Scotland's Housing Expo

Phase 2 study
In-use and post-occupancy

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

InnovateUK project number	450073
Project author	Glasgow School of Art, Mackintosh Environmental Architecture for Research Unit (MEARU) Architecture + Design Scotland
Report date	2014
[1]InnovateUK Evaluator	N/A

No of dwellings	**Location**	**Type**	**Constructed**
Eight	Milton of Leys, Inverness	Various (see p.13)	2010
Areas	**Construction form**	**Space heating targets**	**Certification level**
Various (see p.13)	Various (see p.13)	Various	Scottish Building Regulations

Background to evaluation

Scotland's Housing Expo held in 2010 was an event showcasing innovative sustainable housing. The purpose of the Expo was to promote best practice in design with the aim of making sustainable features commonplace. A BPE study was undertaken on eight dwellings: four were social rented homes and the remaining dwellings were owner-occupied. The dwellings were from four different plots (two dwellings on each plot), each having particular features and design approaches. The study examined the relationships between design intentions and predictions, users' experiences and perceptions, and environmental and energy performance.

Design energy assessment	**In-use energy assessment**	**Sub-system breakdown**
Yes (SAP assessment)	Yes (Detail is dwelling dependent)	Yes (SAP)

An assessment was made of each dwelling's in-use performance against the design expectations. This was determined using the Standard Assessment Procedure (SAP) prediction tool. However, as-built SAP assessments were not conducted. **Note: Individual SAP assessments produced by the various design teams were reported in appendices which were redacted by InnovateUK prior to publication. More information may be available on request from MEARU.**

Occupant survey type	**Survey sample**	**Structured interview**
BUS domestic	29 of 45 (64% response rate)	Yes

Semi-structured interviews were developed to discuss the handover process with the occupants. These aimed to understand the level of advice and support each household had received when moving in to their homes and to understand issues the occupants worried about. Occupants were questioned over their ability to operate and control heating and hot water systems and whether the heating was affordable. The survey also prompted discussion over sound performance and the ventilation systems. The BUS results are available at http://portal.busmethodology.org.uk/Upload/Analysis/yp2nevx2.214/index.html (as of January 2020).

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1 Introduction and overview

1.1 BPE project

Scotland's Housing Expo held in August 2010 in Milton of Leys, Inverness was a high profile event developed to showcase innovative sustainable housing that includes a variety of design ideas and technologies contained within one site (Figure 1:1). This event was the first of its kind in Scotland and was based upon similar Expo models found in mainland Europe and the Nordic countries. The Scottish Expo followed a model from Finland, where historically the 'Housing Fair' concept has proven very successful in stimulating high quality design and innovation for housing.

The purpose of the Expo was to promote best practice in design with the aim of making sustainable design features commonplace in every home. All dwellings on the site were architect designed, and delivered under a unique design and build arrangement by five developers working together on site in partnership with the local housing agency the Highland Housing Alliance (HHA). The project was completed in 2010 and comprises 27 plots: 26 contain individually designed low energy homes; one plot was undeveloped due to the fact that it proved impossible to reconcile the differential between the project cost as designed with the available budget - this is further discussed in sections 1.3 and 1.4.

The Expo was open to the public during the summer of 2010 during which time it generated considerable interest and debate across the architectural, housing and construction sectors in Scotland and the UK. The event attracted over 33,000 professional and lay visitors from home and abroad including visitors from Finland, Russia and Australia. There are 52 houses on the site, 20 for rent/low cost home ownership and 32 houses for sale on the open market. Dwellings demonstrate a variety of layouts and forms designed to minimise energy consumption whilst maximising environmental quality. Contributing energy and environmental features include double height and large volume living spaces, compact form and careful orientation to maximise natural lighting, sun-spaces, external and site design. These houses are now occupied and a living community is developing. During the Expo, visitors were invited to vote for their favourite design - this proved to be a metal and timber clad single dwelling house with a double height living room and a large upstairs hall/study area/play space designed by Malcolm Fraser Architects which is situated on Plot 27.

The BPE study was undertaken on eight dwellings: four of these were social rented homes and the remaining four dwellings were owner occupied, sold under a shared ownership scheme. The dwellings selected for study were from four different plots (two dwellings on each plot) each having particular features and design approaches of interest to the construction sector. The comparison of two dwellings from each plot allowed analysis of the effects of occupancy in identically constructed dwellings as well as, a comparison of performance across the differing dwelling designs.

The study examined the relationships between design intentions and predictions, impacts of the procurement process, users' experiences and perceptions of the design, and metered environmental and energy performance. Occupant engagement, in the form of diaries, and the testing of improved occupant guidance were included as part of the project.

Figure 1:1: Site plan of Scotland's Expo site indicating location of each plot. North is at the top of the illustration. The monitored plots are 3, 4.2, 4.3 and 8.

1.2 Project Team

The project team consisted of:

Architecture and Design Scotland (A+DS)	Lori McElroy Kate Hendry	Based in the Lighthouse in Glasgow, A+DS acted as the project lead and provided support with contacting residents and survey work. Architecture and Design Scotland (A+DS) is Scotland's champion for excellence in place making, and architecture. It is an Executive Non Departmental Public Body of the Scottish Government. A+DS aims to support the creation of places that work, which provide people with real choices and, are ultimately, places where people want to be.
Mackintosh Environmental Research Unit (MEARU)	Tim Sharpe Janice Foster	Based at the Mackintosh School of Architecture in Glasgow MEARU was the academic subcontractor to A+DS. MEARU undertook testing, survey work, and environmental and energy monitoring analysis and report writing.
Cairn Housing Association (CHA)	Simon Campbell	CHA provided initial introductions to project participants living in the socially rented dwellings.
Albyn Housing Society (AHS)	Donald Lockhart	AHS provided initial introductions to project participants living in the owner/occupier properties.

Table 1:1: Project Team for the BPE study.

1.3 Development in a Wider Context

The five hectare site is situated in a semi-rural position on the southern outskirts of the city of Inverness. Set on a north facing slope with views over Inverness, the Beauly Firth, across to the Black Isle and the mountains beyond; due to the elevated position of the site (approx. 170m above sea level) it is regularly affected during winter by heavy snow fall, and is neither ideal in terms or orientation for solar gain or natural shelter. A number of speculative developer homes have recently been erected on plots surrounding the site and the construction of new homes in the locality appears set to continue into the future. The innovative dwelling design and site layout are unique to the Expo site and appear not to have been adopted by subsequent developer homes in the local area.

The project commenced with a competition in 2007, based on a site on the outskirts of the city and for which there was already planning permission. A city centre brownfield site would have been the preferred option, but there was nothing readily available and there was a degree of compromise required if The Highland Council was to deliver an Expo in time for the Year of Homecoming in 2009. In the end, the Expo was delayed until 2010 due to the impact of the recession, which affected market and bank confidence, delaying the start on site.

Scottish Government's Sustainability in Architecture Programme (Sust. - Now part of Architecture and Design Scotland (A+DS)) provided sustainability and environmental performance support to the Expo Advisory Board for the project. Sust.'s role is to raise public awareness of the importance of sustainable design and the contribution it can make in delivering a sustainable future, and improve an understanding of sustainable design for those commissioning new buildings. Unfortunately the onset of the recession and its impact on market confidence resulted in dilution of some of the original ideas.

Key areas of concern and of subsequent interest with regard to monitoring were the change in delivery model from standard contract to design and build, the decision to move away from a site wide energy plant (made as a result of lack of knowledge of the likelihood of buy-in from home owners), an associated decision to locate all of the social/low cost home ownership housing in one area of the site (rather than the original tenure-blind intention) and finally the decision that the only part of the site served by a centralised heating system would be the six flats on plot 8. From the viewpoint of the original design intentions we were always keen to monitor the project both in terms of performance and in terms of how the project was received by the new residents. As a result of the variations in what was delivered compared with the original intent, we shifted our interest in monitoring from the question of ability to deliver against high expectations, to examining the impact of value engineering.

The original objective of the Expo was to explore the potential to make better use of local products in construction in Scotland, with a particular focus on growing the market for Scottish timber, including the potential to develop a market for mass timber products made in Scotland and the development of new high quality window systems from Scottish grown materials. Not all of the intentions were realised, but it should be noted that visitors from the Finnish Housing Fair Co-operative remarked that the Scottish Expo pushed boundaries in a different way from the Finnish equivalent. We were disappointed that we did not follow the Finnish delivery model completely, whereby each architect individually appoints a contractor to undertake the build. However, this did not prove possible in Inverness as the site was small and there were a small number of each of the 30 house types. Ironically - one architect did bring his own appointed contractor and this house was completed first, on time and to the architect's exact specification. However, logistically this was not possible across the Inverness site given the tight timescales, and in defence of the final delivery model for the majority of the houses, in Finland, Housing Fairs are generally of a larger scale and while innovative, they showcase fewer house types in greater quantities. They do showcase state-of-the art, but they also demonstrate readily available top of the range products from the best housing providers in Finland. In other words, it could be argued that we were pushing the envelope a bit harder than they do as we (arguably) were starting from a lower base.

Figure 1:2 illustrates architects impressions of dwelling design for each plot, indicating the diversity of dwellings planned and constructed on the development. The range of dwellings includes detached, semi-detached and terraced housing as well as flats available for first-time buyers and houses with home-working options. The site layout evolved in response to topography and landscape providing areas within the site that reflect rural and urban scenarios, reported as being typical to the Highland Scotland region. The roads are designed as shared spaces for pedestrians, cyclists and vehicles, with no kerbs or road surface markings.

