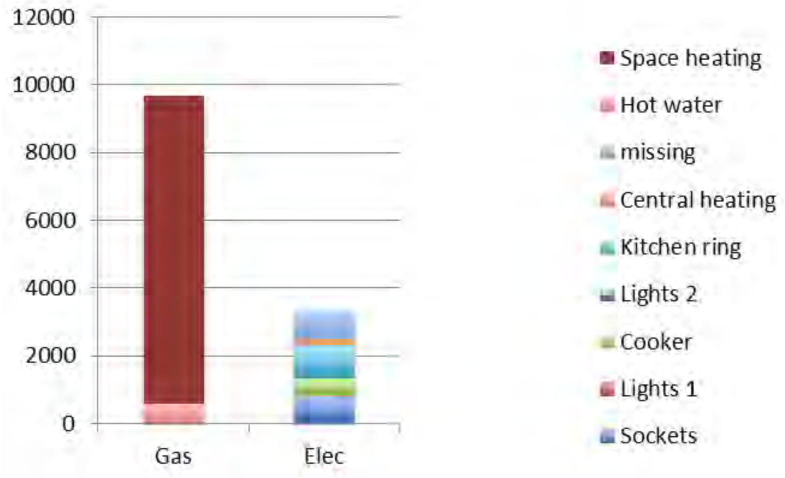


Figure 76: BB1 2013 Annual breakdown of measured energy consumption

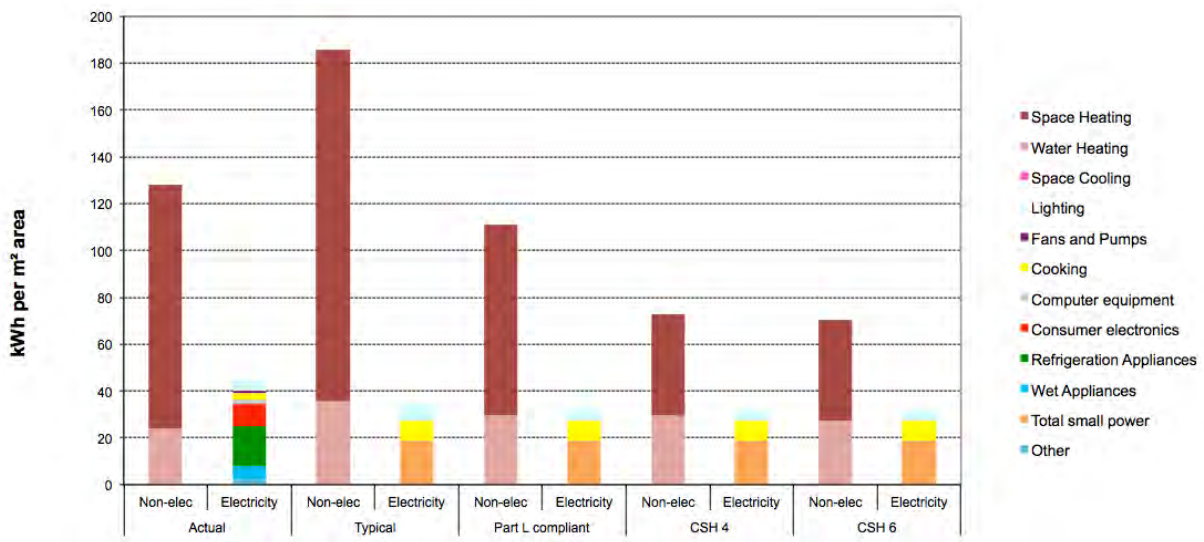


Figure 77: BB1 Level 3 DomEARM estimate of energy consumption

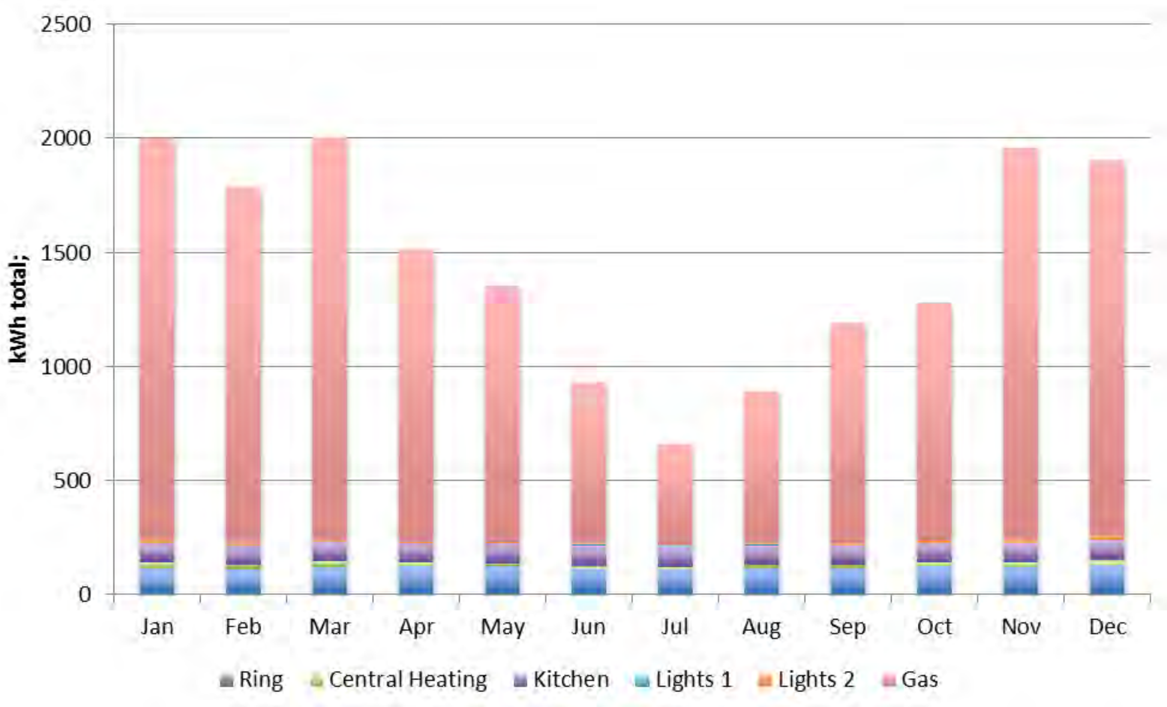


Figure 78: BC1 2013 Annual Monthly sub-metered energy use kWh

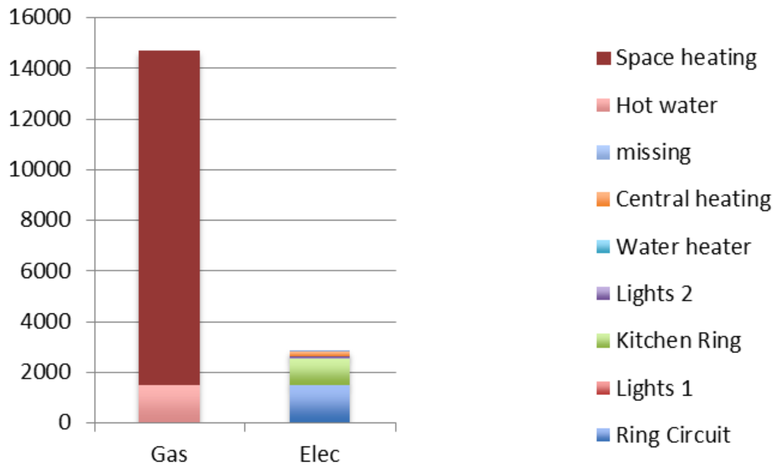


Figure 79: BC1 2013 Annual breakdown of measured energy consumption

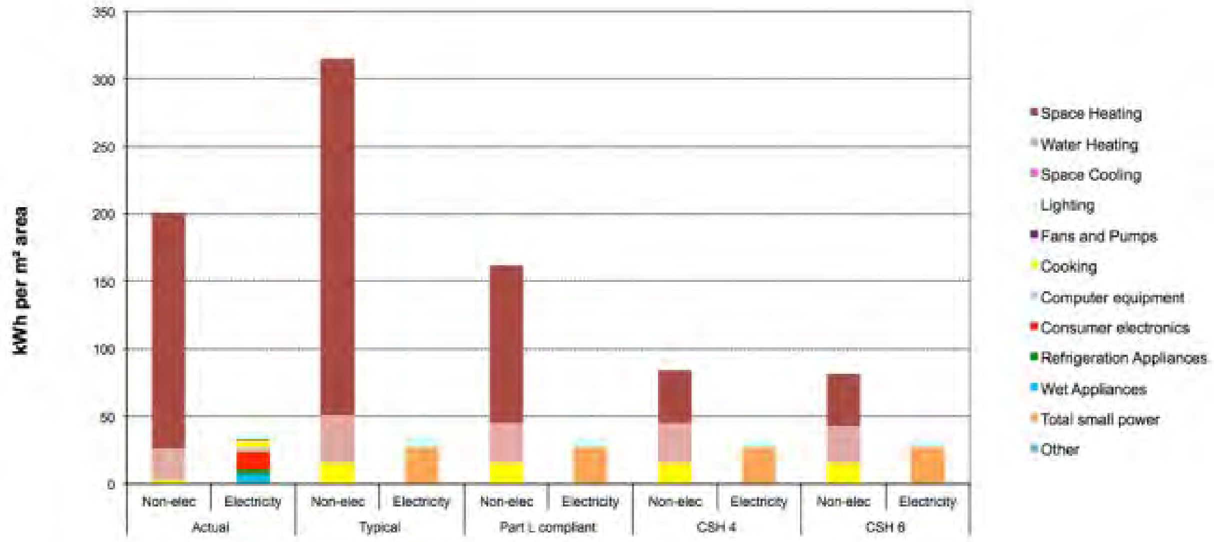


Figure 80: BC1 Level 3 DomEARM estimate of energy consumption

A cross comparison of the DomEARM electrical loads is shown in Figure 81.

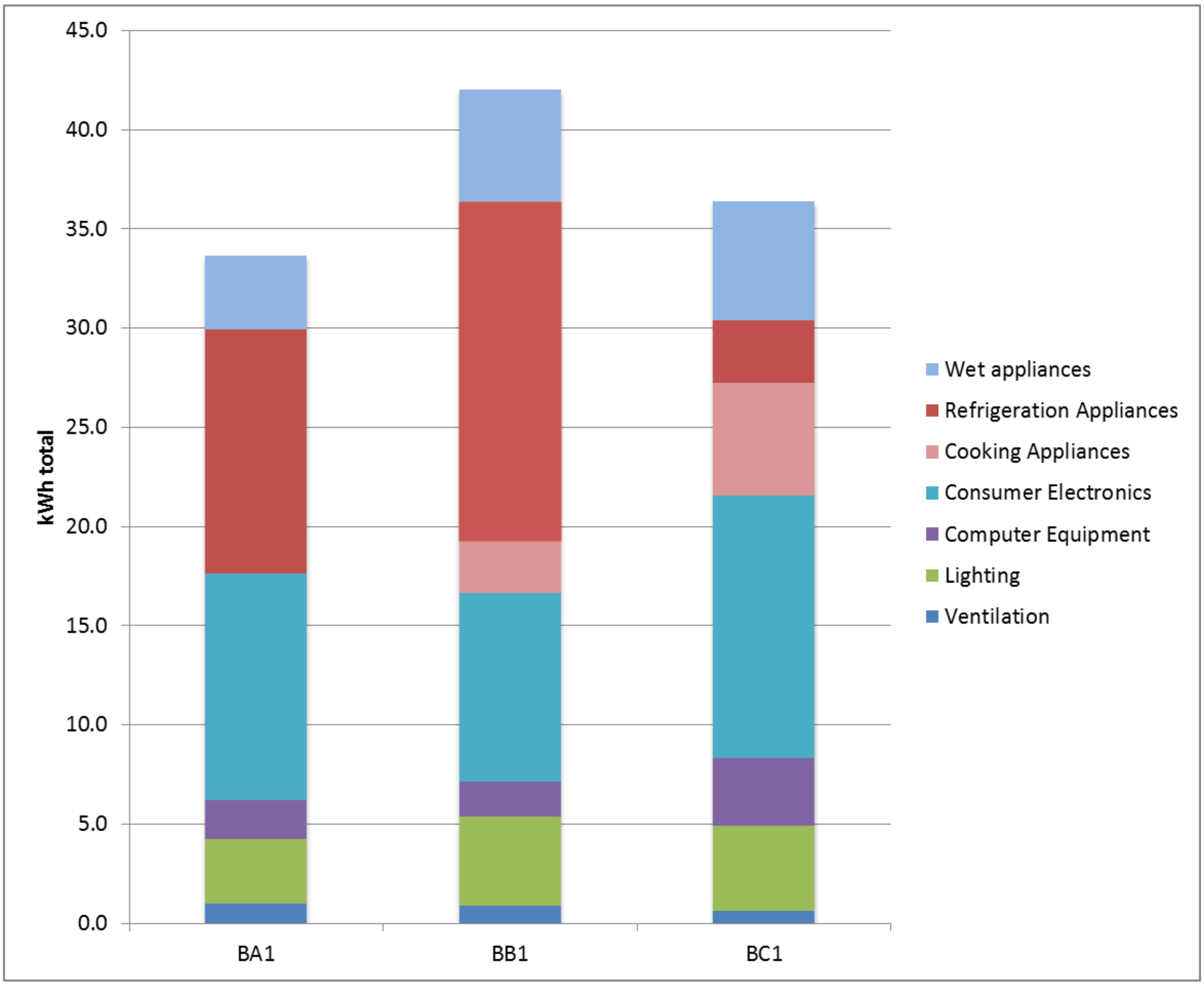


Figure 81: 2013 Energy Use kWh: Comparison of DomEARM electrical consumption between all three dwellings.

It is clear that the majority of the consumption related to electrical appliances in the kitchen. Use of fridges and freezers, washing machines and cooking are large loads. In BC1 refrigeration loads are smaller by a considerable margin due to the use of a very high efficiency fridge freezer using inverter technology. However large consumer electronic loads undermine this gain – in this house there is a very large TV system, which elicited comments from the occupants about its possible contribution to heating in the summer.

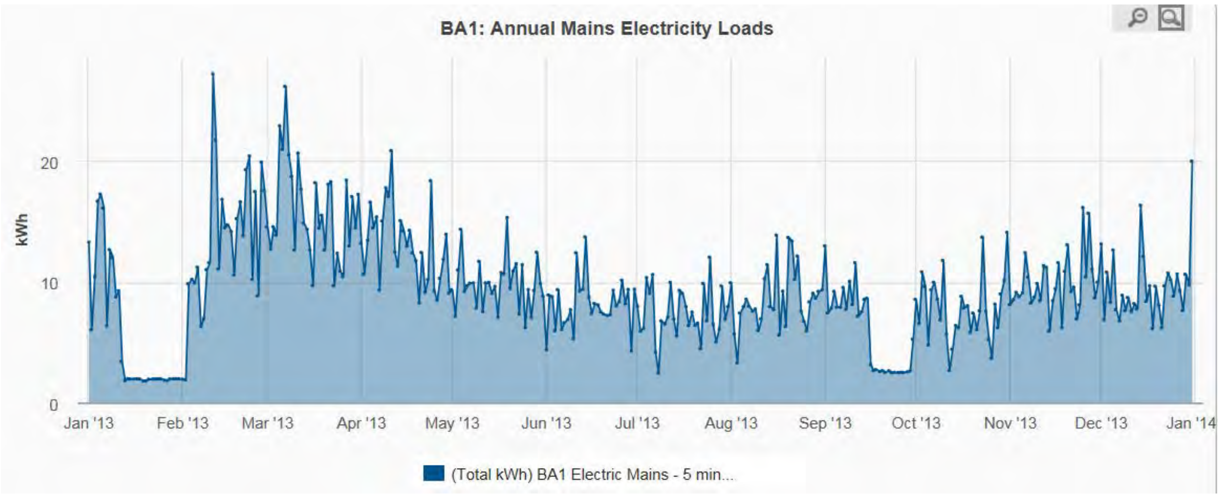


Figure 82: BA1: Annual Mains electricity loads

One interesting observation is the proportion of load due to stand-by. The BA1 annual electrical consumption reveals a number of instances where the occupants are absent. There is a period in later January where the house is un-occupied; one week of this period shows a consumption of 13.44 kWh, or 1.92 kWh/day. A similar absence in September (Figure 82) gives a weekly total of 17.9 kWh or 2.55 kWh/day. Comparing the latter period with the preceding week, which had a total consumption of 60.45 kWh, suggests that the standby and refrigeration loads may be some 30% of normal consumption. Some periods of higher consumption are also identified, for example following a holiday in January; electricity consumption is much higher for a period.

An issue with this type of tenure is that residents will frequently come to a new house with existing consumer equipment, some of which will be old and inefficient. For some appliance types, such as fridges and dishwashers there are very few drivers for upgrade (being mainly energy improvement, but with considerable capital costs). This is not the case with interactive appliances where new features (such as HDTC, soon to be replaced by 4K technology) encourage frequent replacement.

7.4. Solar Thermal Hot Water

The issues pertaining to the installation of the solar thermal system are discussed in Section 6, but the overall output of the systems were evaluated during the project. As identified in section 2.4, the original SAP calculations included a panel size of 4.68 m^2 (in all cases 2 No. 2.34 m^2 modules), this was also reported in the commissioning documents from the installer. Prior to the project problems had been identified at BC1 and remedial measures had been undertaken.

However, during construction it was apparent that due to the arrangement of the roof above the flats there was not enough for 2 panels and only a single panel was installed for BB1. This information was 'lost' in the construction process, and was not recorded in the commissioning sheets and so initial monitoring of output from the panels was at a loss to explain differences between the systems. However the construction review identified the change in panel arrangement.

The overall output from the systems over the entire monitoring period is shown in Figure 83. The output from BC1 has deteriorated during the second part of 2013 and remains poor. Further visits from the maintenance contractor have not yet identified any issues. Whilst there is a possibility that the error is due to monitoring, given that early monitoring did give an output similar to the other panels this is thought unlikely.

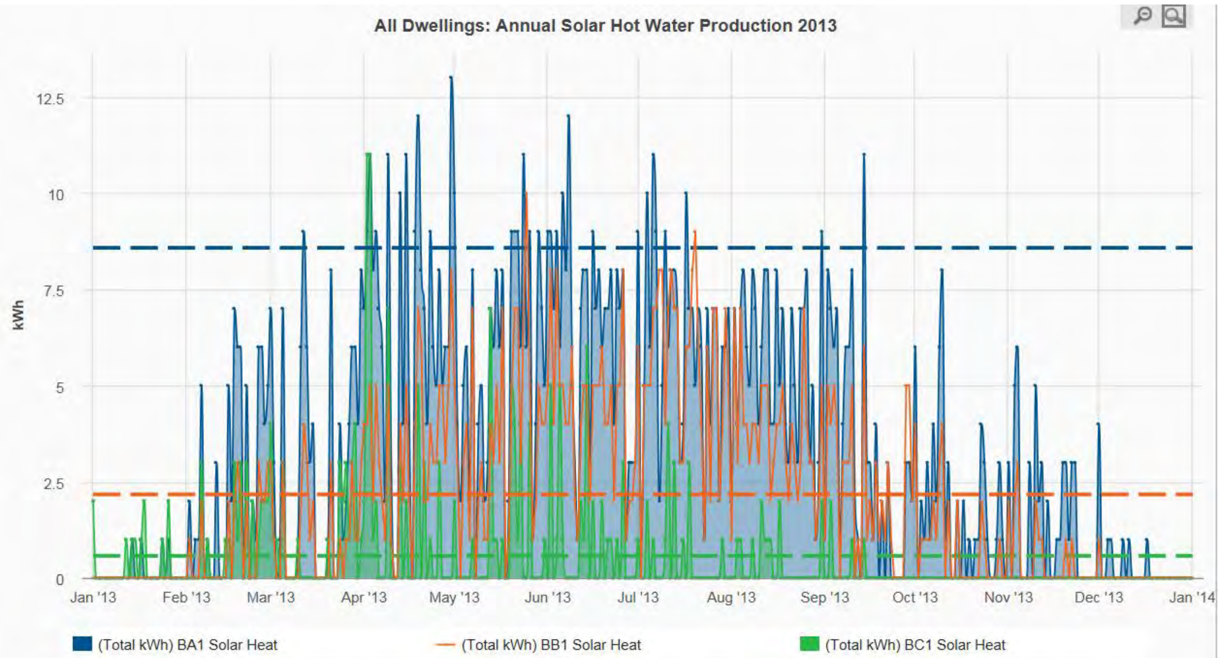


Figure 83: Solar Hot Water production Jan 2013 – Dec 2013.

Looking specifically at 2013, the overall production for 2013 is shown below, with 1298 kWh from BA1, 795 kWh from BB1 and 422 kWh from BC1.

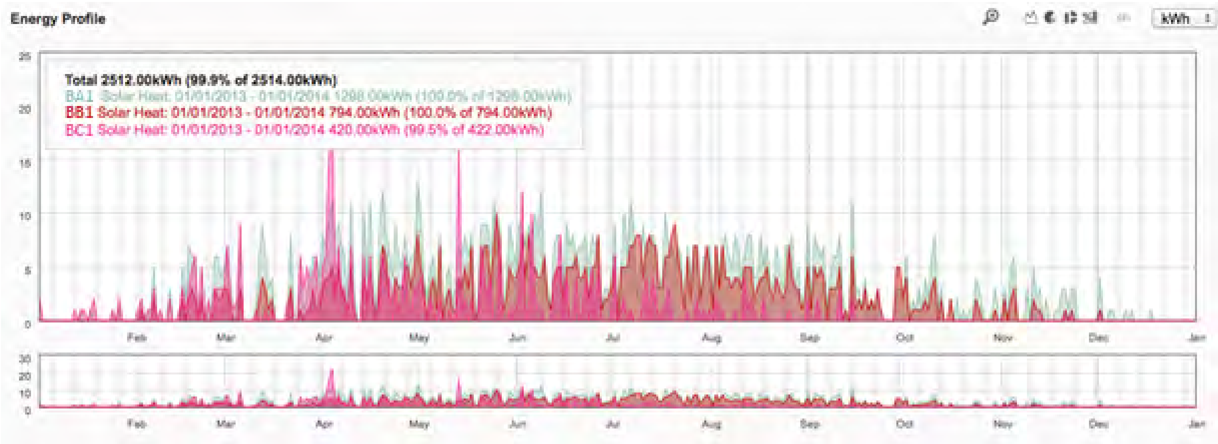


Figure 84: Annual solar thermal output 2013 for all three dwellings

For BA1 the hot water output of 1298 kWh exceeded the SAP figure of 1119 kWh, but both figures are below the commissioning sheet figure of 2340 kWh. The figure for BB1 was initially thought low at 794 kWh, but as this is a single panel the output for the area is actually higher. Although the panel in BB1 is half the size, the contribution is some 63% of the output from BA1. There is no obvious explanation for the differences in these results. Orientation and angle are the same (see Figure 48), the only key difference being the positioning of the panels, with the BB1 panel having a vertical position, it is therefore possible that this is resulting in higher gains as the temperature gradient between top and bottom is greater. The most obvious cause would be the relationship between hot water supply from the ST system and hot water demand. As the hot water demand is lower than the ST supply the system in BA1 will 'stall' more frequently as hot water is not being drawn off. The smaller ST supply from the panel in BB1 is more 'useful' as it is topping up actual demand.