In Scotland timber frame construction is commonplace and on this development the majority of the dwellings were timber frame construction; four were massive timber construction (cross laminated timber (CLT)); another four were pre-fabricated timber cassette and one block-cavity-block dwelling was built. Many of the architects set out to test new ideas and systems such as massive timber (CLT or Brettstapel), Trombe-Michel walls for thermal storage and 'breathing wall' construction (which requires the use of particular building materials and some specified thermal mass). However, the Highland Housing Alliance (HHA) who were responsible for delivering the project were working to standard Scottish Government benchmark cost targets, which were inclusive of land and infrastructure, so given the nature of the project and the fact that they were not building large numbers of any of the house types, most of the houses started out over cost, but not so significantly as to be beyond the parameters of what it was possible for Scottish Government staff to approve. This equated to a build cost in the region of £1,000 to £1,200 per square metre. Post 'value engineering' the averaged out costs for the affordable properties fell within the required limits.

Some of the features discussed above were omitted during the 'value engineering' process that took place after the form of appointment was changed; this is elaborated below in 1.4 and discussed further in Chapter 2 for the specific dwellings in this BPE study.

Figure 1:2: Architects interpretation of dwelling design for each plot.

1.4 BPE Dwelling Summary

The original BPE bid proposed monitoring all six house types (12 properties in all) of the rental/low cost ownership properties, however, this took the study cost to £185,000 which exceeded the available threshold for studies at this time (of around £150,000). The team were advised to drop two of the house types at this point as both had been significantly affected by value engineering and it was felt by TSB that monitoring of these might be of limited value to the wider learning from the project. This was taken on board, despite a deeply held reservation based on our perception of an apparent lack of understanding of the impact of 'value engineering' innovative projects without first understanding that in many of these dwellings the building services and fabric are inextricably linked. The situation was exacerbated by the change from a traditional contract to a design and build delivery model and the consequent novation of the architects. For example - in one of the houses in question a heavy mass, black rubber coated Trombe-Michel wall with an integral passive ventilation system was replaced with a timber frame 'equivalent' heavily insulated but with no mass; in the other project not included, a massive timber house designed to high levels of airtightness had a mechanical ventilation heat recovery system (MVHR) removed - resulting in reported high levels of condensation on windows and behind furniture on external walls. We would argue that there is a lack of focus on such issues, and there is a need to address the associated risks to fabric, performance and occupant health.

The main project was delivered by four main contractors - three of which delivered the housing and the other completed the streetscape and infrastructure. Three of the monitored projects were delivered by one of the three contractors and one dwelling type by one of the other two. We did not monitor any properties delivered by the third contractor. A second BPE bid to TSB to undertake post completion and early occupation monitoring of five of the 32 houses for sale on the site (costed at £76,560) was unsuccessful. The houses finally selected for monitoring had remained close to the original design intent with design changes that could be considered minimal, although House Type D (described later) had originally been designed as a one bedroom flat and the proportions of the rooms were affected by reconfiguration to provide a second bedroom. This affected the size of the living space which had an impact on the occupants' ability to use the sunspace as intended.

A description of the architects' design intent of each of the dwellings is given below:

House Type A: The Shed House (terrace of three 4-bedroom, two storey houses) for Cairn HA. Simple/adaptable floor plan, well daylit using known construction systems - designed to encourage the view that good design need not be radical or expensive. Lightweight timber cladding on a standard 140mm timber frame with trussed rafters and a concrete slab foundation. The houses have been designed using traditional timber frame technology, as well as providing scope for well-insulated, thermally efficient homes. The frames were pre-fabricated off site locally and transportation of building parts was from a short distance. As a model for future projects, it was important to choose a construction type that maximised the potential to use the local work force. The timber clad external envelope of the buildings is designed for minimal maintenance.

Figure 1:3: House Type A, front view, internal view of kitchen and rear view of the terrace.

House Type B: The Healthy House (two units: semi-detached, 3-bedroom, two storey houses) for Cairn HA. Open plan living/well daylit environment/interaction between public areas across both floors. Timber-frame construction with timber cladding externally. By adopting a common sense approach, avoiding the use of maintenance and energy hungry 'eco clichés' the houses benefit from natural ventilation, passive solar gain and increased levels of insulation. The original concept provided a holistic approach to material choices to provide a healthy living environment; especially regarding the internal finishes such as natural clay paints, low toxicity carpets and natural stains/paints within a formaldehyde free construction. Due to budget restrictions these were omitted from the final construction, however the overall form and concept was retained.

Figure 1:4: House Type B, front view, internal view of living/kitchen and south gable.

House Type C: Lios Gorm (fully accessible 1-bedroom flat on ground floor; upper floor flat, 1-bedroom) for Albyn HS. Approach uses off-site construction and pre-fabricated central service cores, built with Scottish timber. Timber framed closed panel wall, floor and roof cassettes with load bearing service cores. The design utilises modern methods of construction to minimise embodied energy and maximise quality. The roof, wall and floor cassettes were all manufactured under factory conditions and the pre-fabricated service cores incorporate all of the electrical, water and ventilation systems. The houses were designed to maximise solar gain from the south (framed construction with south west facing glazed infill) and minimise heat loss to the north (thick, well insulated walls with carefully located window penetrations).

Figure 1:5: House Type C, south and west view, internal view of living room and kitchen, north façade housing entrance doors.

House Type D: The Apartments: (three storey block of six 2-bedroom flats). Shared ownership with Albyn HS. Structural timber frame with masonry construction on steel frame to sunspace and communal stair. The Apartments are orientated to maximise solar benefits, both in terms of natural daylighting into the primary living spaces and passive solar gain, harnessed through the integral 'solar buffer space'. Collecting the sun's heat during the day, absorbing it in the thermal mass of the heavy masonry construction, and releasing the warmth into the dwellings at night. The fenestration patterns assist natural ventilation. The main living areas are predominantly open-plan to increase efficiency of space heating and flexibility of use. All heating and hot water demands for the six apartments is provided through an independent biomass boiler located within the curtilage of the plot. These were originally designed as one bed flats but altered internally to provide a second bedroom - this affected the layout of the open plan living and kitchen areas and the relationship between these and the sunspaces. The desing of the sunspace was also compromised by lack of high level opening windows and the double glazed windows being ill-placed at the building envelope.

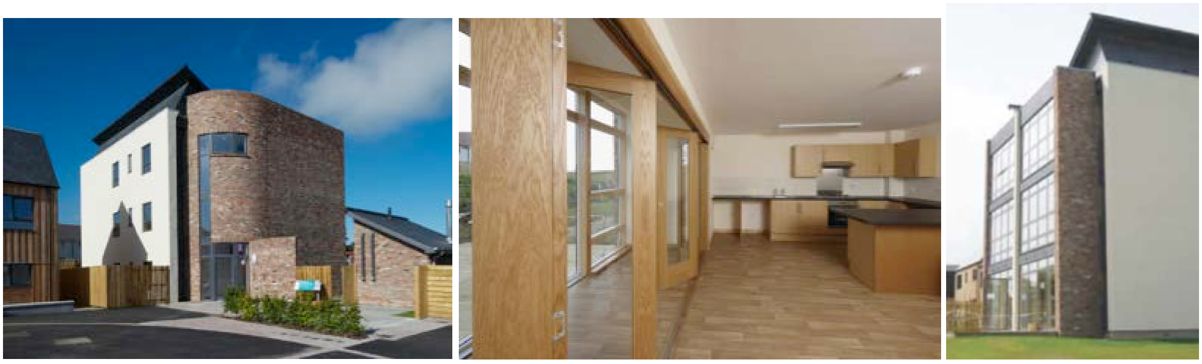


Figure 1:6: House Type D, south and west view of communal stair with dwellings behind, internal view of living room, kitchen and sunspace, west façade showing external view of the sunspace.

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

2.1 Development

The buildings on the Expo site are architect-designed dwellings, mostly of timber frame construction, consisting of flats, terraced, semi-detached and detached dwellings on 27 plots (Figure 1:1). The design and construction was procured through an architectural competition that aimed to raise the bar for Scottish housing by showcasing innovate sustainable housing to help change attitudes towards house and place design, stimulate the construction industry for design-led housing solutions and to trial new ways of thinking about places, design and materials. Each of the plots were developed with 27 completely different designs, but many of the architects embraced similar design principles, such as of orientation, materials and consideration of occupant well-being.

Following the announcement of the competition winners the successful design teams began detailed design of their sketch design entries. However by the time detailed planning consent was obtained (2008) the banking crisis had started to affect and jeopardise the delivery of the programme. A decision was made to postpone the Expo event by one year and to change from traditional procurement to a design and build contract with five local contractors, working together on site in partnership with HHA. The architects were subsequently novated to the contractors. A value engineering process followed to reduce costs with the aim of simplifying construction forms to enable dwellings to be completed within the nine month build timescale. After the architects were asked to identify their one 'must save' item from their respective designs much debate ensued between the architects and contractors; these are explored later in this report. An abridged project timeline is provided in Figure 2:1.

A book covering the full project history and further information about each of the plots is available in pdf format from: http://www.scotland.gov.uk/ Resource/Doc/347799/0115858.pdf the book (ISBN: 978-1-905061-28-0) is published by A+DS (Architecture and Design Scotland).