Taking July 2013 as a sample month, both BB1 and BC1 consume 78 kWh of hot water and BA1 consumes 134 kWh. In the same period the ST systems produce 192 kWh in BA1, 170 kWh in BB1 (remembering the smaller panel size) and only 32 kWh in BC1.

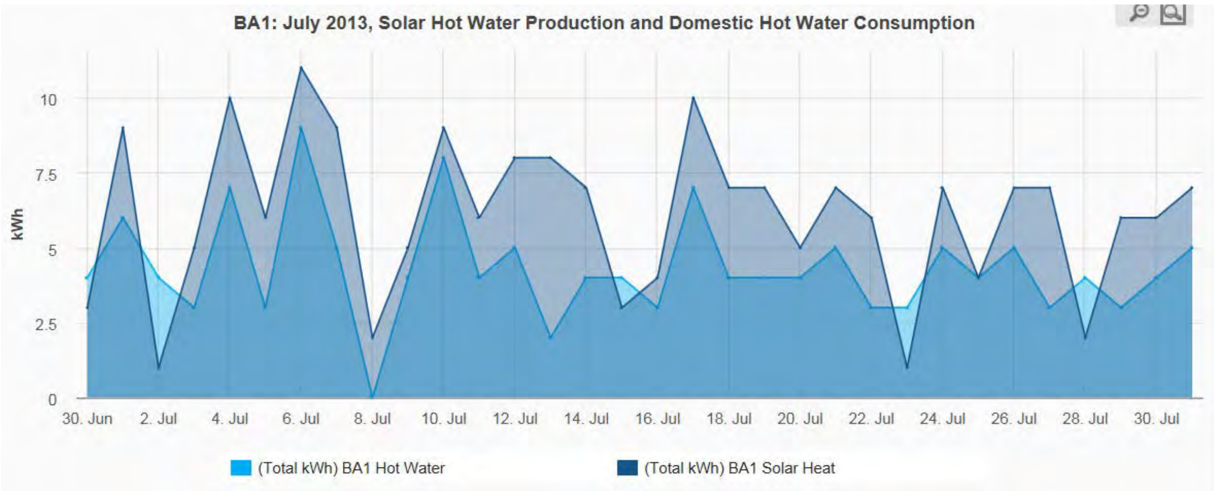


Figure 85: BA1, July 2013, solar hot water production and domestic hot water consumption.

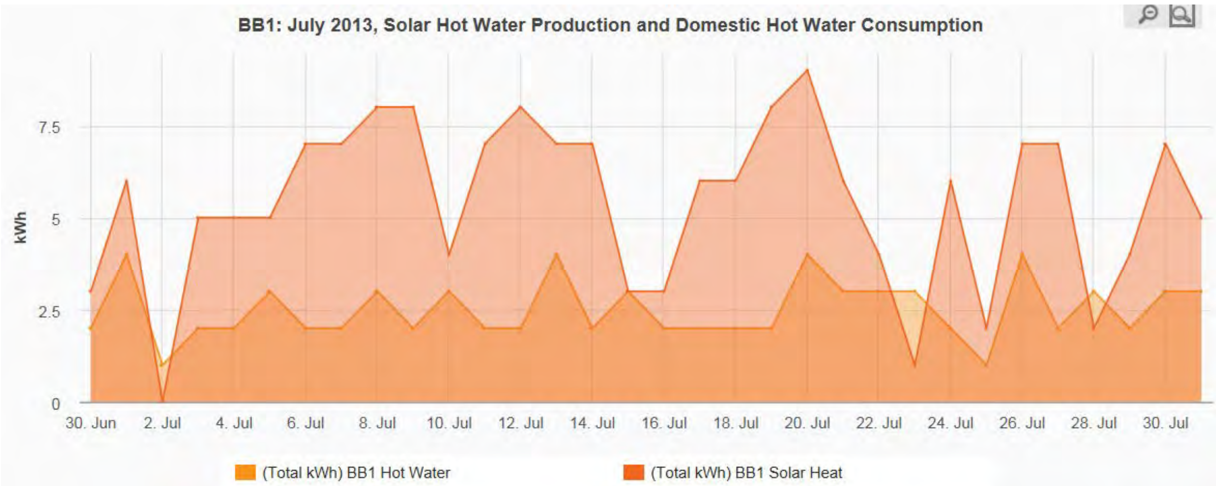


Figure 86: BB1, July 2013, solar hot water production and domestic hot water consumption.

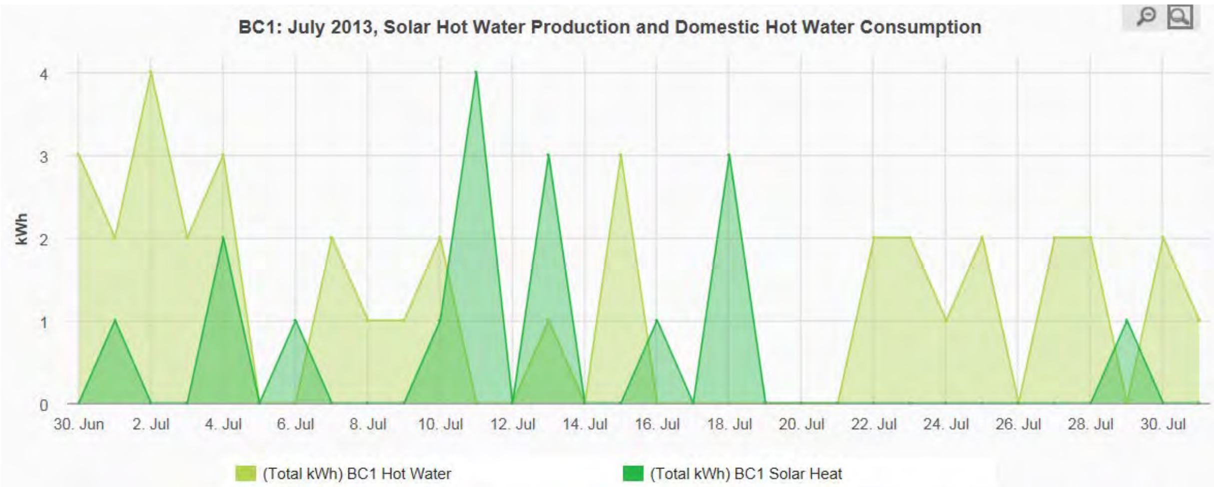


Figure 87: BC1, solar hot water production and domestic hot water consumption.

Looking at gas consumption during this period shows that the consumption generally inversely follows hot water production, with BC1 using 5x BB1 and 2x BB1.

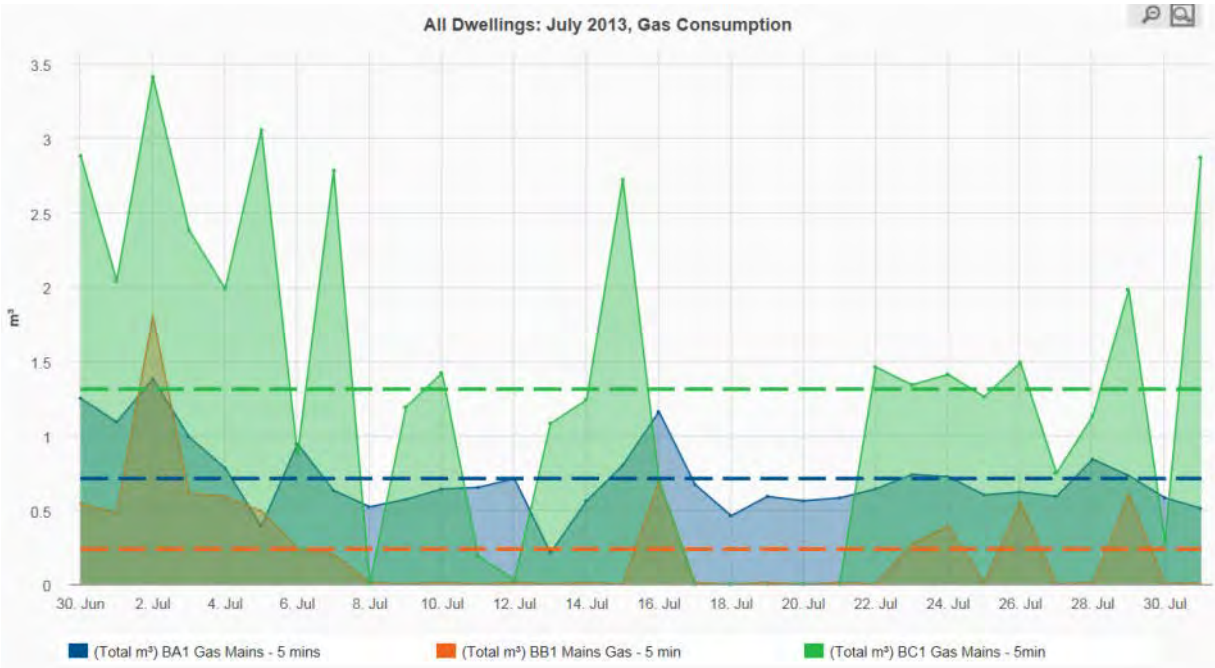


Figure 88: July 2013 all houses, gas consumption

However, gas consumption is 240 kWh in BA1, 28 kWh in BB1 but 441 kWh in BC1. Whilst this suggests that some space heating is occurring and temperatures are higher in BC1, space heating demands would be low at this time and the higher gas use suggests that consumption is increased due to a lack of solar thermal contribution and the poor performance of the system in BC1 would appear to be having some impact on running costs for BC1.

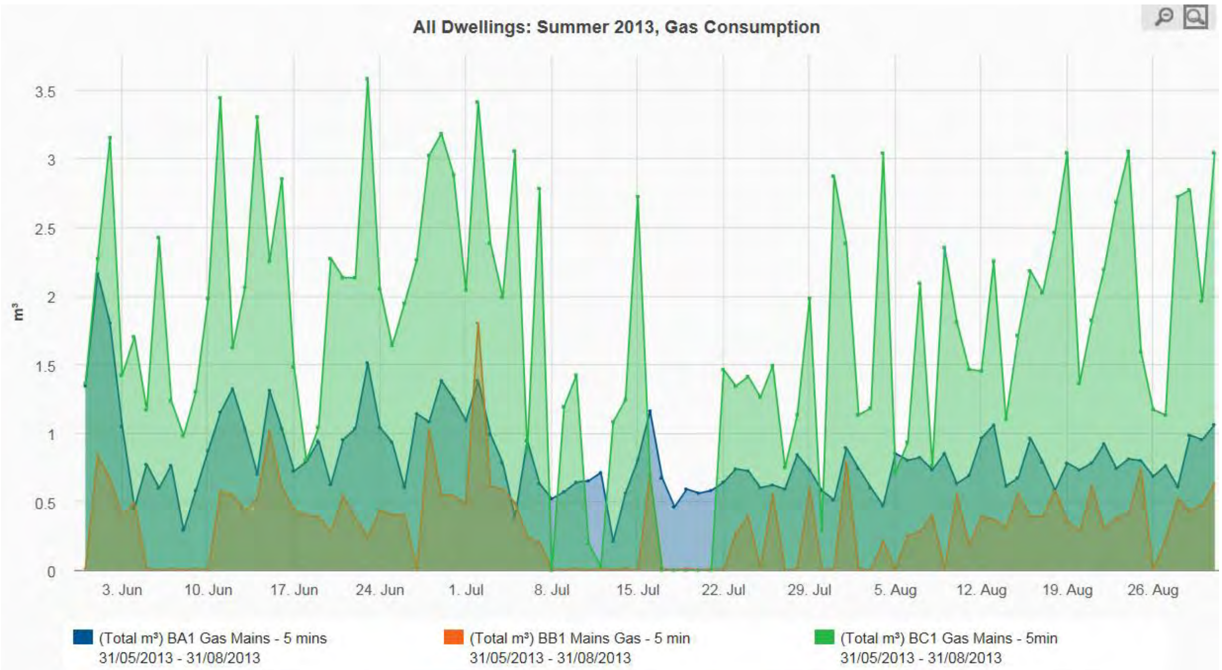


Figure 89: Gas consumption in all houses, Summer 2013

Overall gas consumption was higher for BC1, partly due to the higher temperatures being delivered. However, analysis of gas consumption for the summer months (Figure 89), when space heating requirements would be small, shows a significant difference, with BC1 consuming 1820 kWh compared to 846 for BA1 and 337 kWh for BB1. On a very rough estimate, and allowing for the relatively low hot water use in BC1, this could result in an additional cost of around £40 a year.

The overall patterns of hot water use raises the question as to whether the solar thermal system is an effective and appropriate system for this kind of development. As discussed in the design team interview, use of solar thermal systems has been mandated from the board, with costs incurred by HSHA, but the savings enjoyed by the occupants. The monitoring indicates that the overall value of heat is about £60 a year in BA1 and £35 a year in BB1. However this also assumed that all the heat generated is used - it is apparent that some heat generated in the summer will not be consumed and will be lost through pipework etc. In this project these losses will not contribute to space heating loads (as the cylinder is in the loft), which is a negative, but neither will they contribute to overheating (as seen in other projects) which is a positive. This does not include costs for maintenance, etc. This seems to be a relative small benefit for a significant capital cost, especially in BB1 where the tank, installation and pipework costs will be similar for a smaller panel. The overall savings in energy and costs terms are relatively small, especially given the problems experienced in terms of procurement and maintenance.

This raises the question about whether the solar thermal system is a good investment in this type of property. For relatively small hot water demands a demand driven system such as a combi boiler, may be a more effective system, without either the maintenance, heat loss/gain, or space overhead. The space heating demand remains the largest element of consumption, as might be expected for this type of occupant. A radical idea might be to assist with the purchase of low energy efficient appliances to reduce electrical consumption and incidental gains. With grouped and managed schemes such as this, communal systems are also more viable. Not only are there economies of scale with installation and maintenance costs, a shared system may balance out variations in demand. This argument also applies to space heating systems.

7.5. Environmental Conditions

The nature of the environmental conditions has been the subject of various discussions in the quarterly reports and an overview is provided here. For the purposes of this summary 2013 is used as the reference year (having a complete seasonal data set) and sample seasonal months are February, May, August and October.

Temperature

It is clear that the dwellings are providing warm, comfortable houses for the occupants, with reasonable energy consumption. As identified in earlier discussions there are clear differences in achieved performances between the dwellings, notably BC1 having higher temperatures in both living rooms and bedrooms. The bedroom of BB1 is cooler, this being the preference of the occupants to keep windows open at night and the effects of this are discussed under ventilation. Although overheating was observed in the houses in the summer this was primarily due to incidental gains and lack of ventilation rather than unwanted solar gains – the house with the highest living room temperatures has a north facing living room.

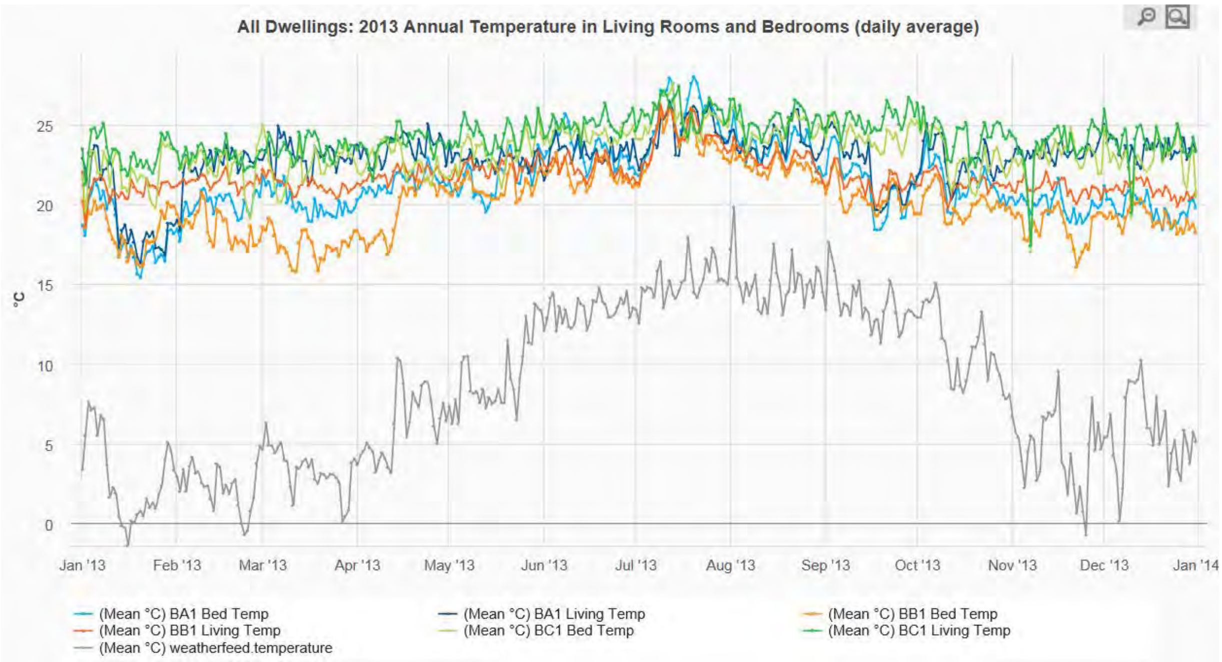


Figure 90: Annual Temperature in all houses, living room and bedroom (averaged daily).

The relative window opening habits and temperatures in the houses are shown in Figure 91; the following analysis aims to identify the effects of this. Looking at average temperatures over the course of the year shows that temperatures generally remain stable even during the coldest conditions, only dropping significantly during absences, and even then not to set back levels. There is a clear difference in levels of temperature being achieved in the different dwellings. BC1 has the highest temperatures by a significant margin, this is reflected in the overall gas consumption for space heating.

In these dwellings it is difficult to be prescriptive about demand temperatures as the occupants are older, with a number of health issues, and greater periods of occupancy, higher temperatures are not unreasonable. Nevertheless, temperatures achieved in BC1, even during periods of low external temperatures, are beyond comfort conditions (CIBSE seasonal comfort zones), resulting in additional heating costs. In the occupant surveys the BC1 occupants identified overheating in the summer, citing heat from the flat screen TV for example.

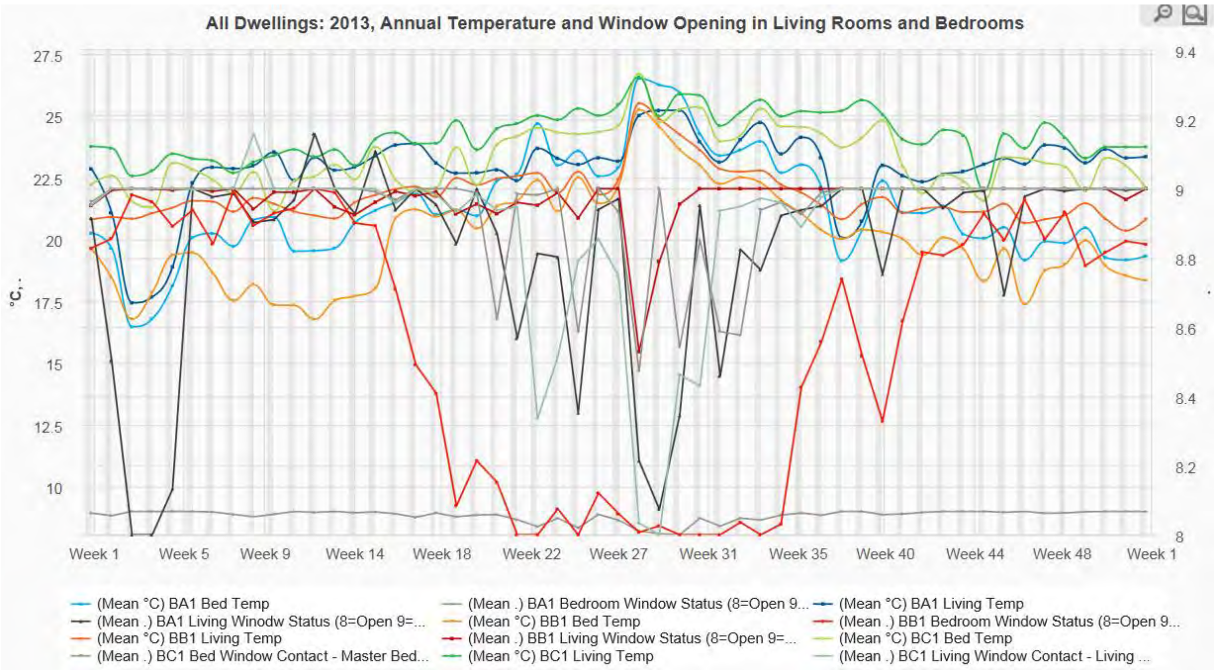


Figure 91: Annual Living room and Bedroom temperature, window opening (averaged weekly data – 9=closed, 8=open)

The other area of interest is the temperature in the bedrooms. There are noticeable differences in the temperatures being achieved in different dwellings. The occupants of BB1 prefer a cool well ventilated bedroom, in which the additional effects of window opening can be observed through frequent opening. The effects of this on ventilation and CO_2 levels are discussed later, but this is also reflected in the overall temperatures, which are generally lower than in the other two houses.

A question arising is whether frequent window opening is resulting in additional heat loss and energy consumption. It is difficult to make an exact comparison between BA1 and BB1, the former being a two story mid terraced house, the latter an upper floor flat, but, taking into account hot water use and different contributions from the solar thermal system, overall energy consumption is similar. The proposition here is that window opening in bedrooms at night may not result in undue heat loss if the heating is not on. Whilst it may affect temperatures and comfort, for some occupants, a cooler, fresher bedroom is seen as healthy and desirable.

The other factor is that the thermal mass of the walls in BB1 may be contributing to an improved mean radiant temperature. However, BB1 also had a poorer U-value for the wall construction and along with the weaknesses on the roof insulation, this may be leading to greater heat loss. The table below reveals these trends in the seasonal data in more detail.

Winter – February 2013

	BA1 BED T	BA1 LIV T	BB1 BED T	BB1 LIV T	BC1 BED T	BC1 LIV T
Average	19.92	22.41	18.43	21.43	22.32	23.01
Max	22.60	26.00	22.20	25.80	26.60	27.60
Min	15.80	19.80	15.00	15.60	17.40	17.00
SD	1.26	1.24	1.48	2.11	1.86	2.52
W/O	7%	9%	8%	1%	0%	0%

Table 11: February summary temperature data

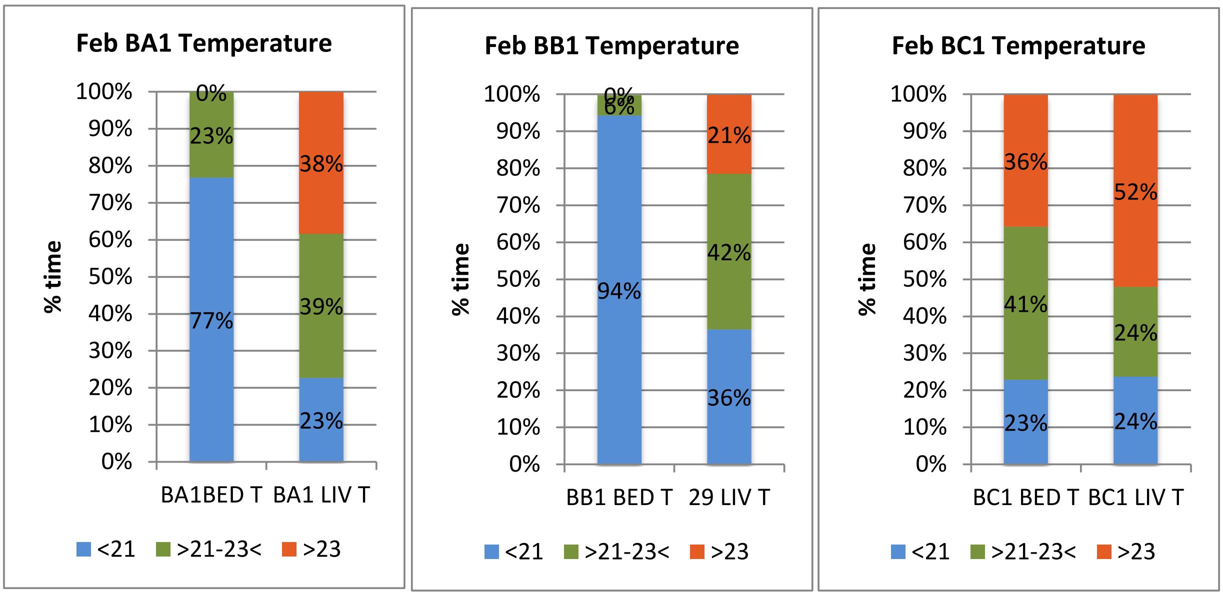


Figure 92: February summary temperature distribution

The average external temperature during February 2013 was 2.33 ^{o}C, max 12.00^{o}C and min -5 ^{o}C. The clear difference is in BC1 in which the living room is 23 ^{o}C for more than 52% of the time with an average temperature of 23.01 ^{o}C. Although the mean temperature is only slightly above that of BA1, the standard deviation is much higher, demonstrating a relative lack of control and tendency to overheat. The bedroom is equally warm with a peak of 26.60^{o}C and an average of 22.32 ^{o}C, much higher than the other two houses.

Spring – May 2013

	BA1 BED T	BA1 LIV T	BB1 BED T	BB1 LIV T	BC1 BED T	BC1 LIV T
Average	21.65	22.74	21.05	22.39	23.40	24.41
Max	25.20	26.00	24.00	26.80	27.80	29.20
Min	18.00	19.80	18.20	17.40	19.20	19.00
SD	1.33	1.24	1.09	1.51	1.56	2.09

W/O	15%	13%	91%	6%	10%	4%

Table 12: May summary temperature data

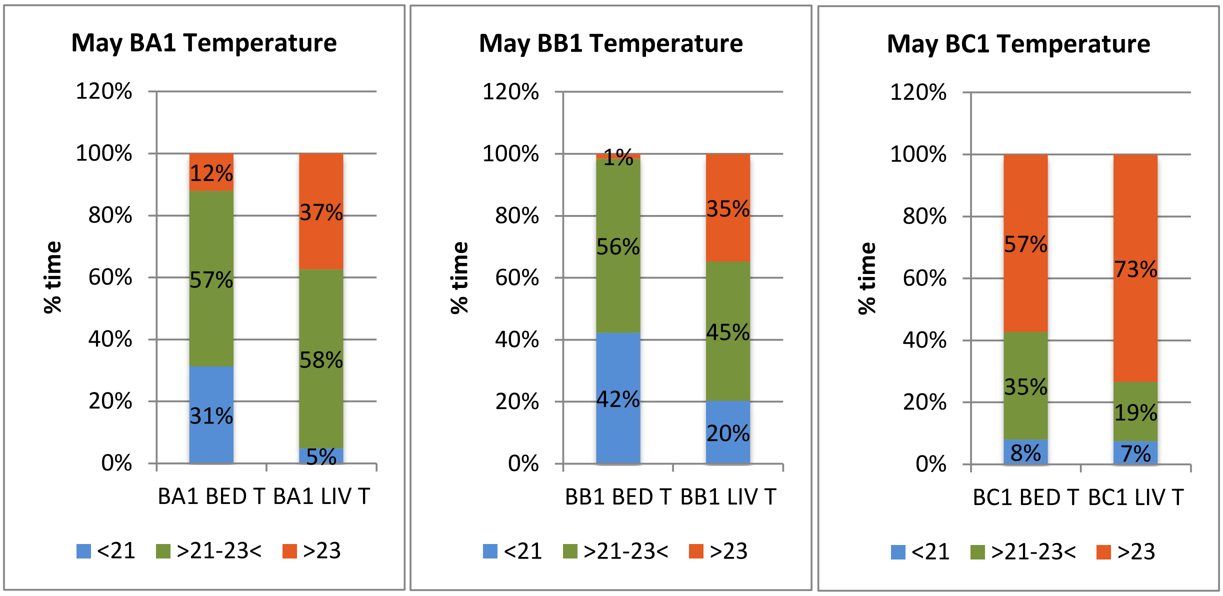


Figure 93: May summary temperature distribution

Of interest here is the greater propensity for overheating. The average external temperature this month was 9 °C, still reasonably cold and well within a heating regime. In this period BB1, which has thermal mass and a night-time window opening regime, is performing well, but there are still periods of overheating (over 26 °C in bedrooms, over 28 °C in living areas). However in all the houses average temperatures were higher. This represents a seasonal lag where heating and ventilation regimes established during the winter persist into the spring. However, it may also reveal deficiencies in the control systems, whereby stable temperatures that should be provided by thermostats and TRV's are not being achieved. The difference in temperature in BA1 which has a more liberal window opening regime in the bedroom is clear.

Summer – August 2013

	BA1 BED T	BA1 LIV T	BB1 BED T	BB1 LIV T	BC1 BED T	BC1 LIV T
Average	23.63	23.87	22.29	22.85	24.69	25.26
Max	27.00	28.60	25.00	26.60	26.80	29.40
Min	21.00	21.00	20.20	19.40	22.20	21.40
SD	1.03	1.47	0.85	1.24	0.88	1.57
W/O	32%	24%	99%	0%	22%	10%

Table 13: August summary temperature data

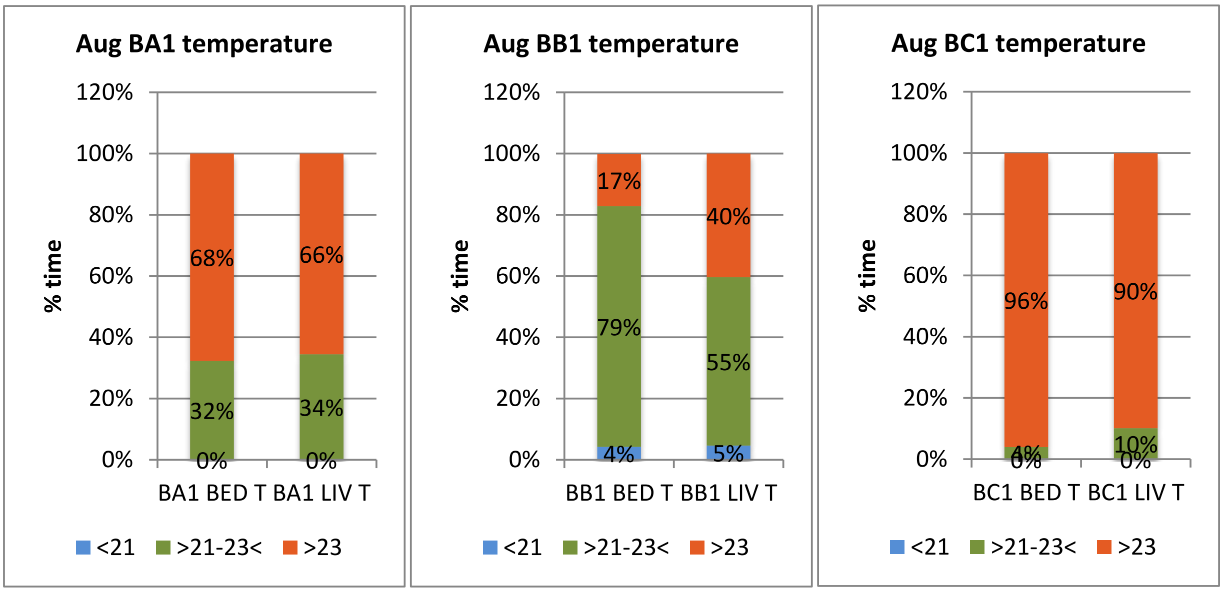


Figure 94: August summary temperature distribution

Average external temperatures during August were 17 ^{o}C with peaks of 23 ^{o}C. There was some overheating in all three dwellings, with average temperatures in BC1 Living Room of 25.26 ^{o}C and 24.69 ^{o}C in the bedroom. Once again BB1 has the most prevalent comfort conditions. Of note is the lack of living room window opening, but almost continuous bedroom window opening. Keeping the living room window closed does help to avoid ambient external gains, whilst the open bedroom window at night assists with the purging of the thermal mass.

In this period BA1 achieved high temperatures, particularly in the Living Room, with an average temperature of 23.87 ^{o}C and a maximum temperature of 28.60 ^{o}C. Of equal significance are the higher temperatures in the bedroom, maximum 27 ^{o}C, and average 23.63 ^{o}C. This is because both the living room and bedroom have south facing windows, during summer 2013 the planting had not yet reached maturity. As the bedroom is the only upper level room monitored, some additional heat gain is occurring due to thermal buoyancy as heat rises in the house.

The summer temperatures in BC1 are of particular concern, with average temperatures in the 'warm' ranges, but high temperatures consistently registering well above 'overheating' guidance. The minimum temperatures recorded during this period are within the 'comfort' range. However, this is a difference of 8^{o}C between the lowest and highest recorded Living Room temperatures.

Autumn – October 2013

	BA1 BED T	BA1 LIV T	BB1 BED T	BB1 LIV T	BC1 BED T	BC1 LIV T
Average	21.36	22.68	19.91	21.31	22.92	24.35
Max	26.20	28.00	22.60	25.40	26.60	28.80
Min	17.80	19.20	17.00	17.60	19.20	19.00
SD	1.28	1.61	1.12	1.41	1.62	2.01
W/O	6%	6%	34%	0%	0%	0%

Table 14: October summary temperature data

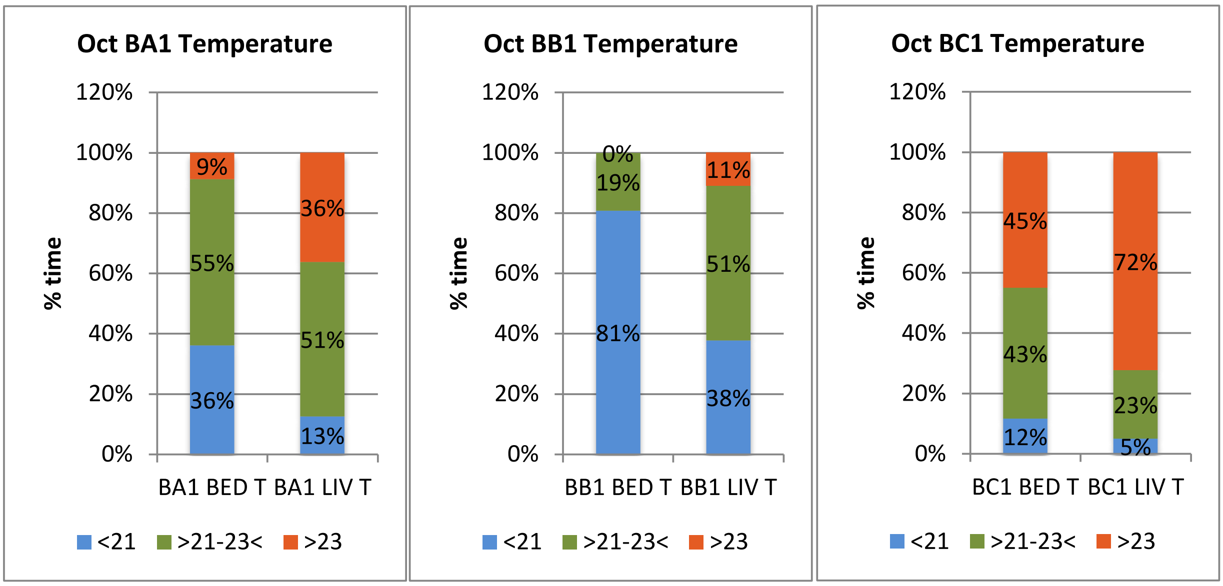


Figure 95: October summary temperature distribution

The average external temperature in October is 10.91 ^{o}C, not dissimilar to May. The general pattern of achieved temperatures is very similar to the spring period.

Window opening patterns

Looking specifically at bedroom data in Figure 96 shows the general pattern of window opening and bedroom temperatures across all three houses. Several things are apparent. Firstly, BB1 has the most frequent window opening and temperatures are also the lowest. The occupants of this dwelling prefer to keep the bedroom windows open at night and this clearly impacts on temperature but also CO_2 (discussed in the next section). In the autumn, BC1 remains consistently warm to hot despite falling ambient conditions.

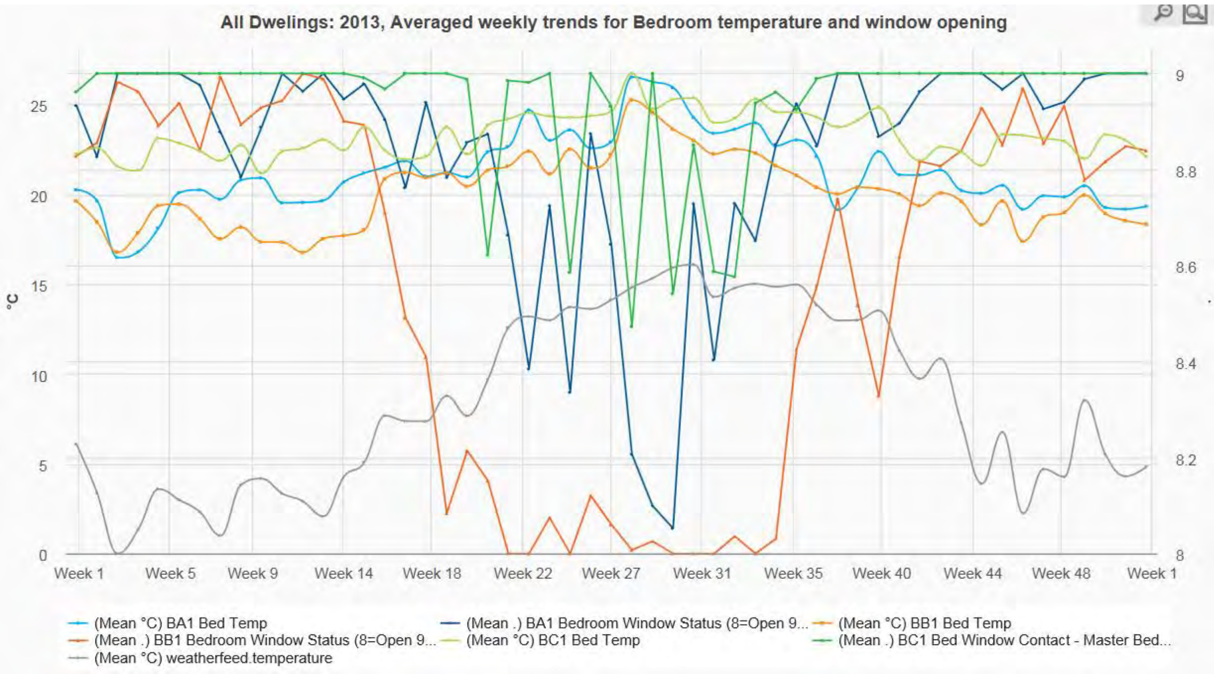


Figure 96: Averaged weekly trends for Bedroom temperature and window opening all bedrooms, 2013

Looking at specific periods indicates the effects of this, for example in February increased external temperatures led to an increased frequency of window open in in both BA1 and BB1 and the bedroom temperature reflect this. However in the same period the windows in BC1 remained closed and temperatures are much higher.

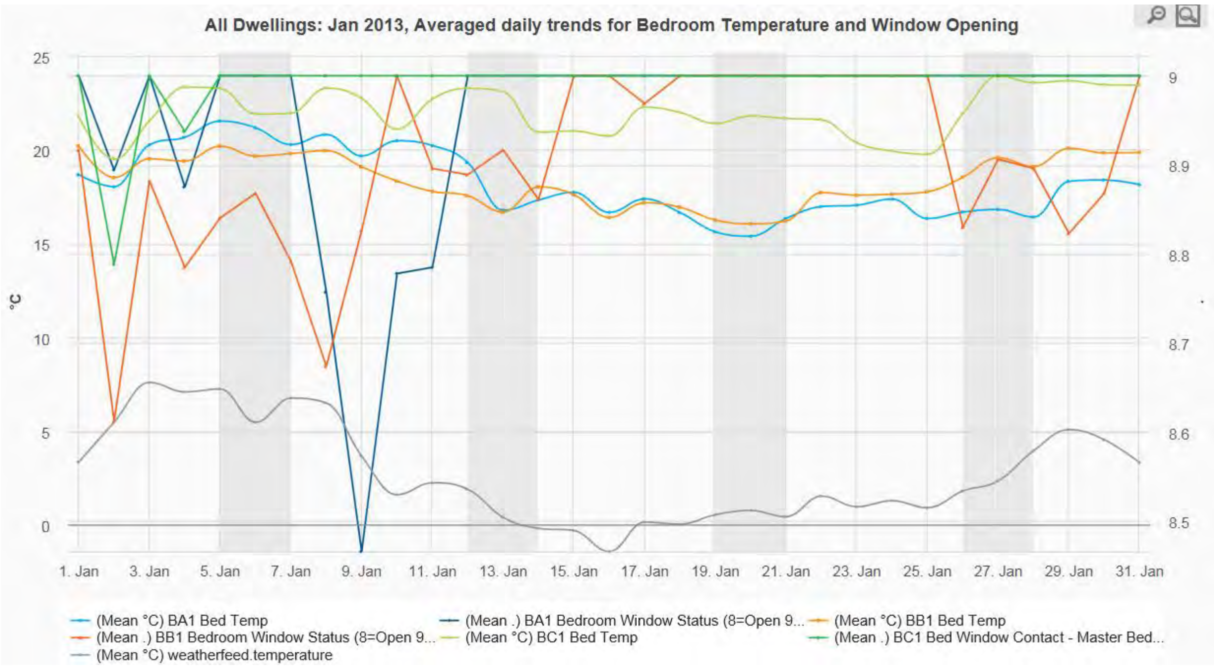


Figure 97: Averaged daily trends for Bedroom temperature and window opening all bedrooms, January 2013

In the autumn period, with external temperatures declining the frequency of window opening in BA1 decreases, and lessens in BB1 but is still frequent and in BC1 windows remain closed.