2007	2008	2009	2010
31 Jan – Design competition launched by RIAS 4 May – Competition deadline 1 Jun – Winners announced Aug – District heating scheme abandoned	Jul - Decision made to postpone project	Apr – Procurement changed to design and build, architects novated to contractors Aug – Initial completion date Nov – Site start date	1st Aug – Expo Event

Figure 2:1: Abridged Expo Project Timeline

As noted in section 1.4, this BPE project researched two dwellings from four plots; four two-storey houses and four flatted dwellings. It is hoped that the findings from the BPE study will inform the design of the remaining north part of the site which is still to be developed (refer to Figure 1:1).

The dwellings in the study are described in the following text with full photographic surveys of each dwelling in Appendix A.

House Type A – 2no. four bedroom dwellings situated in a terrace of three, one is located at the end of terrace and the other mid terrace. These dwellings are rectangular in plan with a pitched roof approximately aligned along a north/south axis. Front (street) elevations face east; rear elevations are orientated west and overlook private garden. The internal floor area is 110m^2 with floor to ceiling heights of 2.4m. The ground floor consists of a reinforced concrete floor slab with insulation below. External walls are constructed from an insulated 100 x 50mm timber frame with 12mm ply sheathing and a rigid insulated layer on the internal face of the frame. Externally, the dwellings are clad with untreated Scottish larch fitted horizontally on ground floor and vertically on the first floor and gables. The front elevation of one dwelling is clad in corrugated cement fibre board, to satisfy fire regulations on the plot boundary. The roof is constructed from timber trusses and has a slate finish. It is a cold roof construction i.e. insulation is placed above the ceilings of the upstairs rooms. Window frames and external doors are painted timber. The house is heated with a gas fired condensing combination boiler serving underfloor heating on the ground floor and radiators upstairs; the boiler heats hot water on demand.

House Type B – 2no. three bedroom semi-detached dwellings, orientated with front and rear façades facing east and west respectively. The dwellings are rectangular in plan with an asymmetric barrel roof clad in corrugated aluminium sheeting. The internal floor area is approximately 90m^2 with 2.45m floor to ceiling height in the open plan ground floor while ceilings on the first floor follow the line of the roof which is fitted with roof lights. The ground floor consists of 22mm chipboard on timber battens over a reinforced concrete floor slab with 120mm insulation below. The external walls are constructed from 145mm timber frame filled with mineral wool. Externally the walls are clad with treated larch cladding fitted in horizontal and vertical orientations. The open plan ground floor faces towards the rear garden (west) and houses the kitchen, dining and living room areas, there is a double height space over the dining area. Window frames and external doors are painted timber. The houses are heated with a gas condensing boiler serving radiators on both floor levels. Domestic hot water is heated by the boiler and stored in a hot water cylinder located in a cupboard off the first floor landing.

House Type C – 2no. one bedroom flats; one ground floor, one first floor. These have external elevations facing north, south and west. The internal floor area is approximately 63m^2 with 2.4m floor to ceiling height. The dwellings were constructed from factory made wall, floor and roof cassettes. These consist of 6.4mm Paneline and 9.2mm Panelvent either side of 95mm timber framing. The cassettes were filled with cellulose insulation to form breathing wall panels. The insulated flat roof cassettes are covered with plywood sheathing, woodfibre insulation and a further layer of plywood sheathing covered with an EPDM roof membrane lapped up the inside of the wall head parapets. External façades are clad in locally sourced larch, which has been stained. Window frames and external doors are painted timber. Primary space heating is provided by electric panel radiators with integral adjustable thermostats, with secondary heating provided by a wood burning stove. Hot water is provided by a domestic hot water cylinder, which is fitted with an electric heating element and located in a cupboard off the hall.

House Type D – 2no. two bedroom flats, situated on the ground floor of a three storey building. The principal living spaces are oriented west, overlooking small areas of private decking which are accessed through an integral solar buffer space. One dwelling has bedrooms and a bathroom orientated towards the south with the same rooms in the second property are orientated north. Both properties have a floor area of approximately 76m^2 with 2.4m floor to ceiling height. The building was constructed from a structural timber kit with engineered members in floors to allow larger spans. The external wall is a staggered twin stud arrangement, filled with cellulose insulation and rendered externally. The circulation space and sunspaces (west elevation) are of masonry construction. Window frames and external doors are painted timber. There was an emphasis on locally sourced, reclaimed materials. Heating and hot water is provided through a communal biomass (wood pellet) boiler located within the curtilage of the plot. The heat is controlled through a room thermostat and provided by radiators fitted with TRVs. Domestic hot water is stored in a hot water cylinder.

2.2 Amenities

The development site lies around five miles south of Inverness city centre and is accessed from the nearby A9 trunk road. The easy road links allow access to supermarkets, post offices, a theatre, a hospital and a number of retail parks, restaurants and an airport. The city centre offers shopping facilities. The increase in dwelling numbers in the locality justified an improvement to the bus timetable between the site and city which now offers a more frequent bus service operating into the evening. Within walking distance is a new primary school as well as a convenience store and pharmacy that opened in December 2013. There are three woodlands within walking distance from the site: Balvonie Wood to the north (just visible north of the site in Figure 1:1), Bogbain and Daviot Woods to the south. These contain marked walks as well as cycle routes. Highland Scotland is a popular tourist destination. As well as arts and cultural destinations there is a wide range of outdoor pursuits, including hill walking, mountain climbing, golf, canoeing and outdoor skiing; all of which are close to the site.

2.3 SAP Assessment

The Standard Assessment Procedure (SAP) is a prediction tool used to assess and compare the energy and environmental performance of dwellings. Its purpose is to provide accurate, reliable and above all comparable assessments of dwelling energy performances that are needed to underpin energy and environmental policy initiatives. SAP calculations are undertaken during the design phase of a dwelling and are a requisite component of the Building Warrant submission (to prove compliance), and as such tend to be accurate in relation to the design status at that stage.

SAP works by assessing how much energy a dwelling will consume, when delivering a defined level of comfort and service provision. The assessment is based on standardised assumptions for occupancy and behaviour input by a trained user. This enables a like-for-like comparison of dwelling performance.

SAP quantifies a dwelling's performance in terms of: energy use per unit of floor area, a fuel-cost-based energy efficiency rating (the SAP Rating) and emissions of CO_2 (the Environmental Impact Rating). Related factors, such as fuel costs and emissions of carbon dioxide (CO_2) can be determined from the assessment. The indicators of performance are based on estimates of annual energy consumption for the provision of space heating, domestic hot water, pumps, lighting and ventilation. Other SAP outputs include an estimate of appliance energy use, the potential for overheating in summer and the resultant cooling load. The regulated energy consumption predictions undertaken as part of the SAP assessment are summarised in Table 2:1.

As noted above the SAP assessment provides predicted running cost for regulated loads in each assessment, these costs have been used by the respective housing associations in part of their documentation to inform costs to potential occupiers of each dwelling. The increased costs for heating have been questioned by the occupants as the dwellings cost significantly more than they were initially led to believe. The issue stems from the costs used in the SAP assessment were unrealistically low fuel costs were used. It should be noted that '*as built*' SAP assessments have not been undertaken and are not required under the Scottish Building Regulations. Individual SAP assessments produced by the various design teams to illustrate Building Regulation compliance are appended in Appendix B and mandatory Dwelling Characteristics forms are located in Appendix C. Each house type is discussed separately below.

Dwelling	A1	A2	B1	B2	C1	C2	D1	D2
Energy Efficiency Rating	79	80	84	84	83	82	86	86
Energy Efficiency Band	C	C	B	B	B	B	B	B
Space Heating (kWh/year)	5583.52	5159.70	3538.00	3663.00	1571.87	1709.00	2166.28	2238.15
Space Heating Secondary (kWh/year)	572.00	528.58	354.00	364.00	485.15	527.41	0.00	0.00
Water Heating (kWh/year)	3483.52	3483.52	3246.00	3246.00	1899.05	1899.05	2809.00	2809.00
Electricity pumps and fans (kWh/year)	175.00	175.00	175.00	175.00	0.00	0.00	0.00	0.00
Energy for lighting (kWh/year)	733.88	733.88	602.00	602.00	339.49	339.49	509.00	509.00
Total CO_2/year (kg CO_2/year)	2383.94	2283.39	1794.00	1816.00	1620.12	1679.05	386.00	388.00
Dwelling Carbon Emission Rate ($kgCO_2/m^2$)	21.75	20.83	19.94	20.19	31.96	33.12	5.08	5.11
Target Carbon Emission Rate ($kgCO_2/m^2$)	21.78	20.83	23.38	23.49	36.01	35.77	662.00	662.00
Improvement over TER (%)	<1	0	15	14	11	7	41	41

Table 2:1: Summary of key SAP calculation predictions for each dwelling assessed in the BPE study.

House Type A

The SAP assessment for this house type indicates a very small reduction in the dwelling emission rate (DER) compared with the target emission rate (TER) providing indication that the dwelling design just meets the minimum standards set in the Building Regulations, despite improved target U-values. Building fabric tests undertaken during the BPE study found the fabric performance (U-values and airtightness) of this house type to show a greater improvement over the design figures stated, refer to Chapter 3 for further details. While the airtightness result was vastly improved over the design figures, the figure of $10m^3/(h.m^2)$@50Pa was presumably selected so that an airtightness test was not required on completion of a weather tight envelope.

However, despite the improved fabric performance the estimated running costs of £188 per annum for space heating and hot water heating were much higher than the SAP prediction. The occupants informed the costs to keep comfortable were in the region of £1,000 to £1,200 per annum. The occupants have expressed their annoyance over the unexpected additional expenditure for space heating and hot water. They advised they partly took up their tenancy based on the low running costs indicated to them by their housing association, thus indicating the unrealistic averaged costs have wider implications on affordability for the occupants. However some of the additional heating costs could be a result of occupant behaviour (heating on for extended hours to suit lifestyles and external doors and windows open when heating is switched on) and the relatively high internal space temperatures maintained in the dwellings, particularly in dwelling A1, refer to section 7.4.

A minor discrepancy with data input into the SAP worksheet was identified; this related to the number of mechanical extract fans in the dwelling, the SAP assessment assumes three fans compared with four that installed. The performance of the fans are discussed in Chapter 6, however, the additional energy requirement for one wall mounted fan wouldn't have a noticeable impact on the SAP calculation.

Overall the regulated energy consumption in this house type exceeds the SAP prediction with actual consumption for space heating being considerably greater (Figure 2:2). The water heating consumption was close to the SAP prediction and the measured lighting consumption was slightly lower than the SAP prediction.

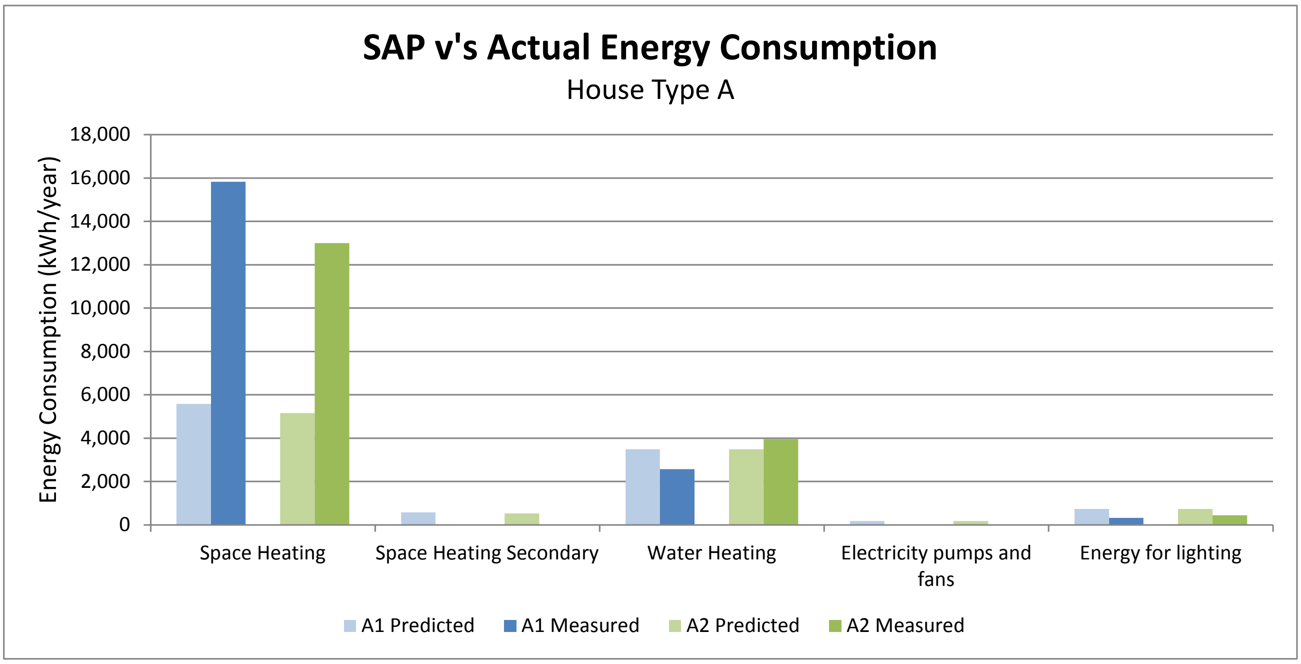


Figure 2:2: SAP prediction v's measured energy consumption - House Type A

House Type B

Both dwellings are rated with a 'B' and the emission reductions predicted using SAP were around 15%. The measurement undertaken indicated a slight improvement on wall U-values and airtightness over the standard default figure of $10m^3/(h.m^2)$ @ 50Pa (testing is not mandated during construction for this target). The running costs were reported to be much higher than the occupants had anticipated, however the acknowledged that they are still lower than where they have lived before.

A discrepancy with the SAP sheet assumed that these dwellings were fitted with a combination boiler, when there is a hot water storage tank located in a first floor cupboard. It is not clear whether the dwellings were initially designed with a condensing gas combination boiler which was later changed to a system boiler as the design progressed to a design and build contract. However, one of the design changes highlighted in section 2.4 was the omission of solar thermal panels and therefore it could be sensibly assumed that the hot water cylinder and system boiler would have been included in the original design.

A review of the energy consumption (Figure 2:3) indicates a smaller performance gap for space heating, compared to House Type A, especially in House B1. The occupiers in this dwelling are normally at home during the day and the lower space heating consumption (45%) is unexpected. The water heating in dwelling B1 is around the SAP assumption but dwelling B2 is around 50% lower than SAP. However, the lighting loads in both households are significantly lower than the SAP standard predictions.

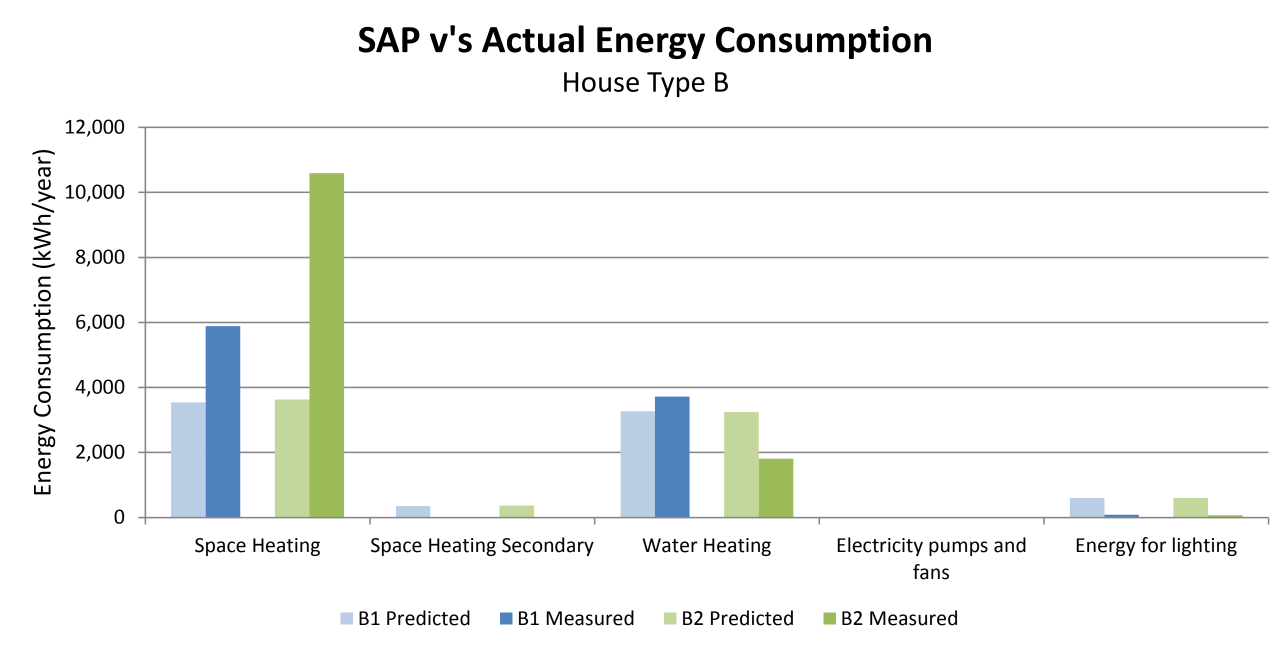


Figure 2:3: SAP prediction v's measured energy consumption - House Type B

House Type C

The improvement in the DER over the TER was predicted as 11% and 7% for dwelling C1 and C2 respectively. The in-situ U-value testing of the building fabric didn't produce results due to a prolonged unheated period in the test dwelling (refer to Chapter 3). While airtightness test results were better than the standard benchmark ($10m^3/(h.m^2)$ @ 50Pa). Discrepancies with the data input in the SAP were not immediately obvious, however the fans indicated in the assessment specified two within the dwelling, although there are two grilles (kitchen and bathroom) there is one exhaust point out of the building and one fan as the extract system is a ducted continuous MEV system. Further the SAP assessment assumes that no energy is used to drive the fans which although a low energy system was installed it does consume some energy, this should have been included in the assessment. However, it was found that the roof element was incorrect, the SAP assessor had simply copied the wall construction layers and altered insulation thickness for the roof.