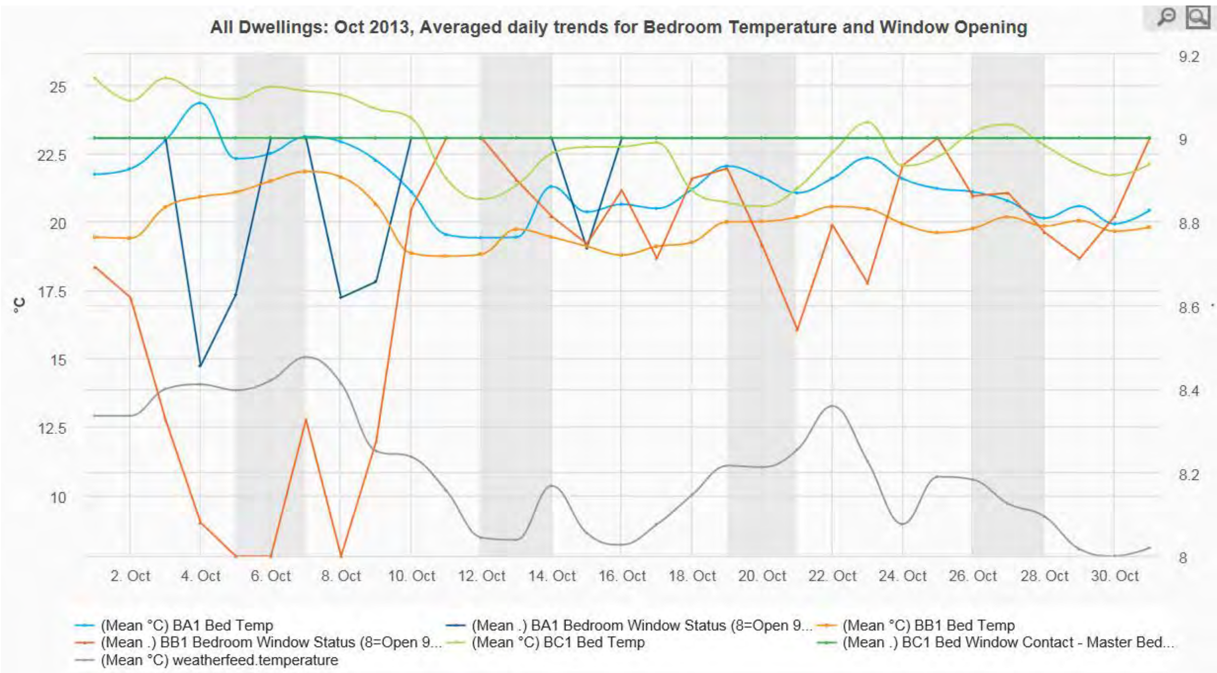


Figure 98: Averaged weekly trends for Bedroom temperature and window opening all bedrooms, October 2013

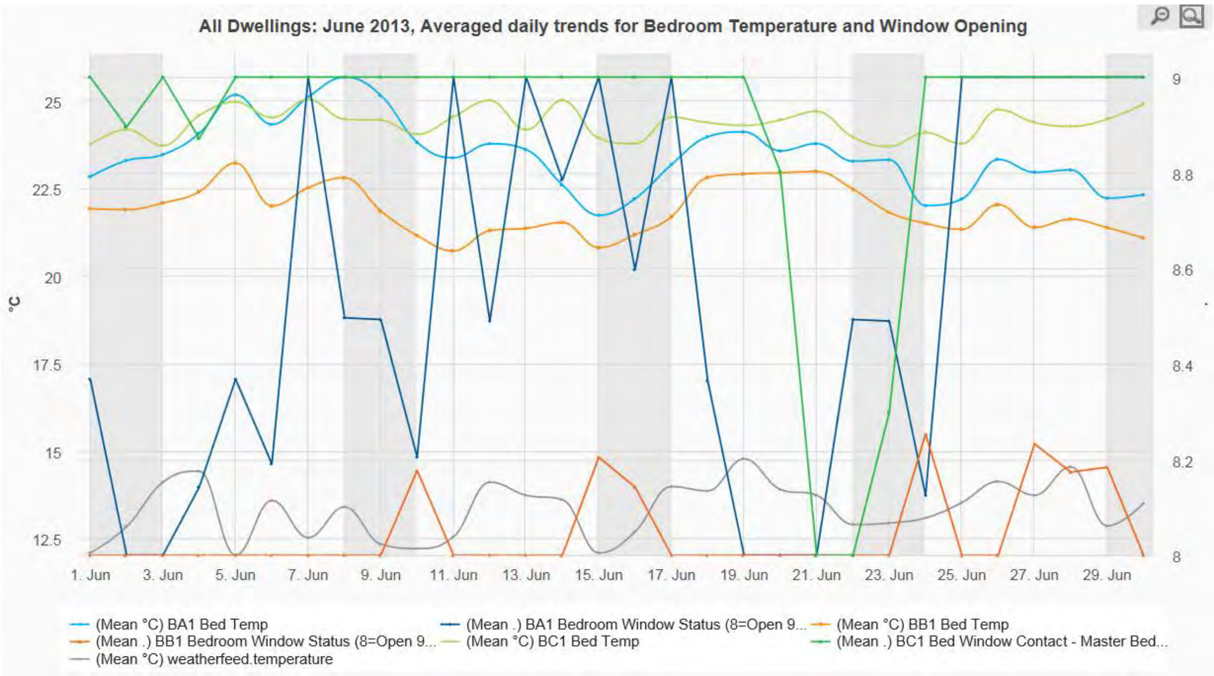


Figure 99: Averaged daily trends for Bedroom temperature and window opening in all bedrooms, June 2013

In the summer windows are opened much more frequently, there is a clear comparison between frequency of window opening and the temperature. The only negative temperature issue encountered during the study was that of overheating. During the summer months, high temperature consistently about 25 ^{o}C are seen in all houses, well above ambient.

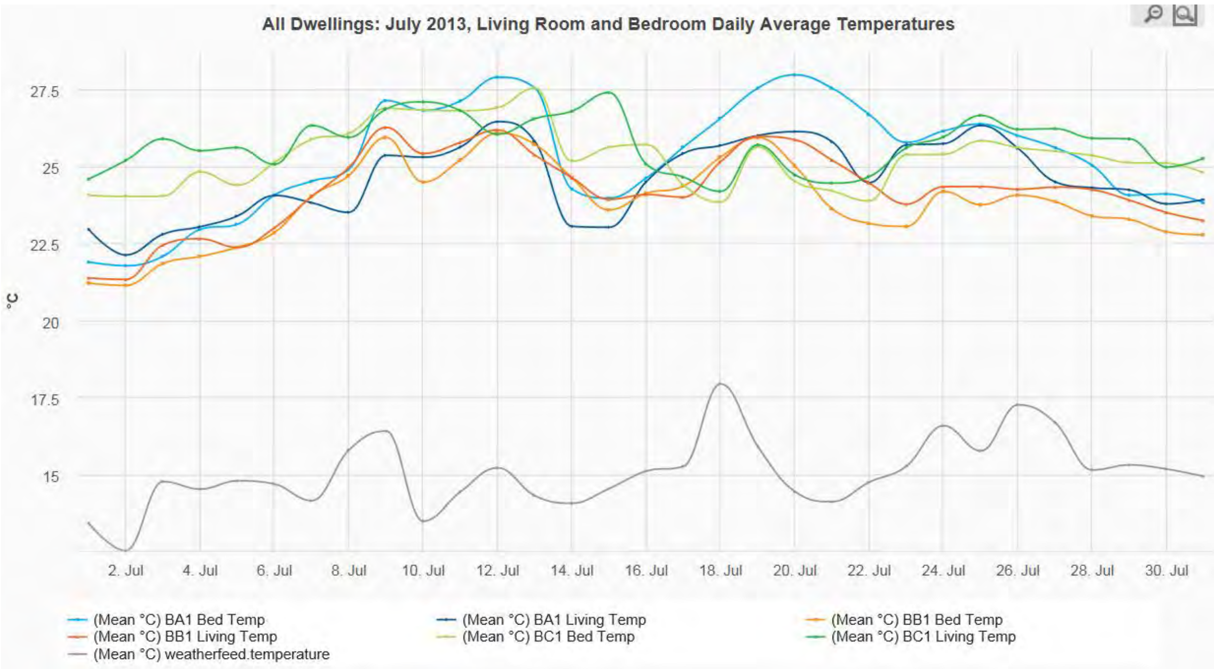


Figure 100: Living room and bedroom daily average temperatures, across all three house, July 2013

When comparing the temperatures monitored in all three houses, of note are the relatively high temperatures of BC1. Also of interest is the relatively high temperature of the bedroom of BA1. This dwelling is two storey and the temperature differential is likely to be due thermal buoyancy. The south facing windows in BA1 are well protected by the external shading and there is also considerable internal protection in the form of permanent blinds and curtains.

Figure 101: Shading to BA1 bedroom and living room

Looking at the propensity of window opening during the summer reveals some interesting characteristics. In BA1 the living room and windows are open similar amounts, but in BB1 there is a big difference, with the bedroom window open almost all the time, but the living room window hardly ever. In BC1 both living and bedroom windows are closed relatively often and this contributes to the very high temperatures being experience in this dwelling.

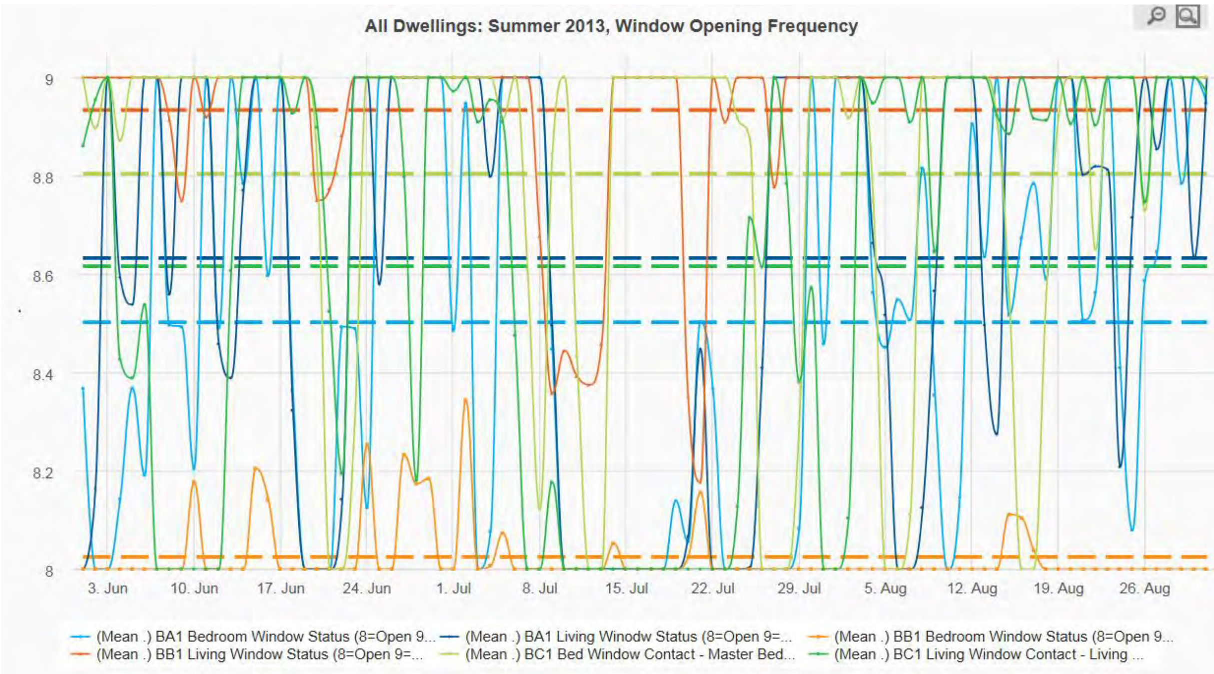


Figure 102: Window opening frequency – Summer 2013 (9=closed, 8=open)

This would indicate that the effects of incidental gains, particularly for longer periods of occupancy are significant, and also that ventilation provision and strategies are not effective. During these periods windows were opened more frequently, with BB1 having the most frequent window opening and lowest temperatures. Night-time opening would be an important strategy with regards to the thermal mass.

Humidity

Data was collected for Relative Humidity (RH) throughout the period. One of the questions in the project was whether the vapour permeable construction affected the moisture levels in the dwellings.

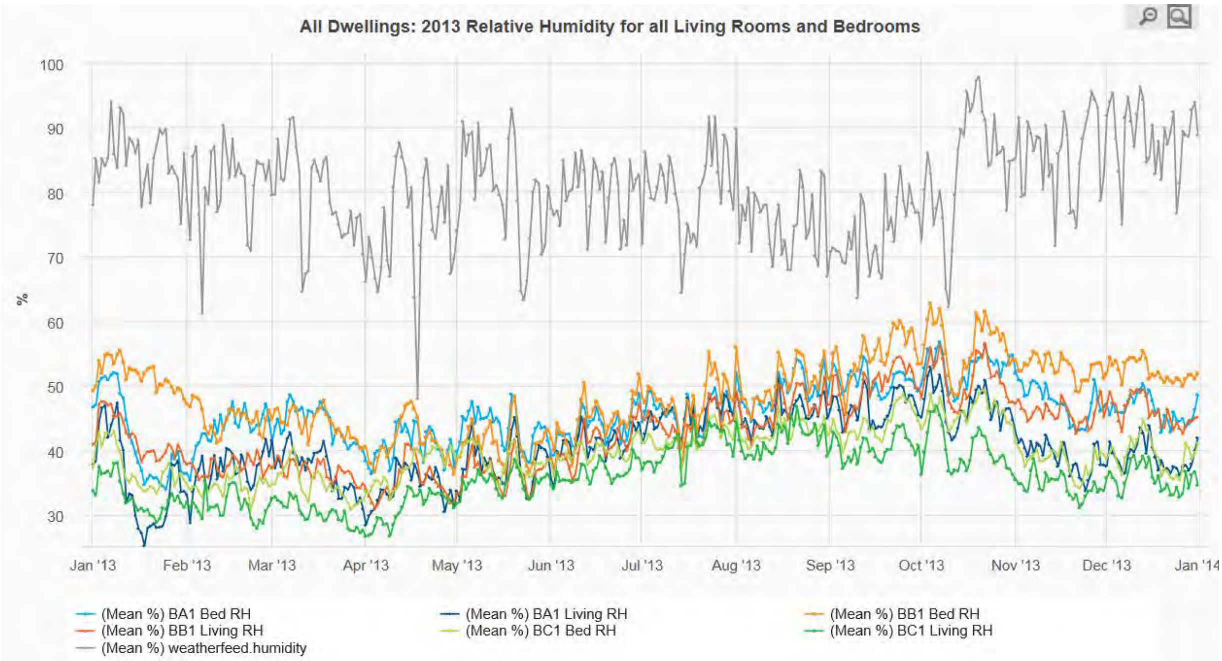


Figure 103: Annual (2013) RH for living rooms and bedrooms

The overall picture is one of low relative humidity, conditioned primarily by temperature. Thus the bedroom in BB1 has the highest RH and the living room at BC1 has the lowest. The distribution of RH does not follow ambient conditions, but is more affected by heating regimes. Lowest RH is seen in spring, when temperatures tend to be highest, and highest RH occurs in autumn, where summer window opening and (lack of) heating regimes persist into the start of the heating season.

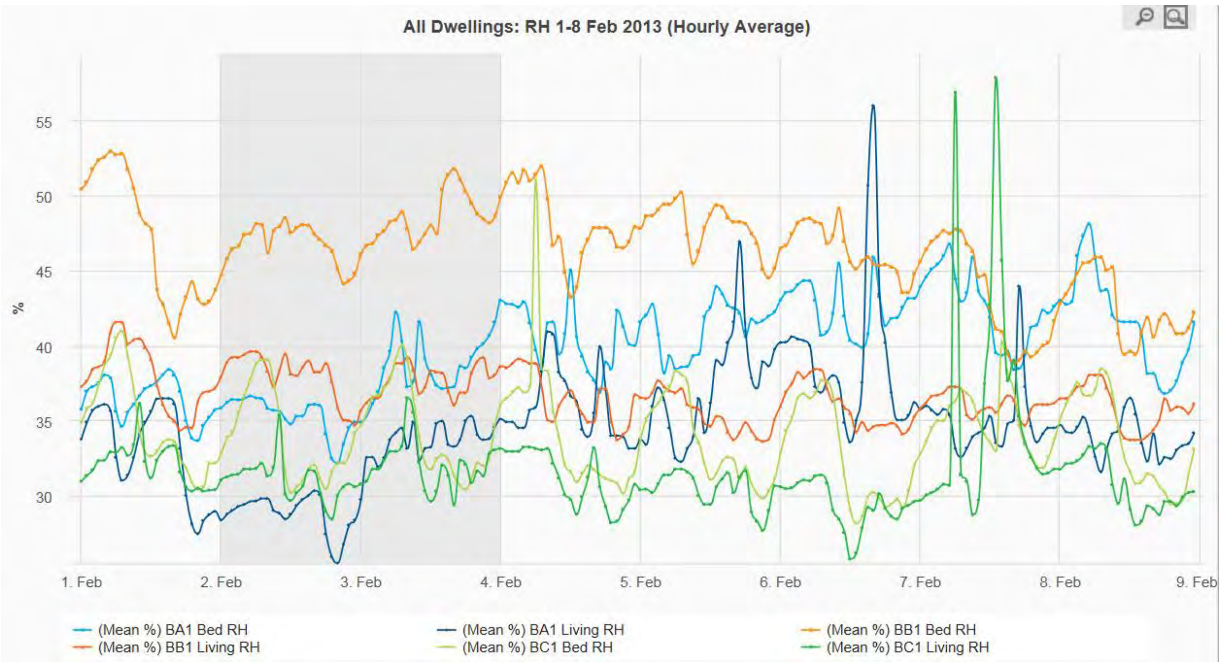


Figure 104: RH all houses 1 – 8 Feb 2013 (Hourly average)

The seasonal summary data for RH is shown below.

Winter – February 2013

	BA1 BED RH	BA1 LIV RH	BB1 BED RH	BB1 LIV RH	BC1 BED RH	BC1 LIV RH
Average	43.22	36.86	44.98	37.54	34.39	31.22
Max	59.60	61.57	53.33	47.20	43.92	53.33
Min	31.76	24.31	34.51	32.16	25.60	25.10
SD	3.98	4.30	2.98	1.94	3.14	2.81

Table 15: February summary RH data

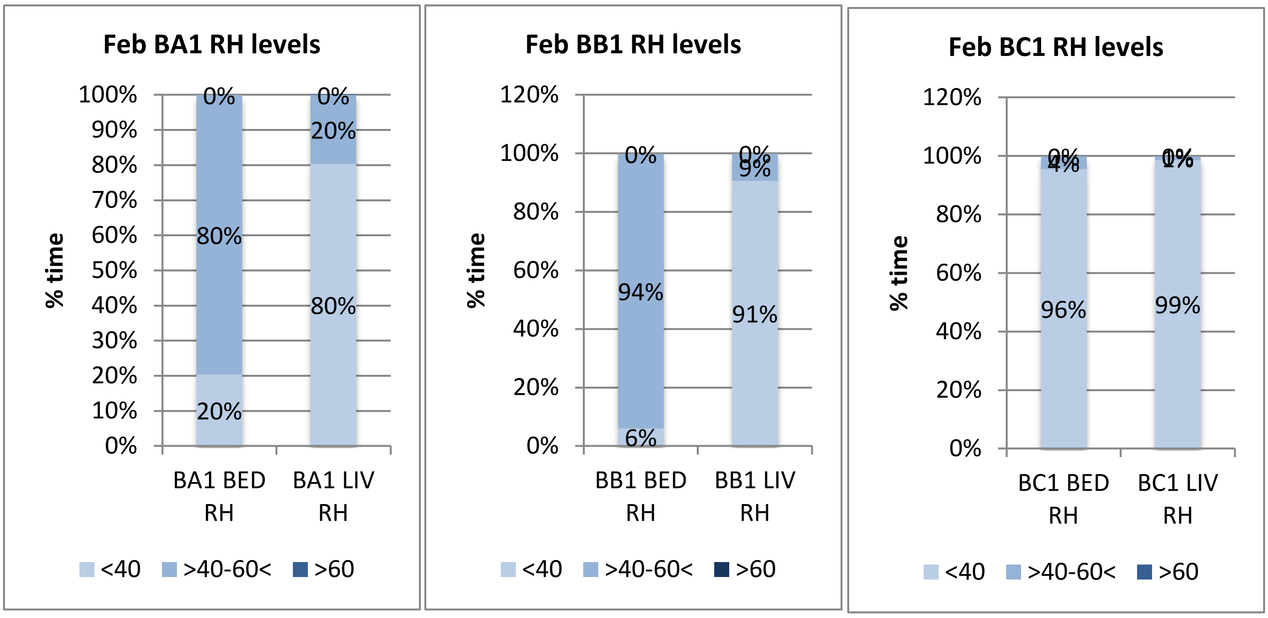


Figure 105: February summary RH distribution

The RH levels in this period are generally low, the only exception being the bedrooms of BA1 and BB1. Although there are some peaks these are very short-lived. For BA1 and BB1 bedrooms are within acceptable ranges, but the bedroom in BC1 and all living rooms are below 40% average RH.

Spring – May 2013

	BA1 BED RH	BA1 LIV RH	BB1 BED RH	BB1 LIV RH	BC1 BED RH	BC1 LIV RH
Average	43.68	38.31	41.36	36.66	38.10	35.16
Max	58.80	59.20	50.80	47.60	47.60	47.60
Min	32.40	27.60	31.20	26.40	29.60	26.00
SD	4.01	4.42	3.54	3.10	3.14	2.43

Table 16: May summary RH data

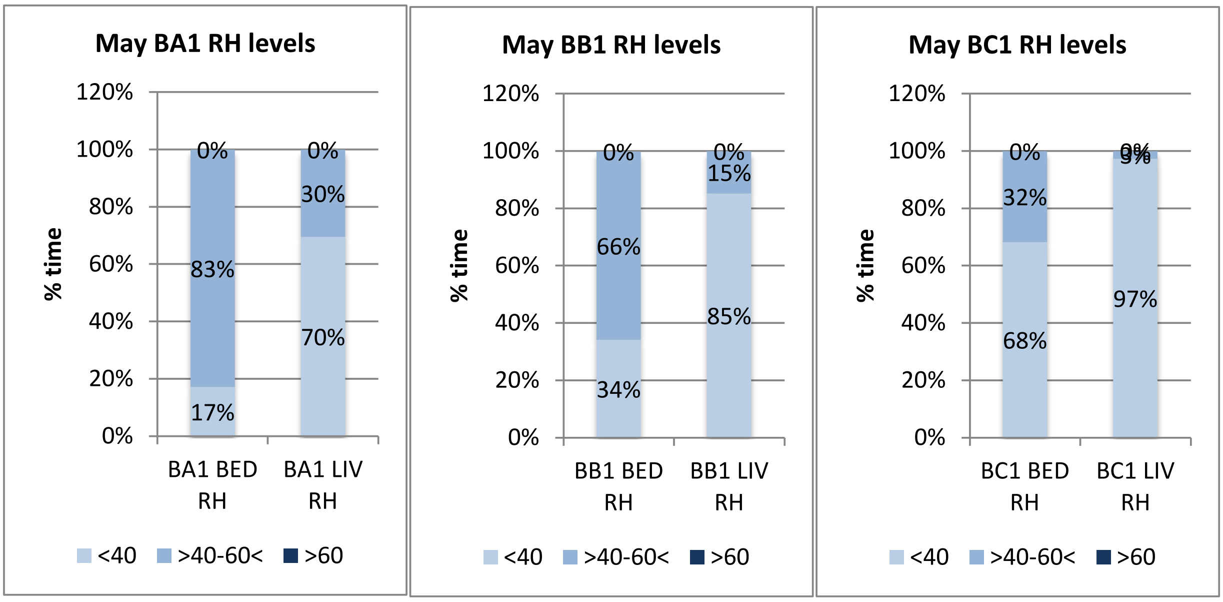


Figure 106: May summary RH distribution

A similar pattern of RH is apparent in the spring. The overall picture is one of very low relative humidity, but this is clearly affected by the relatively high temperatures being achieved, particularly in BC1. Given the nature of the occupancy, with relatively low water use, water producing events are perhaps less frequent than in family houses where there may be large amounts of clothes washing and drying.