Figure 2:4 indicates a large difference in space heating consumption between SAP and actual consumption of each of the properties. Consumption in dwelling C1 is around double that of the SAP assessment and consumption in dwelling C2 is around 30% lower than the SAP prediction. The difference in occupant behaviour is clear when comparing these two dwellings, as the occupant in C1 (at this time) used the electrical heating only to satisfy their space heating needs, while C2 use the secondary heating source (wood burning stove) more than the electric panel heaters. While there is no data available for the amount of fuel used in the stove the occupants (C2) advised they spend £80 a year on wood fuel and complained about the monthly cost for electricity (£66) dictated by the utility supplier who based the cost on their previous experience of other electrically heated properties. While £66 a month for electricity and space heating is much lower than an average electrically heated home, the owner admits that it is still cheaper than what they have paid before living elsewhere, but they compare the monthly payments with the SAP estimation of £60 a year which is what they were informed the heating costs would be.

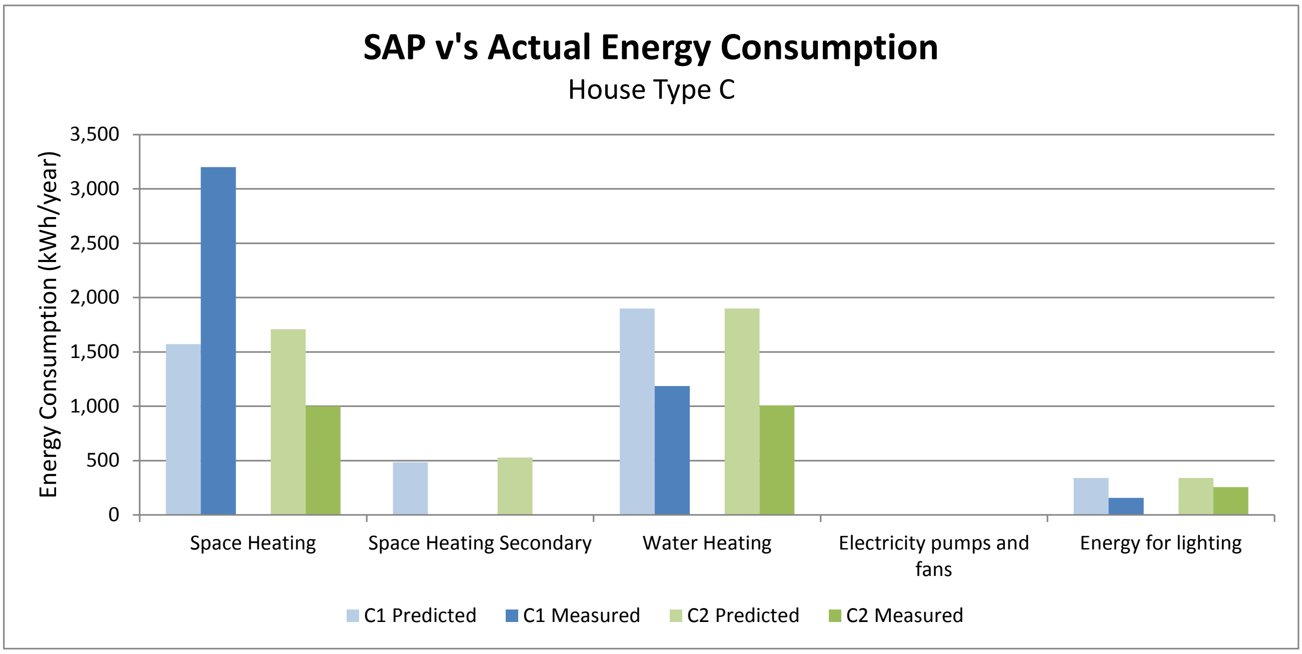


Figure 2:4: SAP prediction v's measured energy consumption - House Type C

HOUSE TYPE D

The percentage improvement of the DER against the TER on the SAP worksheet was a high 41%, both ratings scored very low in terms of CO_2 emissions due to the communal biomass boiler for space heating and hot water generation (Table 2:1). However the monitoring has led to the discovery that the biomass boiler has been subject to an on-going operational fault and rarely operated. The fault was seemingly repaired in July 2014, almost four years after installation. This has meant the space heating and hot water has been provided by the back-up condensing gas-fired boiler. The EPC is based entirely on the biomass fuel for carbon dioxide emissions and therefore the EPC (energy performance certificate) CO_2 rating of '97 - A' is not realistic, as the building has been predominately operating on gas for the first four years of occupation. Using SAP predictions and CO_2 factors (2005 SAP) the total CO_2 per year for House Type D increases significantly as indicated in Table 2:2 and the CO_2 emissions rating for this dwelling operating on gas becomes '87 – B'.

Dwelling	A1	A2	B1	B2	C1	C2	**D1**	**D2**
Total CO_2/year (kg CO_2/year)	2383.94	2283.39	1794.00	1816.00	1620.12	1679.05	**1180.00**	**1194.00**
Dwelling Carbon Emission Rate ($kgCO_2/m^2$)	21.75	20.83	19.94	20.19	31.96	33.12	**15.53**	**15.71**

Table 2:2: Adapted excerpt of SAP CO_2 calculation predictions for each dwelling assessed in the BPE study. House Type D amended.

There was a minor discrepancy detected in the SAP calculation which was the addition of a 110 litre hot water cylinder, these homes are fitted with heat exchange units and do not contain hot water cylinders. However, this might be a shortcoming of SAP 2005 which may have not contained a heat exchange option. For assessment of solar gains, the SAP calculation highlights that the "*likelihood of high internal temperatures during summer weather: **HIGH!***" which has been identified in the environmental monitoring. As with House Type C there was no account for pumps and fans made in the dwelling. House Type D contains two mechanical fans which should have been included.

As with the other House Types the occupants were informed of unrealistic low space heating and hot water costs that have not been realised. The Factor charges each household an annual fee for heating and hot water, this is based on consumption and boiler running costs including wood pellet fuel, these have been significantly higher than the occupants expectations and there is some tension between occupants and the Factor over the amount of money the occupants are charged for heating and hot water, they feel the biomass system is more expensive than gas.

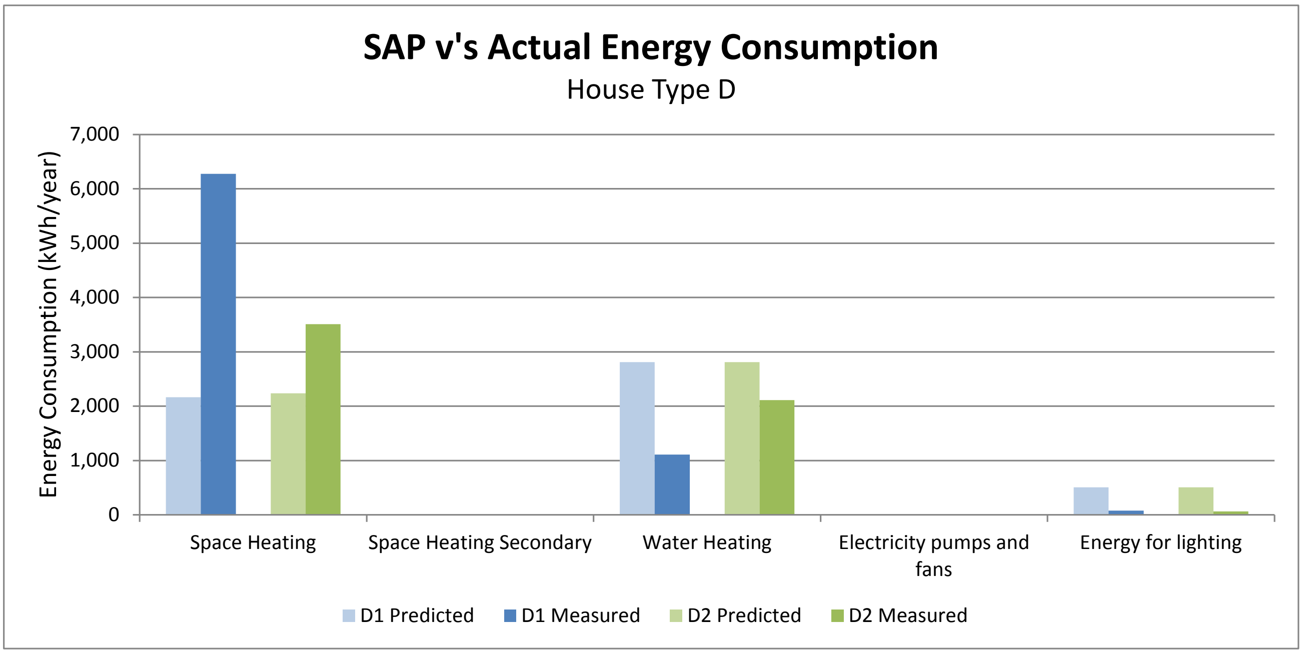


Figure 2:5: SAP prediction v's measured energy consumption - House Type D

The comparison of regulated loads (Figure 2:5) indicate the SAP prediction for space heating to be lower than the measured consumption in both dwellings. However, the actual annual consumption of dwelling D2 is nearly half that of the neighbouring dwelling. The water heating and lighting consumption in both dwellings is lower than the predictions.

2.4 Construction Phase

From the Expo point of view the delivery of each of the plots in time for the August 2010 event was successful; the contractors had largely delivered each of the plots. However a late change in the form of contract to a 'design and build' contract generated dissatisfaction amongst the novated architects and the removal of a site wide district heating scheme resulted in contractor design for building services systems. The architects explained they were asked to identify one key item of their design to retain in their design prior to a value engineering exercise. The resulting designs were no longer innovative and design concepts had been watered down to reduce price (due to economic downturn) and to simplify designs to enable then to be constructed in the nine month construction period.