Summer – August 2013

	BA1 BED RH	BA1 LIV RH	BB1 BED RH	BB1 LIV RH	BC1 BED RH	BC1 LIV RH
Average	49.25	45.75	50.60	46.33	42.95	41.72
Max	62.40	59.60	60.40	56.00	54.40	63.60
Min	41.60	36.40	40.00	35.20	36.00	33.20
SD	3.31	3.42	3.63	3.51	2.26	3.30

Table 17: August summary RH data

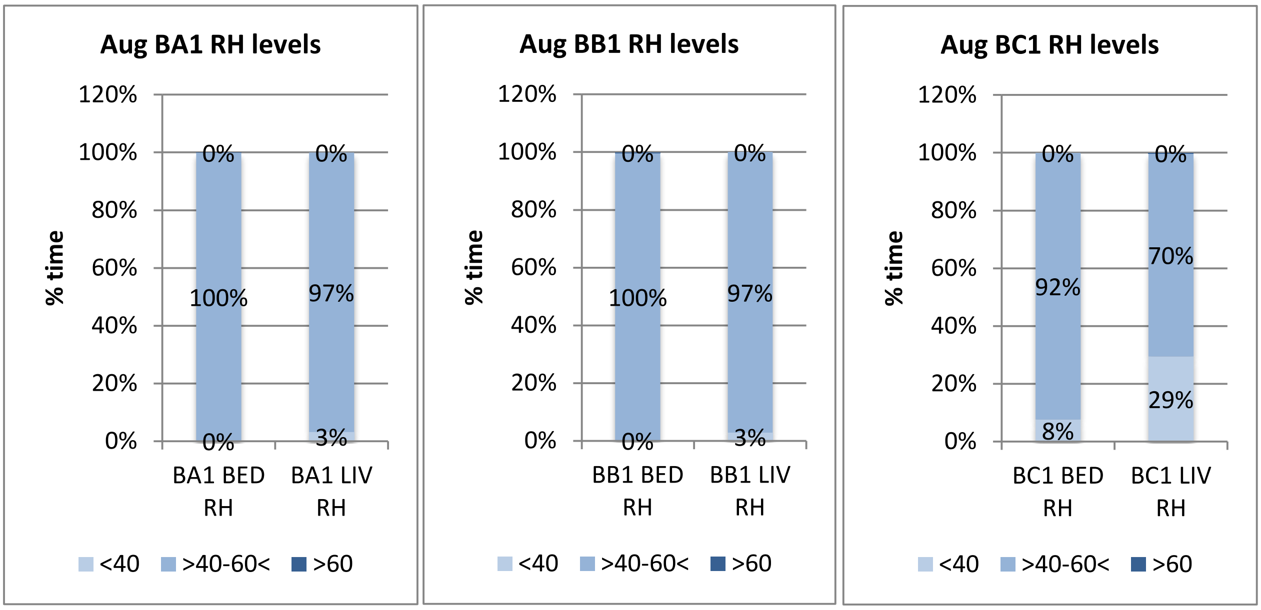


Figure 107: August summary RH distribution

In the summer period relative humidity is higher and closer to ambient. In this period RH levels are much closer to acceptable conditions, although BC1 has lower RH due to higher temperatures and less window opening.

Autumn – October 2013

	BA1 BED RH	BA1 LIV RH	BB1 BED RH	BB1 LIV RH	BC1 BED RH	BC1 LIV RH
Average	52.87	47.02	56.32	51.05	45.93	40.02
Max	65.60	63.60	71.60	65.60	53.60	54.00
Min	43.60	37.20	43.20	41.60	40.00	31.60
SD	3.09	3.63	4.42	3.74	2.67	3.60

Table 18: October summary RH data

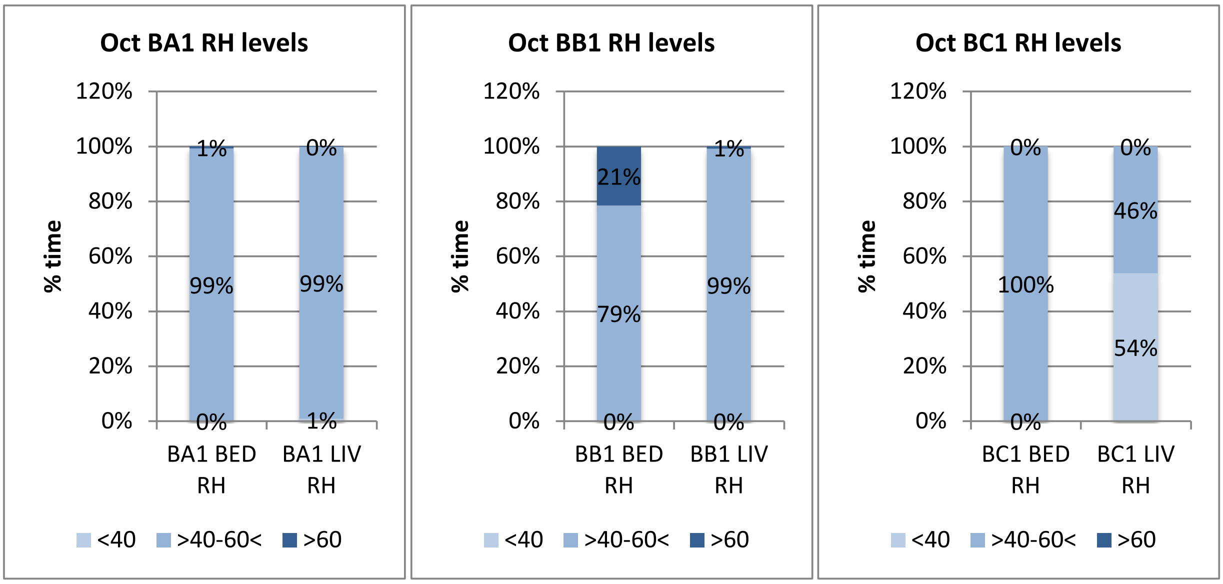


Figure 108: October summary RH distribution

In the autumn period, RH levels are more consistently within acceptable limits. The effect of bedroom window opening can be seen in BB1. In this case, summer window opening behaviors in the bedroom persist into autumn leading some periods of high moisture, above 60% RH.

To observe the combined effects of RH and temperature, scatter plots for different rooms and seasons are shown in Figure 109. It is evident from this that the houses have different environmental characteristics.

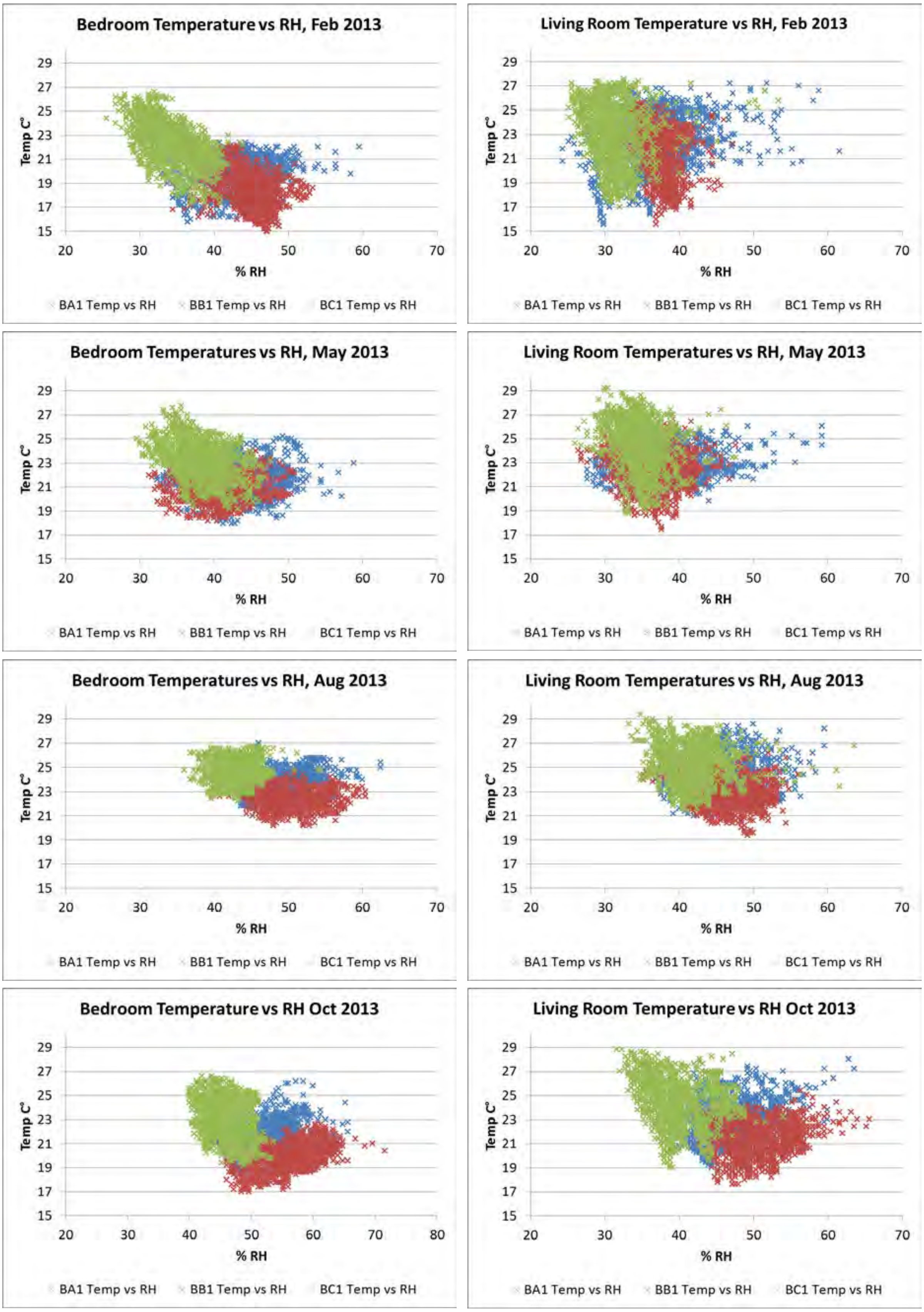


Figure 109: Scatter plots of bedroom and living room temperature and RH comparison Feb, Aug and Oct 2013

Ventilation

Monitoring of CO_2 has been used to assess levels of ventilation in the dwelling. There is a general acceptance that CO_2 keeps 'bad company' and that levels above 1000 ppm are indicative of poor ventilation rates. The provenance of this is well evidenced and corresponds well with a ventilation rate of 8 l/s per person. A literature review undertaken as part of the ventilation study identifies that 1000 ppm is an accepted level of ventilation in dwellings.

Interim reports had identified issues with high CO_2 levels, indicative of poor ventilation. Summary data is provided below showing annual CO_2 levels in comparison to frequency of window opening. Taken in conjunction with the study on ventilation it is apparent that ventilation levels in the bedrooms are quite poor.

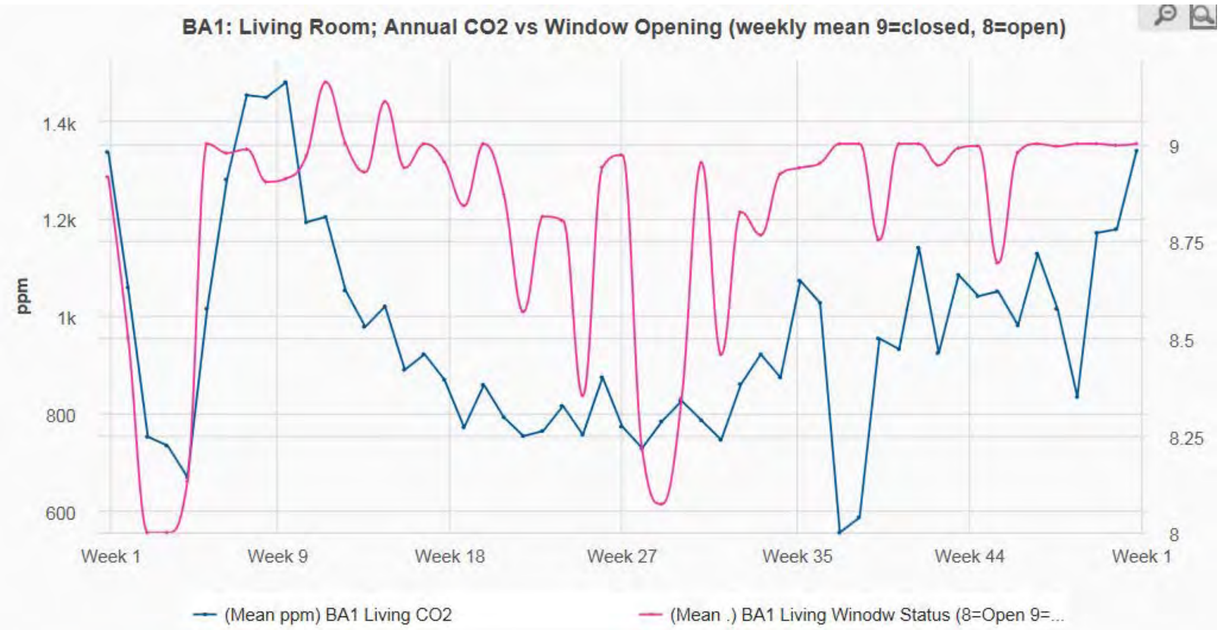


Figure 110: BA1 Living room; annual CO2 vs window opening (weekly mean 9=closed, 8=open)

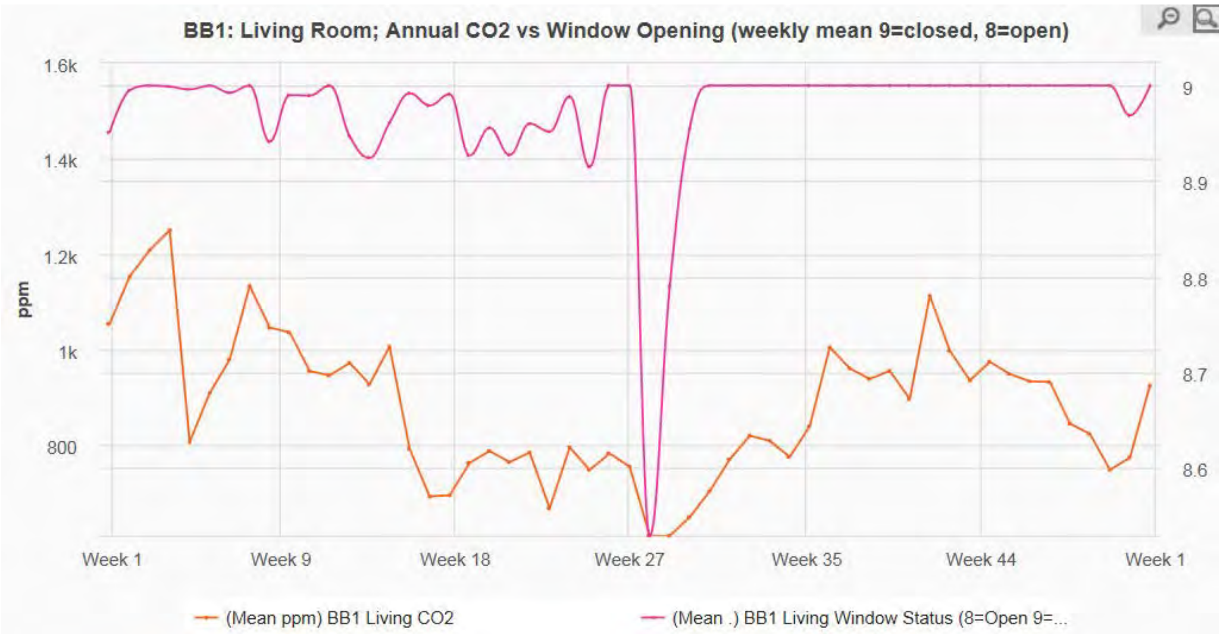


Figure 111: BB1 Living room; annual CO2 vs window opening (weekly mean 9=closed, 8=open)

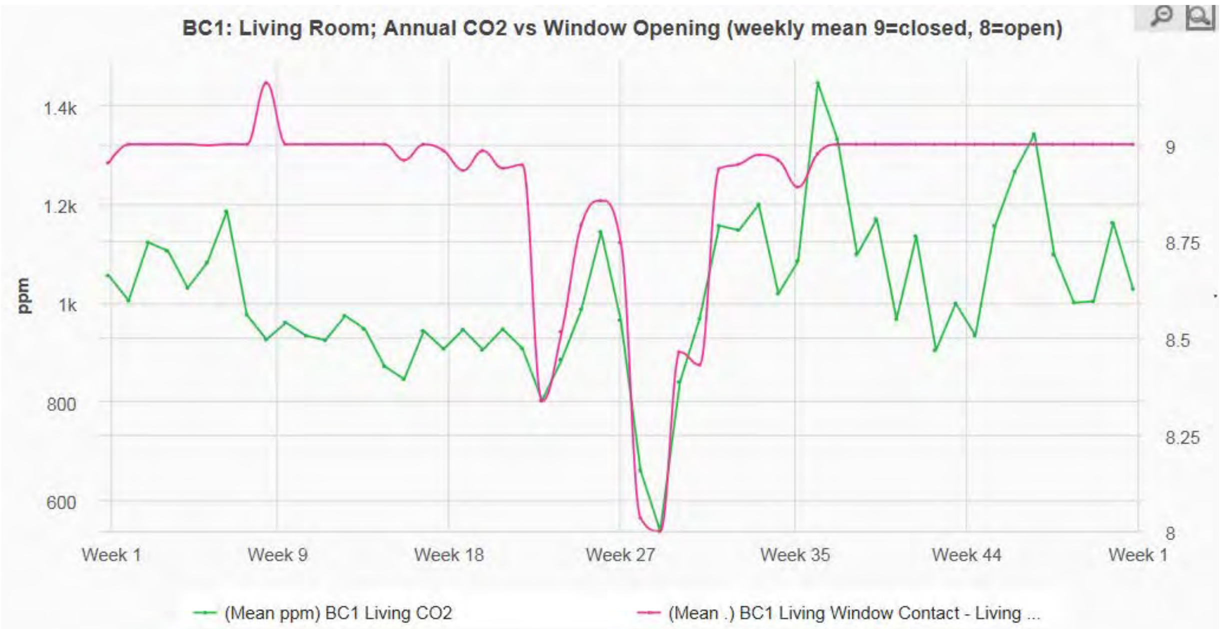


Figure 112: BC1 Living room; annual CO2 vs window opening (weekly mean 9=closed, 8=open)

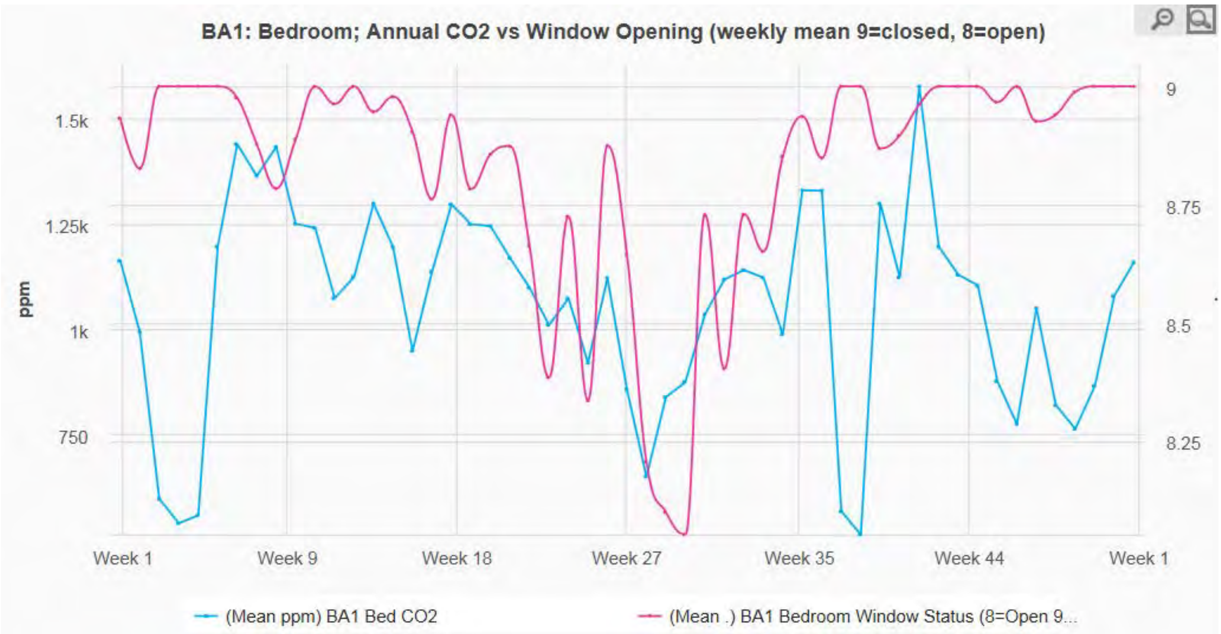


Figure 113: BA1 Bedroom; annual CO2 vs window opening (weekly mean 9=closed, 8=open)