Contractors and clients commented on a build timescale that was considered too short for successful project delivery. The already tight deadline was met delays owing to severe winter conditions with record amounts of snowfall and long lead times particularly for windows, which nearly all were ordered from one manufacturer. The site foreman informed the research team of the necessity for long working hours, many different trades in one dwelling at a time and generally rushing to complete the dwellings on time. It was expressed that the local contractors and trades people did not want to fail to meet the project deadline. The house designs and some building methods were new to the contractors, but they were proud to have been involved in constructing the Expo dwellings and were keen to exhibit their work to their families at the Expo event. The following text summarises any impact this may have had on each house type.

House Type A

Design Intent: From the architects perspective the original concept of the competition "*was to demonstrate sustainability and new* [innovation in] *energy systems*". The dwellings were originally designed to provide a sense of space, high levels of cellulose insulation, breathing walls, mechanical ventilation with heat recovery (MVHR), sophisticated heating systems and to maintain a connection with the garden from the principal living spaces. There were external sheds for storage of bikes and tools etc.

Construction Process/Management: As noted earlier in this chapter, the form of contract changed during the design process, occurring at a time in the project when the design team had completed their detailed design proposals. The architect was novated to the contractor who after being consulted on the one must save item attempted to keep to the specification in line with the ethos of the original intent of the Expo competition. The design changes that followed are indicated below.

The contractor found due to severe snow fall and record low external temperatures there was a delay in pouring the foundations. This had a knock on effect to the already tight construction timescale which meant the building work was rushed. The architect had concerns over poor workmanship identified, however due to the form of contract the identification/reporting of these were out of the architects' control.

In order to keep costs down the various construction teams on site, shared fork-lifts for offloading deliveries and they also shared on-site welfare facilities. The client indicated there was a lot of collective will among the contractors and that without this the project would not have been delivered. The contractor commented that the timing of the Expo, helped to keep local trades people in employment in the area, helping to keep families together and supporting the local economy during the economic downturn.

Design Changes: There were a number of design changes instigated as a result of the value engineering process after the form of contract was changed, these included:

- Decrease in floor area to reduce costs to fall within the cost benchmark for affordable housing throughout Scotland.
- Removal of healthy materials and breathing wall construction. These were considered to be too expensive based on the clients' previous experience with using them in other projects. However, the client understood the value of incorporating these materials and would have retained them if there was a grant mechanism in place to support their uptake.
- Replacement of a heat pump for a gas fired condensing combination boiler. This was a client decision as by default their preference is for simple systems their tenants are comfortable controlling and are more likely able to afford to operate.
- Roof material changed from corrugated sheeting to slates due to perceived noise associated with this type of roof.
- Garden sheds designed to be located in the large gardens for bike and tool storage were omitted.

Delivered Dwellings: The overall design remained largely intact after the value engineering process, however the floor area was decreased. The external wall thickness was revised following the substitution of cellulose insulation for mineral wool; the design U-value remained the same. The dwellings were naturally ventilated and a 'simple' heating system was installed. The connection with the rear garden from the ground floor living spaces was maintained.

Performance Issues: During the monitoring period performance issues have been raised, these include:

- **Building Fabric:** The thermography revealed numerous areas within the dwelling where thermal bridges were present; potentially as a result of poor workmanship (refer to Chapter 3). The air permeability testing revealed infiltration levels were lower than the design target; it is now below the threshold where according to the Building Regulations additional method of ventilation may be necessary. The natural ventilation strategy with intermittent mechanical extract in bathroom, kitchen and utility room replaced the MVHR system. The air permeability testing and in-situ U-value measurement results are discussed in Chapter 3.

- **Thermal Comfort:** Occupants of both dwellings in this house type, highlight that they find the buildings too hot on occasion. The BPE study revealed the dwellings are heated to excess in winter and overheat frequently during summer (refer to chapter 7).

- **Ventilation:** In one unit, one of the main complaints is of inadequate extract ventilation from the kitchen as cooking smells escape the relatively open plan kitchen and filter upstairs. Testing of the mechanical extract fans revealed three out of the four installed extract ventilators (in each house) have insufficient air flow rates, discussed in Chapter 6. When interviewed the occupants confirmed they rarely use the mechanical ventilation in the kitchen as they prefer to open the window. The inadequate extract rate in the ground floor shower rooms has resulted in damage to finished wall and ceiling surfaces in both monitored dwellings. The findings of the study of ventilation ties in with comments made on other projects where occupants noted mechanical extract fans to be either too noisy, or ineffective, or both. In this case, as elsewhere, when there is overheating or smells, the chosen option is to open the door or window for purge ventilation. In this house type, the first floor windows in bedrooms are opened less frequently and condensation has been observed on windows and frames. The window opening frequency is detailed in Chapter 7.

House Type B

Design Intent: For this house type, the design intent was to adopt a 'fabric first' approach that included the architects specification of products/materials they perceived to be healthy. The specification avoided oil based paints in favour of natural paint and insulation products. The dwellings included double height spaces to maintain a visual connection between the two floor levels. The concept was for the dwellings to be designed for simple operation and avoid the use of maintenance and energy hungry 'eco clichés'. High energy and SAP ratings were pursued throughout the design. The Building Warrant drawings, provided to the research team, indicated the incorporation of evacuated solar thermal tubes on the west facing roof and a brise soleil to limit solar gains in the west facing open plan living space.

Construction Process/Management: The change in form of contract affected this dwelling more than some of the others, whilst the overall form is essentially the same as the design concept the remaining aspects were lost after the value engineering process. It is difficult to know whether the contractor understood the concept fully or whether it was a lack of familiarity with the proposed materials. What was clear, through the interviews, was the architect, although novated to the contractor, was not involved in the cost saving process and was unable to defend or explain the design concept. The architect suspected their novation and site attendance was more to comply with a tick box exercise and they felt remote from the build process.

Design Changes: There was a number of design changes instigated as a result of the value engineering process these included:

- Reduction in room sizes, the overall floor area was reduced by approximately 3m^2 on each floor. The client commented they were disappointed with the room sizes, particularly the bedrooms, as they fall short of the space standards normally delivered for social housing. This may be relevant to wider issues of size of bedrooms and indoor air quality, reviewed in Chapter 7.

- The specified woodfibre insulation external to the timber frame and sheep's wool between the wall studs were omitted and replaced with mineral wool. In addition to the healthy aspects of the specified insulation products these have added benefits. The high decrement factor of the woodfibre insulation is able to buffer solar gains (like thermal mass) and therefore contribute to a reduction in overheating on warmer days. While the sheep's wool insulation in a breathing wall construction is able to buffer internal moisture loads. This omission could be a significant loss in terms of delivery of a healthy internal environment and in helping to reduce the overheating experienced inside the dwelling.

- Omission of thermal mass specified in the stone floor and earth wall in the living room, the client noted they were not precious over the omission of these elements; but one questions whether the lack of familiarity on the part of the contractor instigated their removal. The thermal mass from both, if used correctly, would have helped to balance temperature fluctuations in the living spaces and delivered useful comfort and energy benefits. The floor was substituted with a timber floor.

- The brise soleil, omitted by the contractor, was originally positioned to shade summer solar gains on the glazing in the principal open plan living spaces. The omission, especially when coupled with the loss of external woodfibre would increase the risk of overheating internally (as identified during the environmental monitoring, refer to Chapter 7).

- Passivent in the lounge was omitted by the contractor, increasing the risk of overheating in the open plan living space. This ventilator would have complimented the function of the (omitted) thermal mass, perhaps allowing admittance of cooler night air in the dwelling to discharge absorbed heat gains and maintaining an improved indoor air quality, if used correctly.

- The external timber cladding was altered and the contractor was reluctant to construct the specified timber roof as it was considered experimental. The client expressed disappointment for this omission as this was the one element the client would have liked to have retained due to the ethos of the Expo event where the intention was to promote innovation for designing and building things that wouldn't normally be done.

- Healthy natural paints were omitted, these were replaced with water-based paints. However, if the breathing wall had been retained the substitution of natural paints would almost certainly affected the walls breathability, as most water-based paints are film-forming.

- Solar thermal panels were omitted by the main contractor for an additional cost saving to the project. One questions whether the on-going running cost savings to the occupier was considered as part of the decision making process as well as the (future) financial incentive available through the domestic Renewable Heat Incentive. This omission clearly has wider issues in relation to future-proofing the dwelling.

- A garden shed was designed for external storage of bikes etc. for this family home, however this was omitted by the contractor as a cost saving.

Delivered Dwellings: The architect reported that the dwelling layout and form was maintained as well as the construction method of using prefabricated panels but the dwellings were 'dumbed down' from their intended 'healthy' specification and lost the 'fabric first' approach. In hindsight the architect would have made more of the opportunity to highlight occupant health as a key aspect relating to the specified building materials and wonders whether there would be a challenge in terms of air quality as a result of the value engineering process. Other than a few niggles relating to build quality, the tenants are happy with living in these houses and the client believes that these dwellings are the best social housing on the market in the UK.

Performance Issues:

- **Building Fabric:** The fabric first approach relies on holistic design that encompasses a reduction of U-values for all thermal elements, reducing thermal bridging, improvement of airtightness and providing energy efficient ventilation. In addition to a fabric first approach, the architect considered the health and well-being of the intended occupants and specified a healthy living environment, achievable through carefully selected building materials and finishes for the internal environment. During the study the infrared thermography revealed thermal bridges at timber wall studs, this could have been avoided or at least reduced if the external woodfibre insulation was retained. There was also thermal bridging at roof trusses where an external layer of woodfibre insulation had not been specified. While reviewing the architects drawings a discrepancy was identified in regard to the external insulated layer, the drawing indicated the intent to include this beneficial layer, however the written specification indicated OSB (oriented strand board) which has minimal thermal insulating properties compared to wood fibre insulation. This discrepancy was not picked up during the construction phase. The air permeability testing (refer to Chapter 3) indicated an air leakage rate that although lower than the building regulations and the specification in the SAP document, was essentially relatively high at almost $6m^3/(h.m^2)$@50Pa for a dwelling designed to operated passively, especially for a dwelling containing thermal mass as the draughts could affect the storage capacity.

- **Thermal Comfort:** The deletion of the brise soleil and admittance of solar gain in summer will increase the risk of overheating in the summer months. Without thermal mass and the additional ventilation originally specified for the living room the risk of overheating is increased. However, the rear elevation (where brise soleil was intended) faces almost due west, which in itself presents difficulty of shading low angle sun during sunset and during shoulder seasons of spring and autumn. The occupants have commented that the dwellings are hot during periods of warm weather.

House Type C

Design Intent: To provide affordable housing that promotes well-being by using benign materials and breathing walls. The dwellings were designed using a fabric first approach with high insulation levels and minimal glazing to the north, with larger glazed areas to the south and west façades. Designed with a passive stack ventilation system it is a "modernist design idea with a central services core" which included installation of a prefabricated bathroom pod. The method of construction was to promote the manufacture and capability of off-site prefabricated panels made locally.

Construction Process/Management: The contractor reported that the prefabricated panels were too heavy to handle manually and movement and erection of panels necessitated the use of a crane. For a project of this scale it was found expensive, but would become more economical at a larger scale. The contractor reported that there were issues with fitting the EDPM roof covering which once installed had bubbles beneath the surface. The contractor thought the cold weather could have affected the roof covering application or that the bubbles were caused by poor workmanship by the roof sub-contractor. The manufacturer attended site to inspect the roof covering installation and found it to be watertight. The architect observed a number of workmanship issues onsite; however, due to the protocols associated with a design and build contact the architect had no authority to instruct their rectification.

The contractor's positive comment in regard to erecting the dwellings using prefabricated wall panels and belief for a larger development the economy of scale would make this a feasible method of construction. The architect also believes this method of construction is key to future development of the Scottish building industry and integral to sustainable procurement.

Design Changes: There were relatively few design changes between the design concept and delivered dwellings, there were a few minor changes after the change of contract, which the architect had minimal involvement in and also believed that the client was not supportive in the value engineering process. The changes included:

- Serviced bathroom pods being removed from the design, these were built on-site due to the contractor having had a previous experience of pre-fabricated bathrooms on a hotel project in Inverness which went badly.
- Re-routing of wood stove flues from central core to the living rooms, the flue from the ground floor fate rises within boxing at the periphery of the living room in the flat above, it was believed that this change caused sound transfer issues between the two properties.

Delivered Dwellings: The overall floor plan remained true to the architects' initial concept except for removal of served bathroom pods, which were built on site. The external wall panels were manufactured off-site with the specified materials. The architect had commented that the external detailing was contrary to the specification and did not influence well-being as hoped. The wood stove flues were intended to be routed in the services core, however there was not enough space to allow this, these run outwith the cores in the living rooms of the dwellings. The primary heating in the dwellings is through electric panels.

Performance Issues:

- **Building Fabric:** The most significant fabric issue was acoustic sound transfer through the separating floor/ceiling. The contractor has remedied this by improving sound insulation around the stove flue boxing for the ground floor flue that passes through the living room of the upper property. An additional layer of floor sheeting was applied over the complete floor area of the upper flat and re-carpeted and vinyl floor finishes re-laid. The acoustic issues have been reduced but the time that this took was considered excessive and caused significant stress and upheaval for the occupants (particularly those residing in the upper floor) due to their floor coverings being up and heaped in the dwelling for more than a year. The research team have observed sound transfer between the separating wall between ground floor properties.
- The U-value measurement failed the in-situ measurement due to internal temperatures becoming too low to allow meaningful analysis. However the infrared thermography indicated thermal bridges were present due to insufficient fitting of thermal insulation in walls and ceilings, thermal bridges were also identified timber wall studs and floor to wall junctions. There was also evidence of infiltration paths from pivot points on window hinges and more significantly beneath the entrance doors and around bath panels (refer to Chapter 3).
- **Thermal Comfort:** The occupants have noted the cost of heating with electricity is expensive and opt to use the secondary heating (wood stove) to heat the dwellings. The environmental monitoring revealed the living rooms

tend to overheat in winter and summer (refer to Chapter 7) and internal temperature swings in winter are large where internal temperatures are low enough for condensation to occur.

House Type D

Design Intent: This timber kit house type was originally designed to be one bedroom flats. There were no specific energy targets but the project was designed with walls with 300mm of cellulose insulation for low U-values, thermal mass in the solar buffer space to "*regulate temperature extremes*" and orientated to harness solar gains in the main living spaces. The main roof was angled for mounting of photovoltaic panels. "*The idea was to include passive systems to avoid 'plug-in' and 'bolt-on' systems".*

Construction Process/Management: The contractor confirmed this project was the smoothest they were involved with. This could be due to the relationship with the architect having been present from the outset of the project. This project seemed to be favoured by the contractor and was completed one month ahead of schedule, although the contactor admits that the programme was tight and affected by severe snow. The contractor ensured that orders were made early, especially for windows, and floor cassette construction was made and filled with insulation on-site to speed up construction time. With hindsight the contractor agreed the tight time frame affected the build quality.

Design Changes: From the outset of the competition the architect was novated to the contractor under a design and build contract. This meant that the architect had already built up a relationship with the contractor and their form of contract was not affected, however this house type was not exempt from the value engineering process for the costs to come in line with the budgets for social housing. The changes included:

- Deletion of the roof mounted photovoltaic arrays; the pitch of the roof remained.
- Internal accommodation was rearranged to accommodate a second bedroom. This was achieved at a cost to the open plan living space, which has resulted in the dwellers incorrectly using the solar sunspace.
- Omission of high level opening casement windows in the sunspace, this means the space cannot effectively ventilate warm air out of the building during warm weather, as the design intended.
- Outer glazing on the sunspace was considered to be the continuation of the insulated envelope and was double glazed, while the internal bifold screens were downgraded from double glazing to single glazing. The ability of the buffer space to act as a separate thermal zone was much reduced by this move. The residents of the properties all keep the internal bifold doors open to extend their living spaces and all residents complain of overheating during the summer months. The contractor advised the sunspace was changed to deliver a project cost saving, before the project started on site.
- Building orientation (as far as we can gather) appears to have altered and now the solar buffer spaces is not orientated to optimise solar gain, these are orientated 53° west of south. This orientation is not optimised for passive solar design and the risk of overheating is increased by the orientation.
- Roof covering was changed from EDPM to another product due to the difficulties experienced with the roof installation in house type C.
- A section of ceilings in entrance halls needed to be lowered as it wasn't appreciated that the 42mm diameter communal heating pipework would require to be insulated.

Delivered Dwellings: The delivered dwellings were two bedroom flats constructed from a timber kit. The concept of the solar buffer space was not successfully carried through to delivery of the dwellings. The materials appear to have remained true to the original specification. These dwellings were reported to be the first to be completed; one month ahead of schedule.

Performance Issues:

Building Fabric: There are issues with the building fabric, through infrared testing there were insulation defects highlighted that affect external wall and the separating ceiling/floors. The thermography identified thermal bridges in external walls, one of these was measured during the in-situ U-value testing on a north facing wall to confirm the effect on the U-values, refer to Chapter 3 for results. Defects with insulation between separating ceiling may be exacerbating sound transfer issues the occupants have reported.

In the solar sunspace the issues of overheating due to inadequate ventilation and incorrect orientation have become apparent through the monitoring (see Chapter 7). In each dwelling residents have opened up the internal single glazed bifold doors to extend living space as the double glazed element has been installed in the incorrect position, which adds to discomfort issues.

2.5 Conclusions and key findings for this section

The occupants have all responded positively to the semi-rural location of the development, close links to the A9 trunk road and the recent expansion of the local amenities to include a convenience store and a more regular bus service into Inverness. The local woodland and bicycle routes are used frequently for dog walking and recreation.

The SAP review indicates there are minor discrepancies in completion of the worksheets, but there were no 'as built' SAP worksheets to make a meaningful comparison of before and after, as these are not required in Scotland. The Energy Performance Certificates (EPCs) are generated from the design data.

In respect to the delivered dwellings the change of contract (driven by the economic downturn) had a large impact on the original architectural design concepts. These were simplified to speed up construction and remove unfamiliar elements. However what has become apparent is some of the design intents were not fully understood which has impacted on running cost and environmental performance of the dwellings (summary of design changes and likely impact can be found in Appendix D). The re-design of the sunspace in House Type D has illustrated that the owners are not able to operate the space as intended, this brings an energy and comfort penalty.

The key lessons learned include:

- An initial interest in energy efficiency, healthy building materials and fabric first approach was not fully carried through the whole design and construction process, this may have increased overheating risk in the dwellings.
- Overall the Expo event was an exemplary project which has been successful in highlighting use of local timber and proving off-site manufacturing can be beneficial.
- SAP predictions were inaccurate for energy consumption, but were more inaccurate in terms of actual energy costs where running costs were found to be three to four times higher due mainly to unit costs used within SAP.