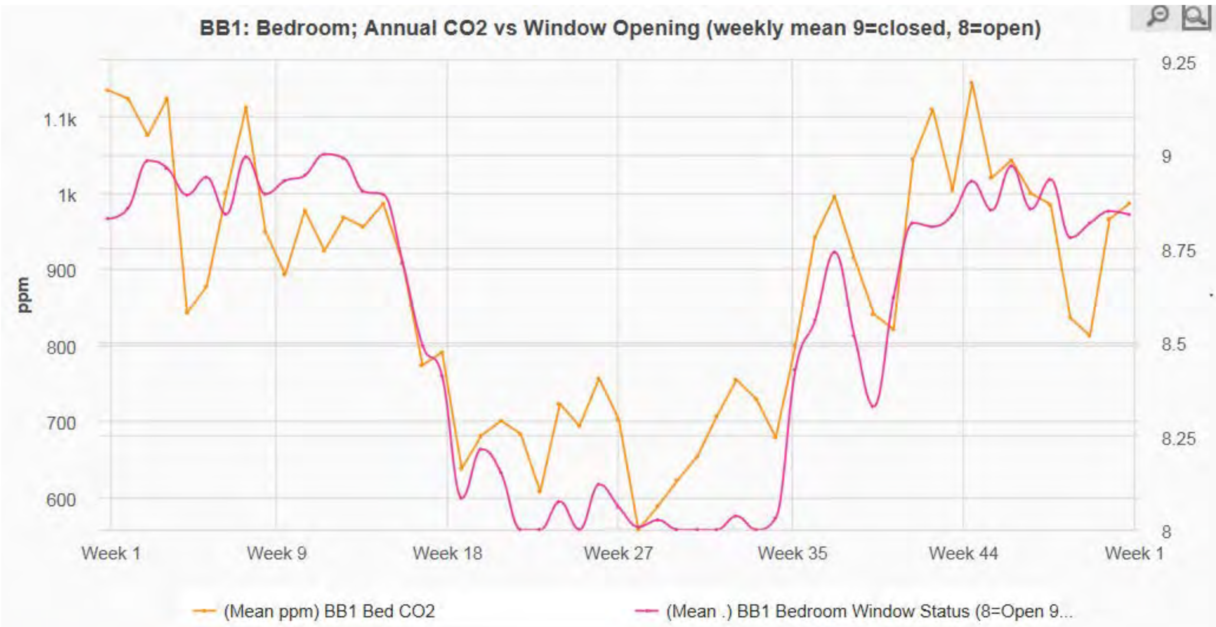


Figure 114: BB1 Bedroom; annual CO2 vs window opening (weekly mean 9=closed, 8=open)

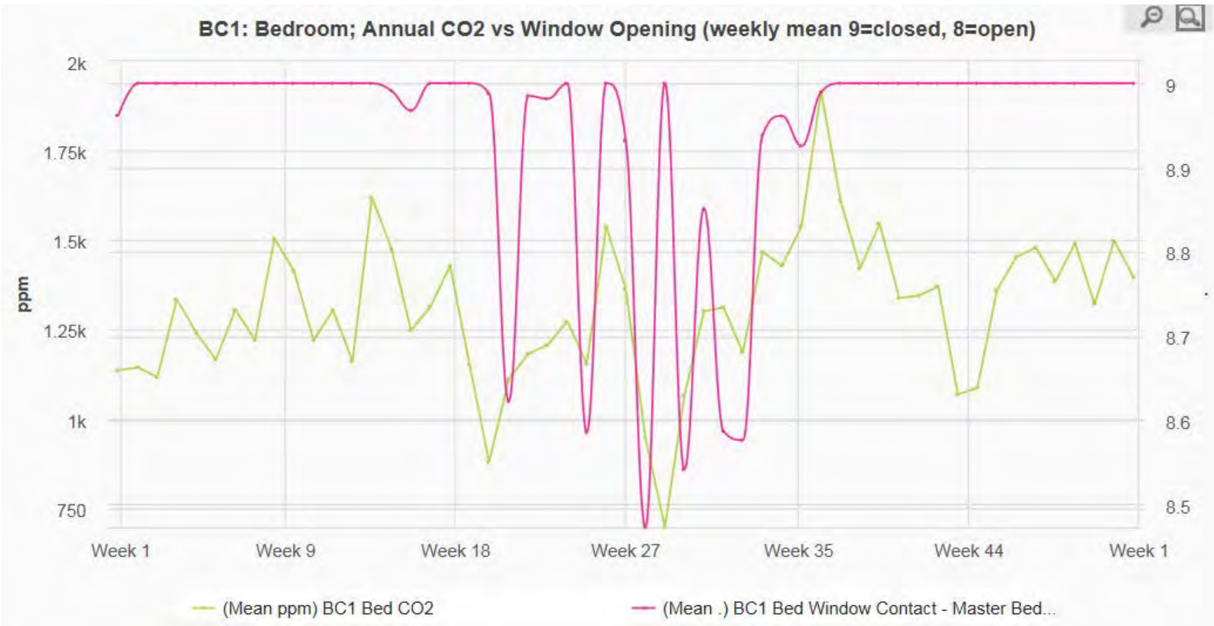


Figure 115: BC1 Bedroom; annual CO2 vs window opening (weekly mean 9=closed, 8=open)

The dwellings were included in a study and subsequent report[2] that examined the effectiveness of trickle ventilation; the findings of this are described in Section 7.7. However this study looked in some detail at ventilation rates during a sample week in February 3 - 9 2014, during which period the houses were monitored and occupants were asked to keep a detailed diary of activities and occupancy. The results of this for the Barrhead houses are as follows:

House	BA1 Bed 1	BB1 Bed 1	BC1 Bed 1
Air Perm	4.25	2.88	4.98
Floor Area (m^2)	12.62	13.15	12.54
Room Volume (m^3)	31.23	31.50	30.34
Trickle vents	Yes	Yes	Yes
Room Occupancy	2	1	2
Room Occupant(s)	Adult	Adult	Adult
Freq window use	N	Y	N
Av Peak CO_2 Bedrooms	2203	1246	27462
Average Hours CO_2 > 1000 Bedrooms	12.99	7.52	7.52

[2] http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards/publications/pubresearch/researchenviro/oiaqd [Accessed 15.12.14]

House	BA1 Bed 1	BB1 Bed 1	BC1 Bed 1
Average CO_2 when > 1000 Bedrooms	1660	1136	1808
Total Time (hours) > 1000	117	68	109
Time Weighted Average 11pm - 7am	1889	1124	2101
Time Weighted Average 11pm - 7am	1889	1124	2101
Bedroom CO_2 Mean	1341	921	1458
Temp Mean Bedroom	20.87	17.72	21.96

Table : Summary Environmental conditions, test week 3 – 9 Feb 2013

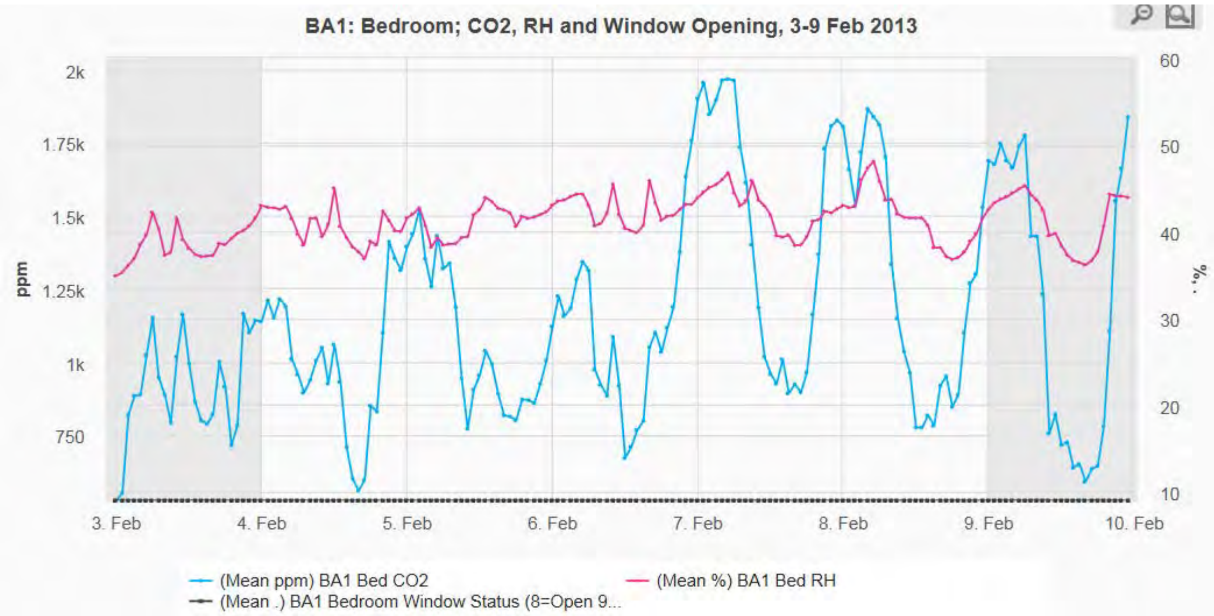


Figure 116: BA1 CO2, RH and window opening 3 - 9 Feb 2013

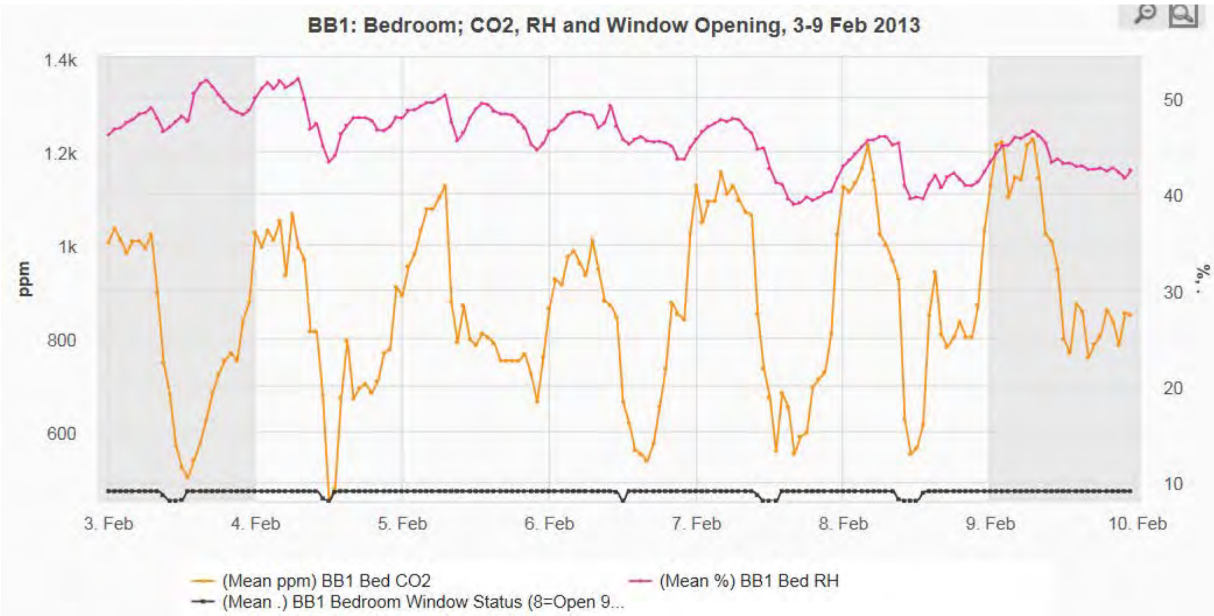


Figure 117: BB1 CO2, RH and window opening 3 - 9 Feb 2013

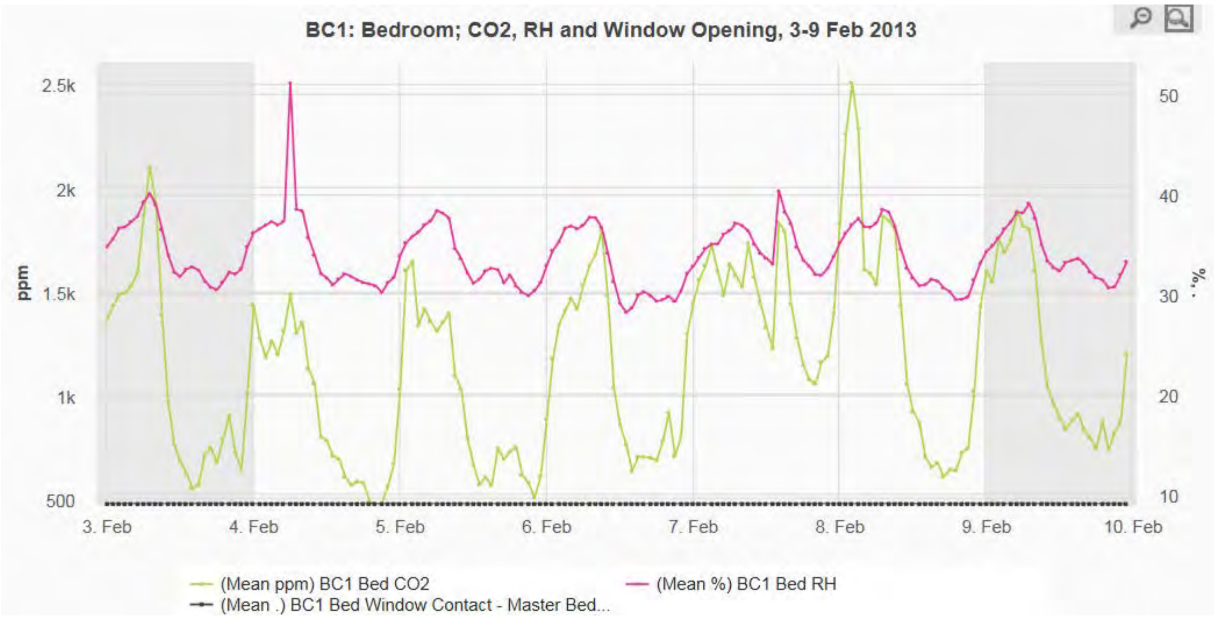


Figure 118: BC1 CO2, RH and window opening 3 - 9 Feb 2013

It is evident from the monitored data and specific studies that ventilation rates in the bedrooms are poor. The conditions are considerably mitigated in BB1, which undertakes more frequent bedroom window opening. It also clearly demonstrated the relationship between CO_2 and RH levels. Looking at temperature and RH during this period indicates the effects of temperature on RH.

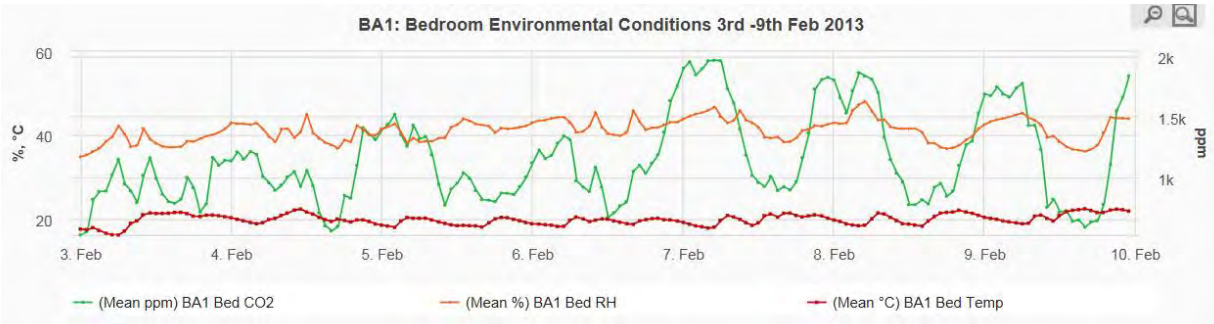


Figure 119: BA1 – Bedroom Environmental Conditions 3rd – 9th February 2013

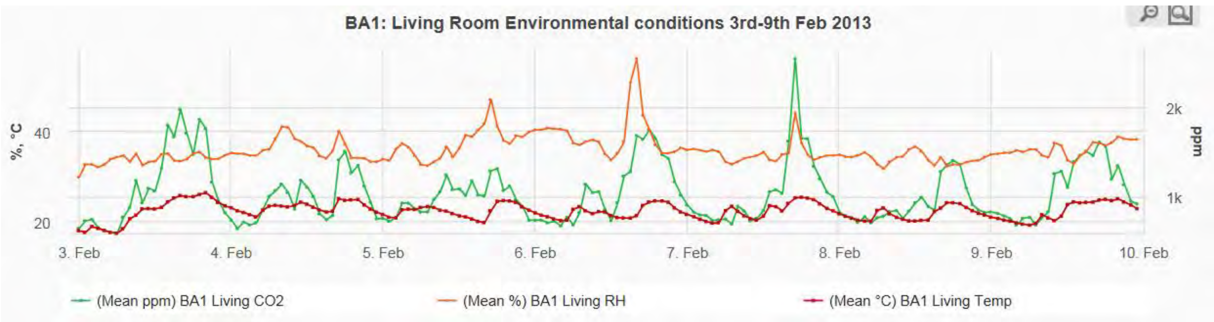


Figure 120: BA1 – Living Room Environmental Conditions 3rd – 9th February 2013

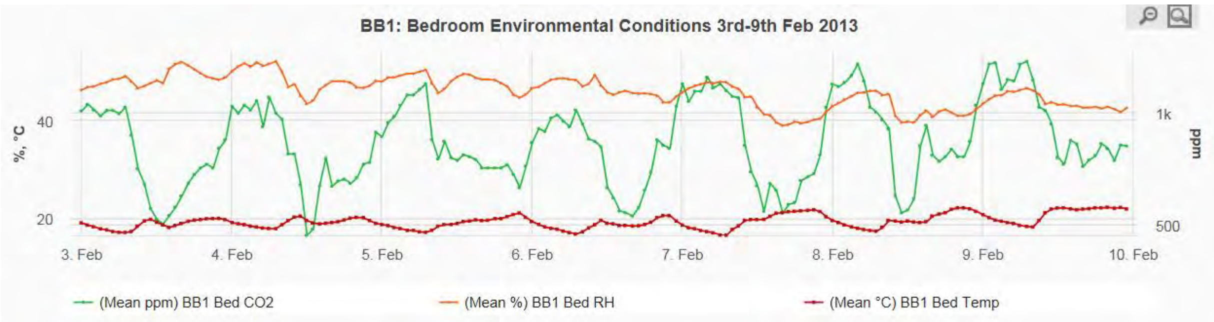


Figure 121: BB1 – Bedroom Environmental Conditions 3rd – 9th February 2013

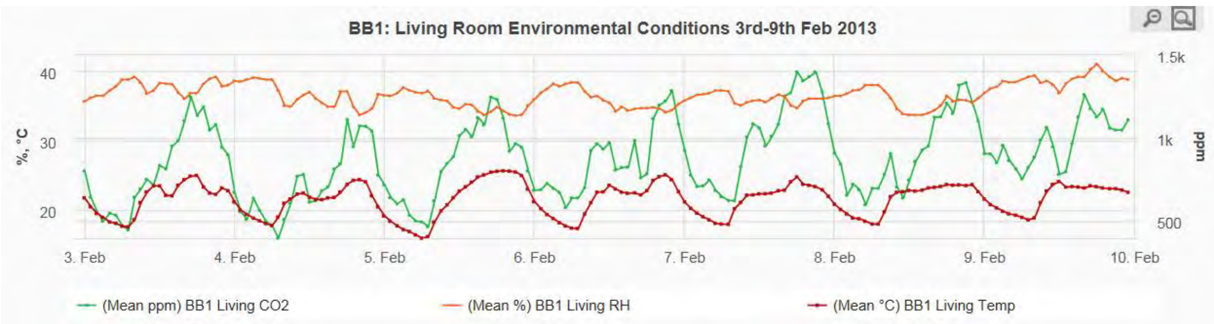


Figure 122: BB1 – Living Room Environmental Conditions 3rd – 9th February 2013

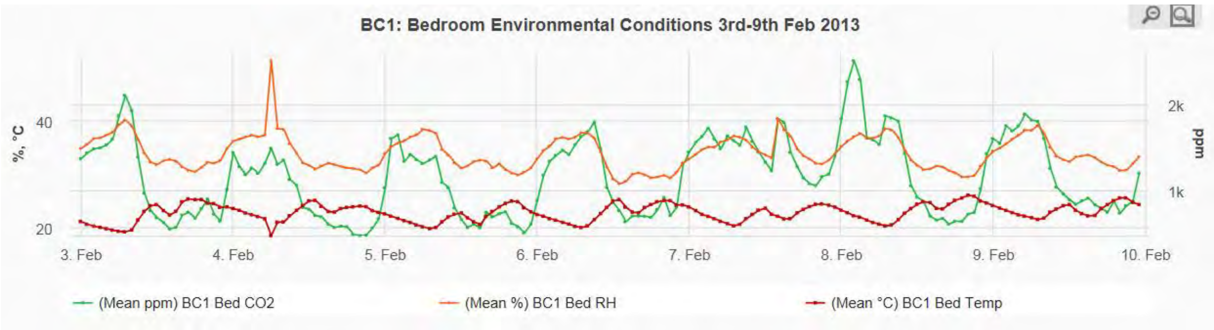


Figure 123: BC1 – Bedroom Environmental Conditions 3rd – 9th February 2013

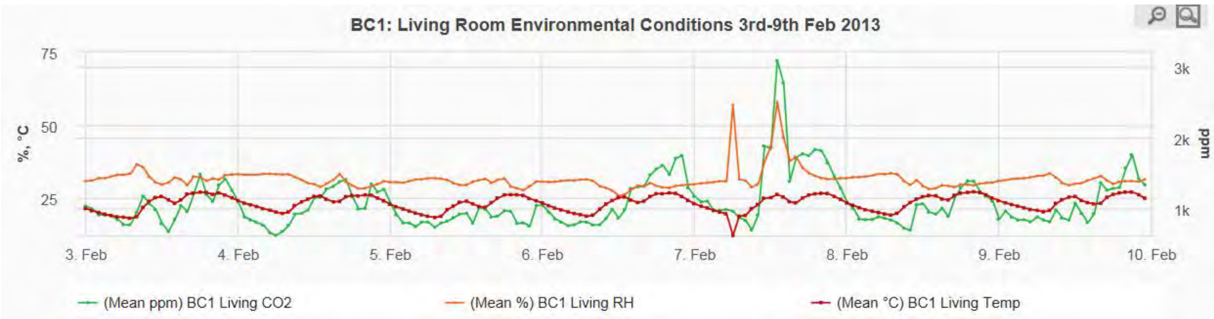


Figure 124: BC1 – Bedroom Environmental Conditions 3rd – 9th February 2013

From the above graphs, it is apparent that the conditions and overall CO_2 levels are not as bad in the living rooms. However, an accurate assessment of ventilation provision is extremely difficult in these types of spaces. Whilst peaks of CO_2 levels were apparent, occupancy, in terms of both time and the number of occupants is highly variable, as are other confounding v ariables, such as window and door opening, cooking, clothes drying, and physical form. Consequently, high CO_2 levels may be the result of a number of occupants rather than the ventilation measures. As a result is it very difficult to isolate specific incidences of occupant interaction with trickle ventilation and window opening from this data.

In comparison bedrooms are the spaces in which occupants spend the most uninterrupted time, typically 7–8 hours, and children may also use bedrooms for socialising and schoolwork in which case they could spend almost all their time at home in the bedroom. Furthermore, bedrooms over-night present steady-state conditions with occupants asleep, with little or no adaptive behaviour – ventilation regimes established at the time of going to bed remain in force overnight. Accordingly, environmental conditions in bedroom spaces are of particular interest.

It would appear from the data that something of a trade-off may be occurring in the dwelling. For BC1, temperatures are high and ventilation is poor, this is resulting in the high levels of space heating energy consumption. For BB1, lower temperatures are being achieved, but this is with the benefit of better ventilation rates, whereas the opposite is the case for BA1.

7.6. Breathing wall vs Thermal Mass

One of the key differences in construction of the dwellings concerned the use of vapour permeable construction. The BPE project sought to examine differences in performance between these construction types, and the more conventional blockwork used in the flats. As the flats (and in particular the living rooms) are of a similar size, with similar types of occupancy; comparison may be made. However, it is important to note that there are confounding factors, including frequency of window opening, moisture production events and demand temperatures which may result in variations. However a comparison is made between the living rooms of BB1 (with blockwork) and BC1 (with timber frame). They are both single story, with a similar wall and roof area, although BC1 has a heat loss surface to the floor.

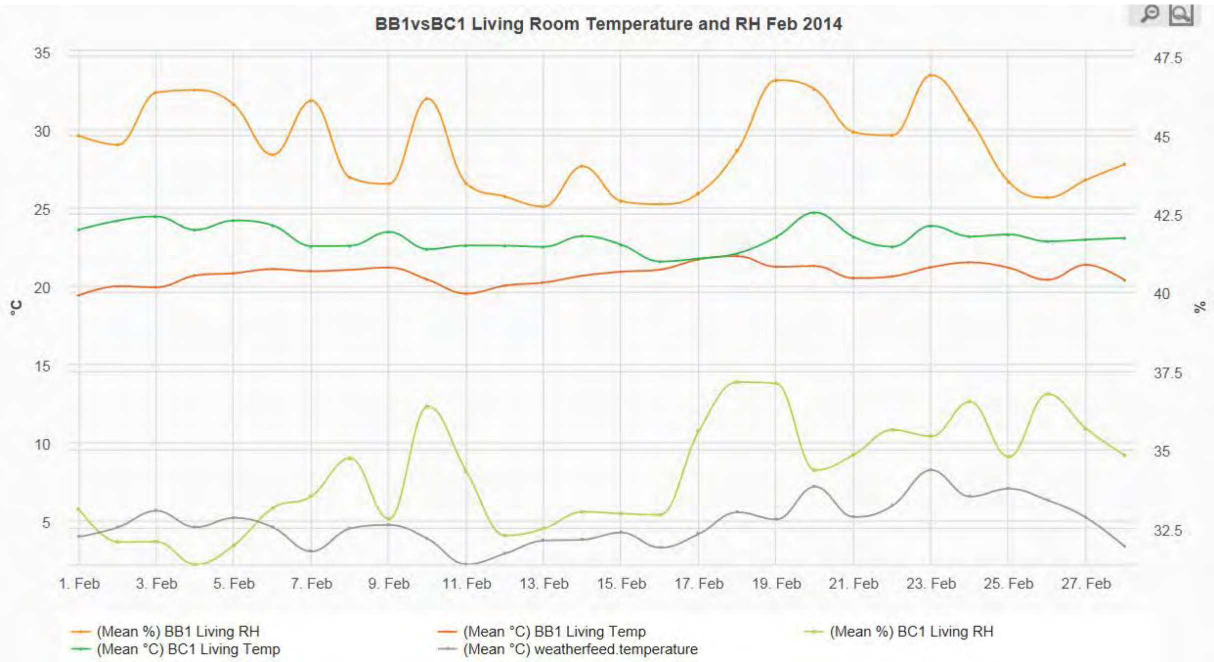


Figure 125: Comparison of temperature and RH in February 2014, BB1 Living room vs BC1 Living room.

Figure 125 shows the temperature and humidity for February 2014 and Figure 126 is a scatter plot the temperature and relative humidity over this period, in which occupancy is similar, and there is little or no window opening. The differences are quite apparent, the respective figures for relative humidity are: 34.53% for BC1 and 47.20% for BB1. When read in conjunction with the interstitial analysis discussed in Section 3.4, in which interstitial moisture levels follow room conditions but decline more slowly, it would appear that the vapour permeable construction is having a positive effect of levels of relative humidity.

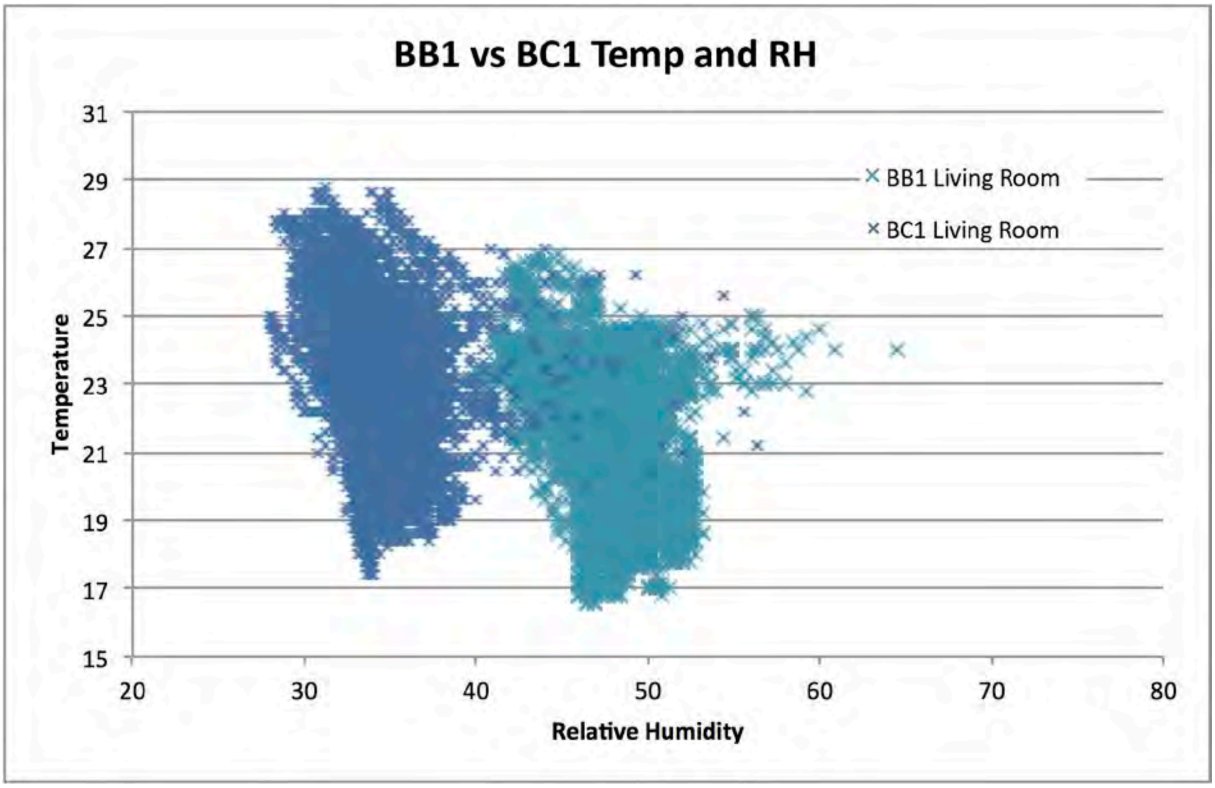


Figure 126: BC1 Living room vs BB1 Living room, temperature and humidity, February 2014

Comparing temperatures over the same period, the average temperature for the period was 22.95 °C for BC1 Living room and 21.70 °C for BB1 living room. In addition the standard deviation in temperature was lower in BB1 (2.27 °C in BC1, 2.11 °C in BB1). This could be due to the effects of the thermal mass dampening out temperature fluctuations.

Analysis of the relative temperatures shows; the two period heating regime is evident in both houses, but in BB1 the temperature is more even. A possible further explanation is that comfort conditions are achieved in the thermally heavier house with lower air temperatures, due to beneficial effects of mean radiant temperature. However, the occupants in BC1 may simply feel comfortable with higher temperatures. Some of these effect may be ascribed to thermal mass, and others to control.

The effects of temperature are therefore relevant in relation to the relative humidity levels. Examining this in more detail, but taking a day when temperatures are broadly similar shows that when temperatures are very close, the RH in BB1 remains lower.

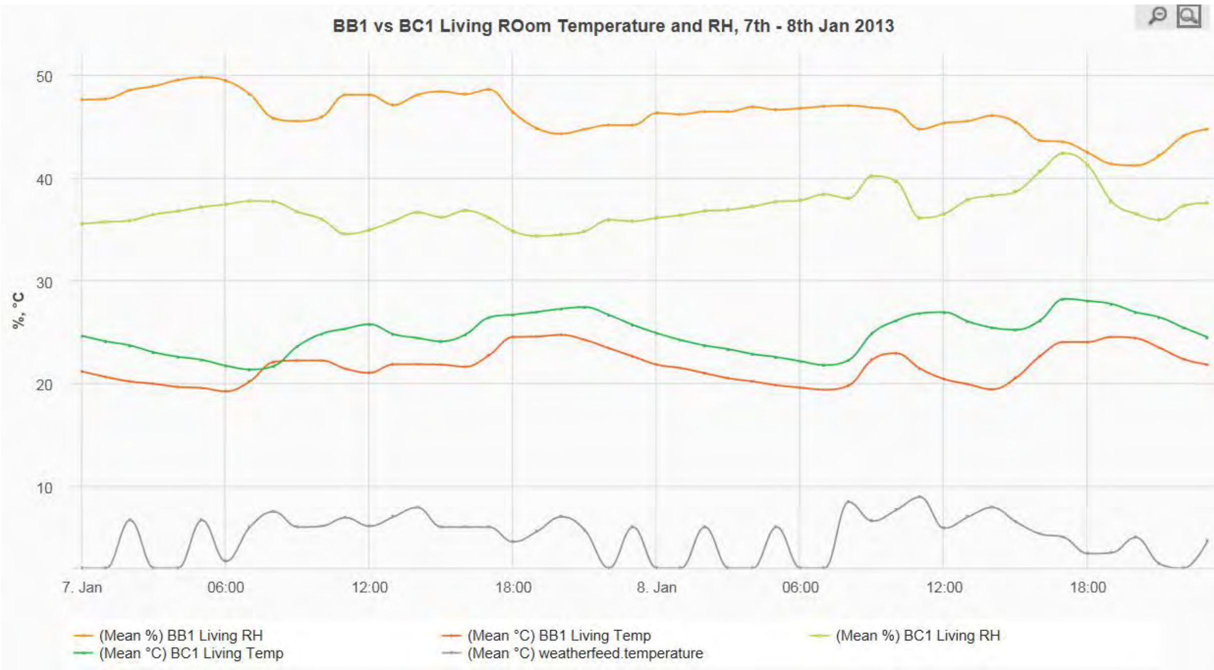


Figure 127: BC1 Living room vs BB1 Living room: Temperature and RH, 7-8 Jan 2013.

This would appear to present a dilemma in terms of future decision making. On the one hand, the thermally heavy house uses less energy, and does not have the peaks and swings in temperature. On the other, there does appear to be a beneficial effect of the vapour permeable construction on moisture levels. Conversely, moisture levels in the block house are not at worryingly high levels and relative humidity does not exceed 60% in either dwelling. Peak RH in BB1 is 64%, and exceeds 50% RH for 12% of the time. Of perhaps greater concern are the very low RH levels in BC1 which are below 40% for 98% of the time.

On balance this would suggest that in modern, well insulated houses with relatively low occupancy, relative humidity is less of a problem. This might well be different in the case of a family house, with greater occupancy and more moisture producing events such as showering and clothes washing/drying. The context of ventilation is also important in this regard. The benefit of the vapour permeable construction is that the effect of passive ventilation and the shortfalls of both the mechanical extract and background ventilation (discussed in Sections 6 and 7) are important components for achieving equitable environmental conditions.

Contemporary construction in Scotland is heavily weighted towards timber frame and this trend is set to increase, suggesting that adopting a vapour permeable specification may be beneficial. However, in the case of continuous occupancy, and the need for comfort and health, there is a strong argument for increasing the levels of thermal mass in dwellings. Testing elsewhere in the BPE programme (the Glasgow House project) was able to identify both thermal, comfort and energy use benefits of a thermally heavy construction. However, in both projects, discrepancies between designed and measured U-values were apparent and the poorer measured U-values in BB1 are likely to contribute to greater heat loss.

Whilst the humidity levels in BC1 are lower than desirable, it is suggested that this is due to the temperature levels being high, in particular the peaks of temperature due to the intense heating regime.

7.7. Trickle vent effectiveness

These dwellings were used as part of a study that looked at the effectiveness of natural ventilation, particularly trickle ventilation in contemporary housing. There is concern that in some instances indoor air quality in recently constructed dwellings can decline to levels that may be detrimental to the health of the occupants as well as to the construction of the dwelling. Poor indoor air quality is one of the main suspects driving the large increases in diseases such as asthma and allergies.

In December 2013 the Scottish Building Standards Directorate commissioned research to gather information on occupant use of natural ventilation and to relate this to indoor air quality[3]. This required fieldwork to: a) gather quantitative data on occupant interaction with ventilation provision within the homes and; b) undertake more detailed investigations into the effects on indoor air quality. This included detailed longitudinal information about ventilation and also undertook sample monitoring of IAQ. The houses at Barrhead were included in this study which undertook a specific week long period of monitoring in February 2014, during which detailed information was collected through occupant diaries on occupancy, heating and ventilation habits.

This part of the research looked at both living rooms and bedrooms. Low levels of ventilation, as evidenced by high CO_2 levels were apparent in living rooms, but it was difficult to isolate effects of ventilation strategies, particularly trickle vent use, from other occupancy factors, such as number of people, internal door opening or cooking. However a more accurate assessment of the effects of ventilation, particularly background ventilation strategies, can be made using the bedroom data. In these rooms the hours and levels of occupancy are known, and overnight there are steady-state conditions. In addition it was apparent that CO_2 levels are higher for longer periods in bedrooms than in living rooms. Thus both the length and intensity of occupation can be more accurately assessed in the bedrooms.

The study found that poor levels of ventilation were apparent in the majority of the bedrooms. On a daily basis an average of 77% of the rooms had periods where CO_2 levels

[3] http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards/publications/pubresearch/researchenviro/oiaqd [Accessed 15.12.14]

exceeded 1000 ppm. Over the course of the week all of the bedrooms experienced some period when CO_2 exceed 1000 ppm, with an average of 53% of the time (about 4 hours a night) when these levels occurred. Keeping windows open at night was the only strategy that resulted in reasonable levels of CO_2.

Despite similarities of design features, is apparent that some properties are performing at different levels than others. There are a great many variables that might affect ventilation rates, but (excluding window opening) three areas: number of occupants, door opening and external wind speeds were examined. Examination of relative CO_2 levels in relation to these factors reveals some interesting data.

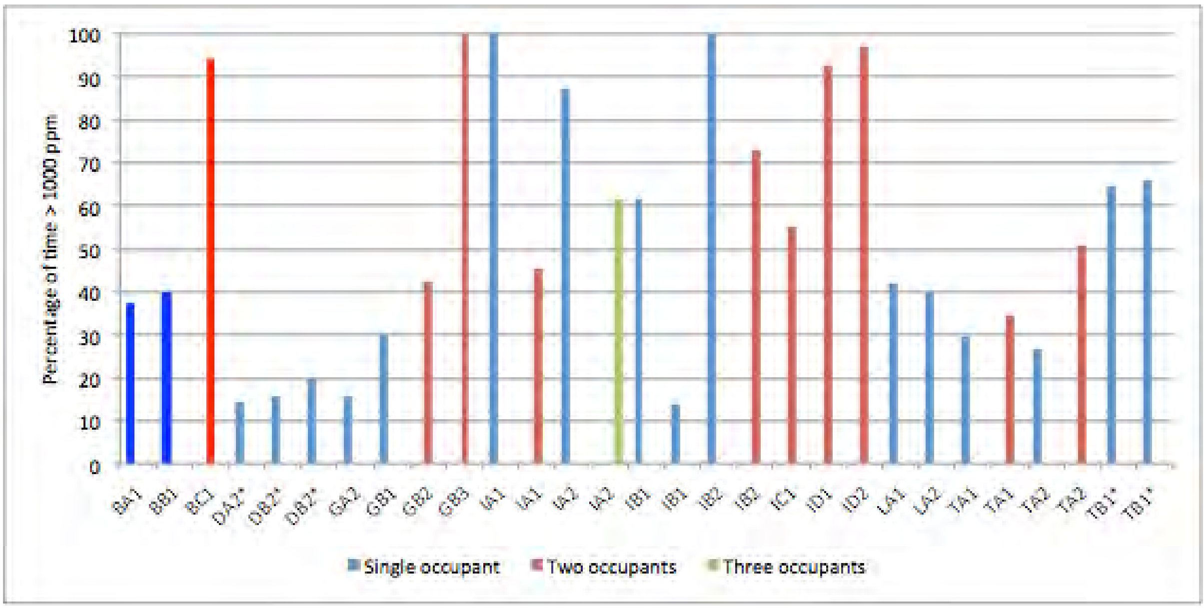


Figure 128: Variation in average CO_2 levels and % of time >1000 ppm CO_2 for number of occupants and door opening.

	any door state		doors open		doors closed	
No of occupants	avg CO2 ppm	% > 1000 ppm	avg CO2 ppm	% > 1000 ppm	avg CO2 ppm	% > 1000 ppm
any occupants	1224	52	1162	42	1288	60
1	1161	43	1099	26	1232	49
2	1286	60	1226	57	1478	72

Table 19: CO_2 levels and CO_2 intensity (% t >1000 ppm) by door opening and occupancy

Looking at whether doors were open or closed (omitting properties where data was incomplete or with open windows) shows a clear difference, with doors opening leading to average CO_2 levels 18% lower, and % t >1000 ppm 23% lower. Looking only at the number of people indicates that on average CO_2 levels for single occupants are 10% lower, but the CO_2 exposure is more obvious, with % t >1000 ppm 28% lower.

Controlling for number of people in the room gives a clearer picture. With one occupant opening doors results in average CO_2 levels 11% lower, but the intensity of CO_2 exposure drops by 46%. With two occupants, average CO_2 levels reduce by 17% and % t>1000 ppm by 20%.

The values for percentage of time above % t >1000 ppm over the week were compared with the daily average wind speeds. A strong correlation was observed, with CO_2 levels rising as wind speed decreases. This illustrates quite clearly the important effect that wind has in driving ventilation, but also raises questions as to what the drivers are when wind speed is low, or effects are reduced by the built form.

The results from this detailed monitoring confirm the findings from the sample monitoring. This data also corresponds to results from other studies identified in the literature review concerning the effects of occupant interaction with available ventilation strategies.

The overview survey found that most occupants have their trickle vents closed. Very few occupants interact with trickle vents on a regular basis. The main ventilation strategy is window opening, which is conditioned primarily by control of temperature (keeping windows closed to retain heat - opening windows to reduce heat). With regard to trickle vents the key finding is that, even with trickle vents open, high CO_2 levels were observed for significant periods of time. The main planned mitigating factor was window opening, but fortuitous effects were the number of occupants, internal door opening and external wind conditions.

Accepting that the 1000ppm threshold remains a satisfactory goal for ventilation strategies, the evidence is that the monitored houses at Barrhead fall short of that standard. Calculated air change rates are relative low in relation to desired rates for good indoor air quality. High CO_2 levels correlated with increases in the levels of VOCs, however, with more liberal window opening, levels of particulates increases. The levels of air change, and observed levels of relative humidity, appear to be sufficient to address moisture.

Further analysis would be required to examine actual vapour pressure; the relatively high temperatures may be masking moisture content in the air. High levels of CO_2 were observed in living rooms, but the complexity of living room conditions and opportunities for adaptive behaviour (such as window opening) hampers an assessment of the effects of background ventilation provision.

7.8. Conclusions and key findings for this section

- 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.
- There is evidence of poor levels of ventilation across most dwelling types.
- Development of ventilation strategies has not kept pace with energy reduction measures such as increasing air-tightness.
- The trickle vent study has resulted in a call for consultation by the Building Standards Directorate, with a view to amending Scottish Building Regulations
- Heating and ventilation strategies, in particular occupant usability, need to be considered more carefully by the design team.
- Further work is needed to identify health effects of ventilation rates, particularly on older people with sedentary lifestyles and high levels of occupancy
- At present there is no control of source VOC pollutants. The specification of low pollutant materials and finishes is of increasing importance in contemporary airtight dwellings. Advice and guidance to occupants about choice of decorative materials and furnishings would be beneficial.
- The dwellings are providing warm, dry conditions for residents and the problem has shifted to one of overheating and dryness.
- Effects of incidental gains is an important contributory factor. In some cases this was perceived by the occupants: e.g. the flat screen TV referred to in the BUS comments.
- 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 – for example between 670 and 736 kWh of electrical energy were consumed in the houses between June – August.
- Increased demand of high temperatures is leading to higher fuel consumption. However, for this type of occupancy group this may be both desirable and necessary. Design decisions about environmental strategies ought to reflect this and should override SAP assumptions.

- Lower hot water consumption may also inform design decisions for hot water provision, particularly solar thermal systems. Communal systems may be more effective due to economies of scale, reduced maintenance costs, demand sharing and condition monitoring.
- 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. Is low water use being driven by concerns over costs, or heating habits due to experience of damp or cold properties?
- Both the vapour permeable construction and the thermal mass appear to have beneficial effects. Given the issues surrounding existing ventilation provision, adoption of vapour permeable construction would appear to be a more passive approach to moisture control. However, thermal mass is likely to be beneficial in terms of both comfort and resilience to greater ventilation rates. Given that high relative humidity levels are rare in well insulated houses, and assuming that moisture can be controlled at source by ensuring extract provision is robust and that there is provision for clothes drying in winter, additional mass is likely to have more impact.

8. Other technical issues

8.1. The BPE process

This study was undertaken with the support of the TSB Building Performance Evaluation programme. Whilst this provided the necessary resource to undertake the project, the administration of the project was burdensome and complying with regular reporting requirements restricted activity on the project.

There are several key issues:

- Although fully funded, the approximate ceiling of £60k is insufficient for a Phase 2 project. It was only apparent when all of the documentation was available that a Phase 2 project needed to undertake the majority of the Phase 1 tasks as well.

- There was no clear source of information or location of guidance, templates, etc. The connect website was very difficult to access and navigate. A better web resource would have been helpful and would have reduced correspondence, but could also have enable projects to link with each other and share information.

- The standardised commissioning sheets required to be completed for the project do not acknowledge the statutory regulations for Scotland. Requirements to complete sections relating to Approved Documents did not apply to the this project and Scottish templates should be developed for future projects.

- Some of the guidance on test methodologies requires revision. Minimum U-value test durations noted in TSB methodology are too short to ensure confidence in validity. In this instance this required retesting which was only feasible due to the fact that the houses were not normally occupied.

- There was a lack of clear reporting templates and tools. Access to a consistent set if template documents for reporting, would have given the project better support. The status and version of DomEARM was unclear throughout the project, and requests for information to the help email address did not provide answers.

- The quarterly reporting mechanism became unduly burdensome and became the primary exercise of the project. It would have been far more beneficial to identify particular tasks.

- There is a lack of clarity about how ethical issues will be addressed by the TSB post project. With small numbers of houses it is inevitable that individual occupant factors may be identified, and in fact are important to report. Whilst the report has made efforts to anonymise individuals and houses, it is nevertheless possible to identify houses by their characteristics. As a result we would request that these reports and data are not made public in any way without a clear process of redaction.

Occupants

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.

An exit survey was undertaken with the participants on 11th September 2014 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.

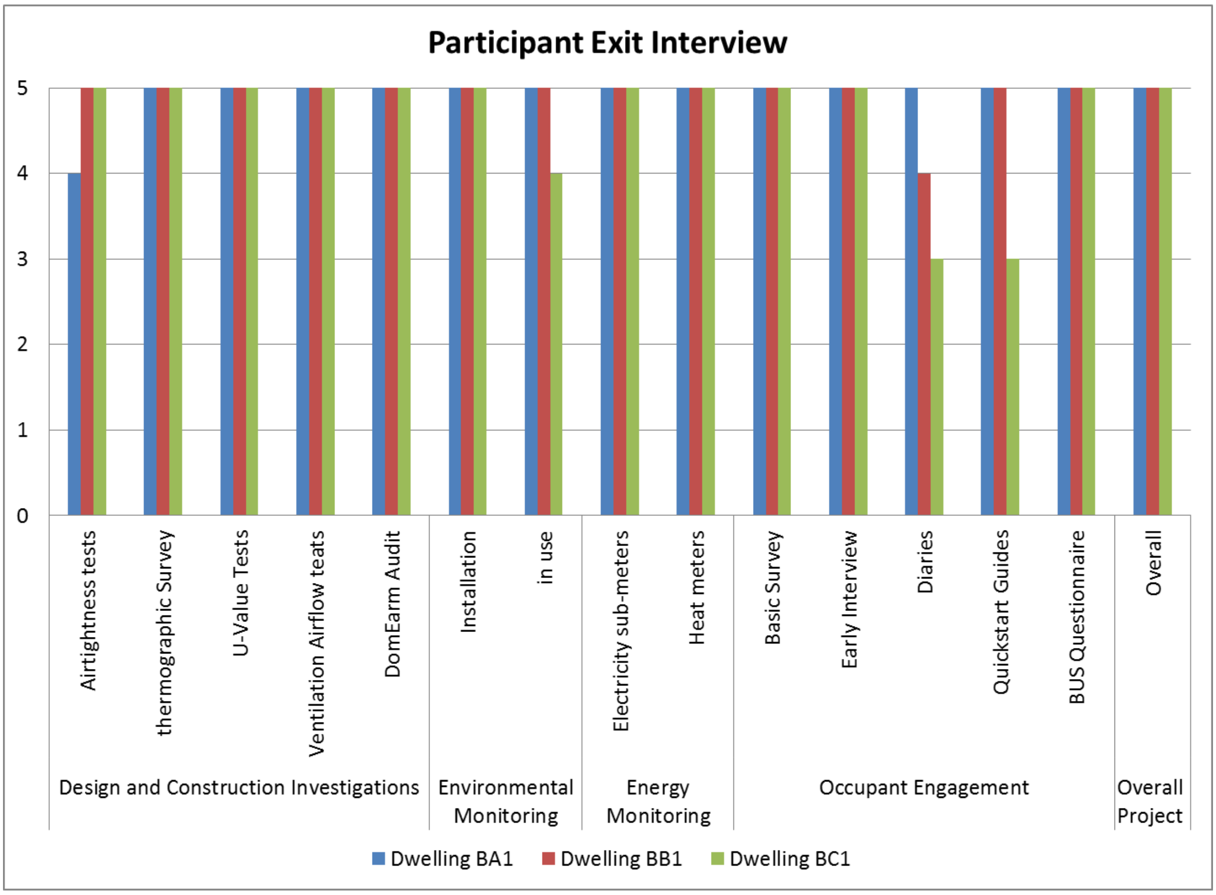


Figure 129: Exit survey interview

To do this a standard questionnaire was developed containing a selection of quantitative questions relating to each task undertaken as part of the BPE study. Section 2 of the survey intended to capture qualitative information relating to participants expectations, research team performance and if their landlord's engagement had changed in any way through the process.

Both occupants in each household were interviewed in their homes by a researcher from MEARU. Overall all three sets of occupants found the process to be straightforward and awarded a score of '5' for the project as a whole. The chart indicates that there were a few areas ranked lower than five, indicating there was slight disruption in certain areas of the research. These were minimal and related to; airtightness testing, occupant diaries, environmental monitors and the bespoke quick start guides developed. The reasons given why these were scored lower were minor reasons, which included whether the dwelling was tidy, a dislike of completing forms and a sensor falling into a bucket of wallpaper paste when re-decorating.

All things considered the occupants found the thermographic survey to be interesting, it is noteworthy that this test was visual and provided instant results that were relatively easy to interpret. There was a comment made in relation to the small size and lack of wires for the monitoring equipment used for monitoring internal environmental conditions, the occupants mentioned that they hardly noticed the equipment. A surprising comment from one respondent was that they "liked the company as well" this perhaps provides an insight into the relationship built up with the researchers and occupants over a period of time.

Only one household confirmed that they had made changes to how they operate their house as a result of the BPE project. They reported closing windows more often to conserve energy and to allow the heating thermostat to be set at a lower setting.

There is some evidence emerging of a reduction in energy use, with generally lower energy consumption in 2014 compared with 2013; however further monitoring is required to have two full year comparisons.

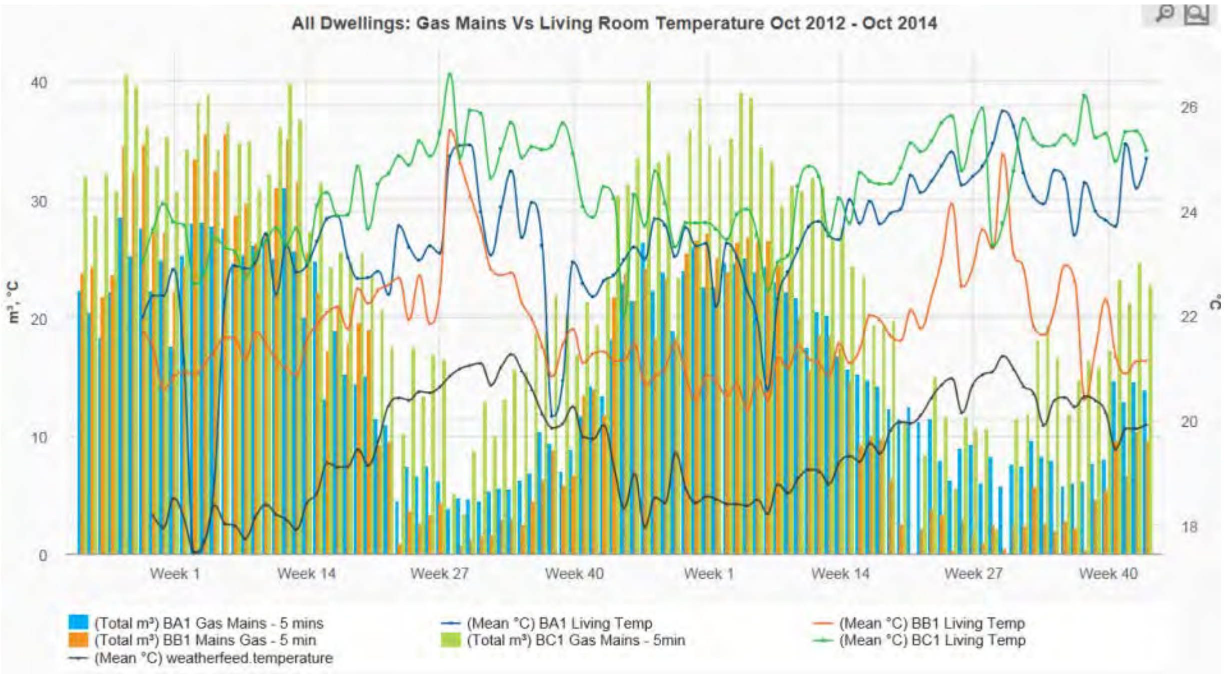


Figure 130: All Dwellings: Gas consumption (m3) and Living Room temperatures Oct 2012 – Oct 2014

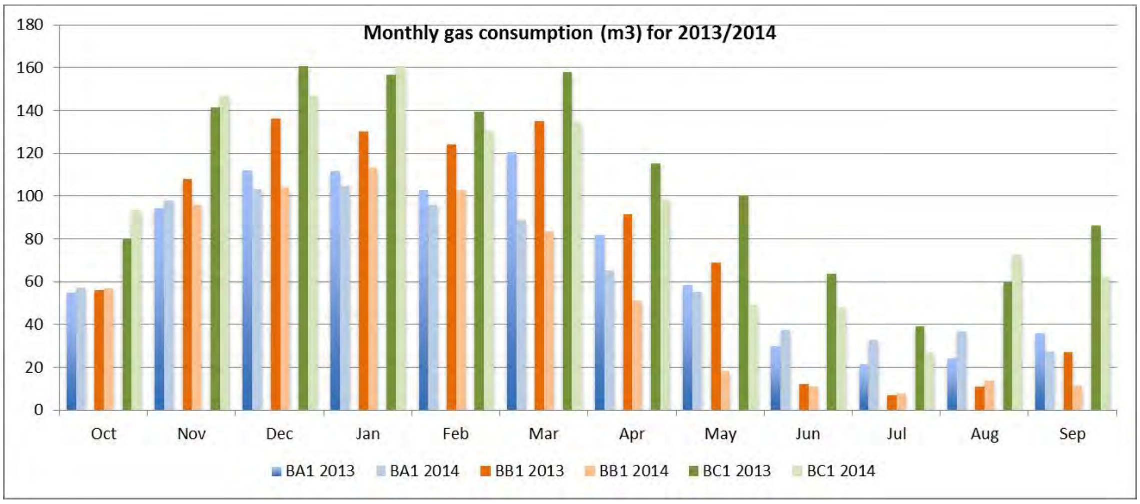


Figure 131: Relative monthly gas consumption (m3) for 2013 and 2014

Each household had differing viewpoints when discussing their landlords' engagement with the project. One household thought the engagement had changed for the better, while another associated landlord engagement to one individual in the Housing Association who ensured that work was undertaken. The third respondent related their communication experiences with the Housing Association and was dissatisfied with the lack of appointment making.

To conclude, the occupants were satisfied with the overall BPE project and found that they had learnt more about the operation of their homes. The occupants were pleased to help, especially if the lessons learned are used to help others in the future. The thermography was interesting to all of the participants; this is due to the engagement by the researcher undertaking the survey work and the visual results that can be discussed.

The occupants were pleased with the response from the Housing Association who instructed additional insulation to areas where insufficient insulation levels were found in the roof space.

The monitoring equipment was found to be discreet and the research team were found to be polite, provide plenty of warning for access and give clear explanations of the work and results.

8.2. 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.

- 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. 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.

- Notwithstanding this, there is emerging evidence of reductions in energy use due to some technical improvements (e.g. repair of solar thermal systems, replacement of insulation), and improvements in users knowledge (information on the boiler programmers), and general awareness of energy issues. However some issues remain (e.g. preference for high internal temperatures).

9. Key messages for the client, owner, occupier and industry

9.1. Fabric

Overall there are generally high satisfaction levels with the development. The houses are providing affordably warm and safe living environments, with a high degree of amenity. There have been some problems with elements such as the solar thermal system and extract fans, which have been exacerbated by the Housing Association maintenance response procedure, the quality of certain repairs.

The overall fabric performance is good, but the study has identified areas where improvements could be made. The importance of detailing is crucial, particularly in respect of buildability, an issue addressed in the revision to the standard eaves detail. This is a function of the brief development, design intentions and construction skills.

A specific example here is the eaves detail used industry wide for timber frame construction. This is impractical in reality, as it is too difficult to tuck the insulation quilt over the wallplate and down the face of the timber frame head binder. This has no doubt contributed to heat losses at the head binder and cooling of the ceilings where cold air can infiltrate below the insulation layer.

On subsequent projects (for all clients) the eaves detail has been changed to include a rigid insulation board installed before the soffits, allowing the insulation quilt to then be pushed against this to give better continuity of insulation and reduce the risk of cold bridging at the head binder.

With regard to thermal performance, whilst the emphasis tends to be on a build-up to meet a specific U-value, non-standard junctions and elements need to be considered. Both the vapour permeable construction and the thermal mass appeared to be beneficial, the former in helping to mitigate moisture, the latter in providing thermal comfort, particularly in the context of housing for older people.

Insulation was found to have been omitted in one area of roofspace, resulting in a walk-in wardrobe being cold. The contractor remedied this, but this would not have been revealed without this study. It raises a question about how frequently this occurs.

The vapour permeable construction does not seem to have made an appreciable difference to internal air quality, and window opening seems to be by far the most more significant factor. Vapour permeable specification is not being prioritised on current projects.

9.2. Active Systems

Further work is clearly required to address ventilation strategies in future projects. The trickle vent provision is not effective and whilst the detrimental effects of this may be masked by window opening, some consideration is needed as to how a health background level of ventilation can be achieved, especially in bedrooms

The architects have used the knowledge gained form this project on future designs. They have introduced a CO_2 detector in the bedroom on a Passive House project in Orkney, with this being connected to the MVHR system in order to boost the ventilation when elevated CO_2 levels are detected. This has also been specified for six subsequent houses in Orkney with a view to achieving demand-led MVHR and maintaining suitably low CO_2 levels.

Extract fan performance was found not to accord with the manufacturer's data. The manufacturer has recommended a higher performance fan for future projects; this has been incorporated into current specifications for HSHA. The manufacturer indicated that part of the problem may have been the resistance of the roof terminals and this merits further study. In the meantime the architects are taking fans to wall terminals where possible.

The programmer for the boiler needs to be simplified. The 7 day programmer appears to be too complex for many older people. It is too small creating difficulty identifying switches. A more simple set up for example an on/off switch for hot water and an on/off switch for heating with a simple remote thermostat control would be a better option, but support is required through the handover process to ensure that the systems are being used as intended.

HSHA would give consideration to undertaking the random testing of fans/ heating installations or perhaps undertaking a simplified POE on a random selection of properties within a development approximately 9 months after handover.

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. Blanket policies, whilst well-meaning may lead to inappropriate technologies. The requirement for solar thermal systems should be reviewed on a case by case basis.

9.3. Handover and Maintenance

The association needs to look at how it upskills housing staff involved in letting properties on the operation of heating systems and solar thermal controls, in fact generally all mechanical and electrical services. The demonstration of heating systems at Barrhead was undertaken by staff however this would probably have been lost on the viewing day with tenants having to cope with overload, such as viewing flat, thinking about furniture/carpets/white goods dealing with the prospect of moving house and giving up a tenancy elsewhere.

There is a need to review the building user manual supplied 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.

The Association is considering introducing a six-week review to explain again the workings of the heating system etc. This aims to avoid over reliance on family members assisting with demonstrating how systems operate.

The design team would look to involve manufacturer of solar thermal boiler/ equipment earlier at both the design and commissioning stage and again at handover to assist with commissioning, and address the gaps between solar thermal and heating system installation and maintenance.

The quality of commissioning needs to be reviewed to ensure that proper evaluation and tests are conducted.

Clearer targets and performance standards are needed to assist design, installation, commissioning and handover. 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.

9.4. The BPE Process

It is clear that important and useful data and knowledge has been produced about the Barrhead 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. As discussed in Chapter 5, the BUS is not yet sufficiently developed as a methodology for domestic environments and this, combined with its high cost means that it will not be used in future MEARU projects. The reporting process was unduly burdensome and has directed time and effort away from the project itself. The outline costs indicated in the bid process were unrealistic for a Phase 2 project which had not undertaken a Phase 1 analysis.

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 lost 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 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 – should be provided at installation. 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.

9.2 Industry recommendations

- BPE is a crucial strategy in examining the energy and environmental performance of housing for HSHA.

- Organisations need to develop capacity for undertaking BPE and feeding this back into specification, design procurement and construction processes.
- Building Performance Evaluation has revealed significant, useful information on performance; it is able to identify improvements in existing and future buildings and is a vital component is producing effective buildings in contemporary contexts.
- It helps to inform design and legislation, is able to improve (achieve) energy savings and environmental performance, health and well-being, by ensuring that what has been paid for is delivered, meets landlords ethical responsibility to occupants and ensures that targets and objectives are being met.
- Changes are required in the industry to ensure that BPE processes are undertaken as a matter of course. This project revealed issues that would otherwise have remained unreported and led to problems in the future.
- An increased resource is required to achieve significant levels of increased performance. At present the industry is inching forward using conventional materials and systems. Innovative materials and technologies are not generally affordable, and without industry demand, economies of scale cannot be achieved.
- This project has demonstrated that alternatives to the industry standard timber frame with a vapour barrier can be beneficial. It also calls into question the developing lack of thermal mass in contemporary housing in Scotland, particularly for control of comfort and overheating. However, development is needed to ensure that thermal standards match those of lightweight construction.
- Greater attention needs to be paid to the 'weak links' in design and construction. Whilst 'typical' wall and roof build-ups are fine, most areas of a building are some form of exception at corners, junctions with opening, the materials in the openings, wall/floor and wall/roof junctions.
- Improved 'buildability' combined with more robust on-site testing and inspection is needed to improve build quality. The case in point identified here is the eaves detail, and this type of thinking could be applied to many other areas within construction.
- The utilisation of technologies and active systems in buildings needs a more nuanced assessment of their costs and benefits, including whole life costs such as maintenance and repair. Some form of risk management is also required to assess the impacts (in both energy and environmental terms) of sub-optimal operation or failure.

- Assumptions in SAP about the effectiveness and efficiency of active systems is giving these technologies greater weight at design stages and may lead to the selection of inappropriate systems that satisfy SAP, but not the building or end users.
- The reliance on SAP for compliance is reducing innovation, partly because of the undue reliance on SAP by building control. Manufacturers cannot develop new products as they do not have a market unless they are contained within SAP. Designers cannot develop alternative systems and strategies as they cannot demonstrate compliance.
- With decreasing energy demands, there is increased scope for communal systems, particularly for managed developments for these types of clients.
- Communal systems would certainly be worthwhile for complex active systems such as solar thermal. There may be a tendency away from these systems in the future as PV with direct water heating becomes more efficient and cost effective.
- Whilst controls can be effective, their current design and user interface is very poor, particularly for this type of occupancy. Consideration is needed for a) improved or simplified systems; b) more robust and passive design of environmental strategies which requires less close control to be efficient; and c) better placement and consideration of ergonomics and comprehension of controls (including physical elements such as windows and trickle vents).
- A far more 'joined-up' approach is needed for the design, installation, commissioning, handover and maintenance of heating and ventilation systems. It is important that this begins with design so that the holistic intentions of environmental and energy strategies which engage with the building as a whole are not compartmentalised through the procurement process.
- This is particularly the case in relation to ventilation strategies, which need to be revised in order that energy reduction does not compromise indoor air quality. The importance of occupant interaction, the available strategies and advice for occupants need to be considered more carefully at design stages.
- Elevated CO_2 levels in bedrooms indicate trickle ventilation is inadequate despite complying with Building Standards and a revision of the standards is required. This project contributed to the evidence which has led to the consultation on a revision of the Scottish Building Standards.