- The development had to be achieved within conventional cost parameters, the success of the project shows that innovative low energy projects can be delivered without excessive costs.
- The build process was characterised by very good working relationships between different contractors. This was achieved by a mutual recognition that this was to be a learning experience for all involved, and due to the tight Expo requirements drove the entire exercise and were ‘owned’ by all parties involved.
- The most difficult aspect on site was building within a tight site during record low temperatures with record levels of snow.
- The plumbing and electrical works were contractor-design packages and have proved the most problematic post completion.
- Apart from issues associated with understanding of the active services, the main issue for occupants has been overheating.

3 Fabric testing (methodology approach)

3.1 Fabric Testing

The BPE monitoring mandated non-invasive testing of the building fabric to provide an indication of construction quality and to identify whether specified design targets were met. Each dwelling underwent two air permeability tests to determine where air leakage occurred and to determine how the air permeability of each building performed over an extended period of time. In-situ U-values and thermographic surveys were undertaken in sample dwellings (one from each house type). Each of these tests are discussed in more detail herein and Table 3:1 summarises the findings to allow easy comparison of whether the as built dwellings met the design criteria.

		House Type A		House Type B		House Type C		House Type D	
		A1	A2	B1	B2	C1	C2	D1	D2
Air Permeability* ($m^3/(h.m^2)$ @ 50Pa	Target	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
	Initial	3.82	4.21	5.82	6.07	5.93	6.00	5.71	4.53
	Final	3.50	4.20	5.73	5.43	5.47	4.78	6.06	6.64
U-value Wall (W/m^2K)	Design	0.18		0.27		0.15		0.15	
	Measured	0.14		0.23		Test result not valid		0.14 0.40 (thermal bridge)	
U-value Roof (W/m^2K)	Design	0.16		0.14		0.16		Not tested	
	Measured	0.11		0.16		Test result not valid		Not tested	

Table 3:1: Comparison of design targets against as built building fabric.

*Air permeability results presented for dwellings tested under negative pressure.

3.1.1 In-situ U-value Measurements

U-value (thermal transmittance) is the measure of the amount of heat that will pass through one square metre of building fabric when the temperature on either side of the element differs by one degree Celsius. U-value is expressed in units of Watts per square metre per degree of temperature difference (W/m^2K) between inside and outside and does not apply to separating walls and floors. The in-situ measurement of U-values is a prerequisite of the BPE project and was carried out on a sample dwelling from each house type. U-values are incrementally being improved in new revisions of the Building Regulations to improve energy efficiency, therefore, as the dwellings were designed in 2007 the Building Regulation in force at that time have been used to compare the in-situ U-value results with. Table 3:2 indicates the maximum elemental U-values for construction elements 2007.

Two in-situ thermal transmittance measurements were taken in each dwelling; one on an external wall and one on the roof. In one of the subject dwellings it was not possible to measure the roof element due to the property being a ground floor flat, in this case in-situ measurements were taken in two locations on the same wall to evaluate construction quality. In each case the apparatus, as described below, was set up in a bedroom that was in use, and heated, at the time of the testing.

Element	U-value (W/m^{2}K)
Wall	0.30
Floor	0.25
Roof	0.20
Windows, doors, rooflights	2.20

Table 3:2: Maximum U-values for building elements of the insulation envelope, extracted from Technical Handbook 2007.

Measurements were taken between 16th December 2013 and to 11th February 2014 with the purpose of the test being to determine the real, rather than predicted, U-values for each construction element tested. The results were used to compare the design prediction against the actual U-value.

Methodology

The methodology for the testing and subsequent analysis follows the procedures set out in ISO9869:1994.

- Wall and ceiling elements were surveyed using an infrared thermographic camera to determine suitable heat flux plate (HFP) mounting positions. This was to avoid unintentional placement of HFPs on thermal bridges, such as timber frame studs and rafters, of the construction element subject to testing.

- Each HFP was secured to the internal face of the element under test, in accordance with TSB guidance selecting north facing elements where possible.

- Ambient air temperature sensors were positioned on both the inside and outside of the building element in a position close to the HFP. To obtain heat loss data of acceptable accuracy a temperature difference between internal and external temperatures at least 10°C is needed. It was assumed that undertaking these tests during winter would achieve this.

- A remote data logger was set to receive data, via wireless signal, from the HFP and ambient air temperature transmitters and the equipment was set to log at 10 minute intervals.

- Care was taken to site and mount the apparatus and trailing wires to reduce disruption to the occupants and minimise the risk of the equipment being accidentally dislodged or damaged. Apparatus was mounted with masking tape and non-marking fixings to avoid damage to the decorative surfaces.

- The measurement period was a minimum of two weeks in each dwelling.

Apparatus

The apparatus used for the test was as follows:

- Eltek Squirrel 1000 series, type RX250AL, Radio telemetry data logger.
- Eltek GenII, type GS-44 HB, voltage input transmitter.
- Eltek GenII, type GD-32, thermistor input transmitter – with 2no. Hukseflux HFP01-10 heat flux plates.
- Eltek GenII, type OD-12, external thermistor input transmitter.

Figure 3:1: Eltek Squirrel 1000 series, type RX250AL, Radio telemetry data logger set up on a landing.

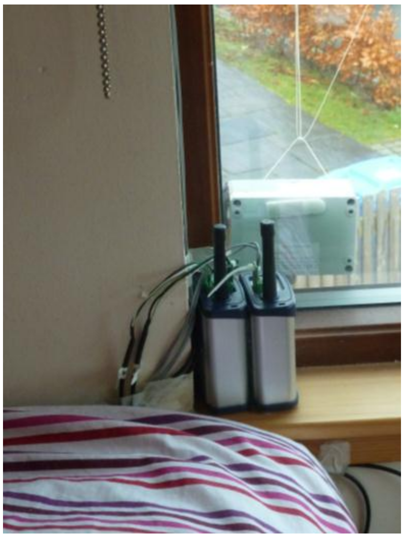


Figure 3:2: Eltek GenII, type GS-44 HB, voltage input transmitters for monitoring and transmitting data from HFP and ambient air temperature. An Eltek GenII, type OD-12, external thermistor input transmitter can be seen outside the dwelling.

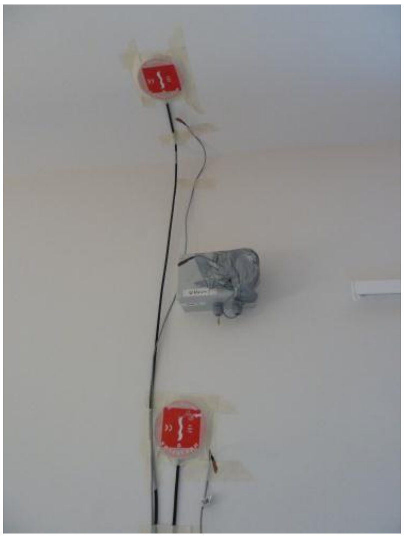


Figure 3:3: 2no. Hukseflux HFP01-10 heat flux plates (red discs) and ambient air temperature sensors (short black objects) installed beside each HFP. The HFP and temperature sensors are wired to two Eltek GenII, type GD-32, thermistor input transmitters. An Eltek GenII, type OD-12, external thermistor input transmitter is located internally as a back-up should an ambient air temperature sensor become loose and fall.

Figure 3:4: Eltek GenII, type OD-12, external thermistor input transmitter.

Results

Analysis was performed using the results average method as defined in ISO 9869:1994 where all but two tests were found to be within the 5% accepted error permitted by the ISO document. A summary of the design U-values and the measured results are recorded in Table 3:3.

HOUSE TYPE	CONSTRUCTION ELEMENT	TESTING PERIOD	MAXIUM BACK STOP VALUE (W/m^2K)	DESIGN U-VALUE (W/m^2K)	MEASURED U-VALUE (W/m^2K)
House Type A	**External (W) Wall**	28.01.14 - 11.02.14	0.30	0.18	**0.14**
House Type A	**External (W) Roof**	28.01.14 - 11.02.14	0.20	0.16	**0.11**
House Type B	**External (N) Wall**	08.01.14 – 27.01.14	0.30	0.27	**0.23**
House Type B	**External (E) Roof**	08.01.14 – 27.01.14	0.20	0.14	**0.16**
House Type C	**External (N) Wall**	17.12.13 – 07.01.14	0.30	0.15	**Circa 20% error 0.07**
House Type C	**External (Flat) Roof**	17.12.13 – 07.01.14	0.20	0.16	**Not Passed 0.07**
House Type D	**External (N) Wall Circa 1.2m FFL**	27.01.14 - 11.02.14	0.30	0.15	**0.14**
House Type D	**External (N) Wall Circa 2.5m FFL**	27.01.14 - 11.02.14	0.30	0.15	**0.40**

Table 3:3: Comparison of in-situ U-value measurement with design U-values and Building Regulation maximum back-stop U-values for four house types monitored as part of TSB BPE 450073.

Discussion

The in-situ U-value testing demonstrated a large variation between U-value targets at design stage and the measured U-value in each house type. Most noticeable is the circa 50% difference between measured U-values and design U-values for House Type C; which is discussed later in the report. Full reports of the testing procedures and results are located in Appendix E, while a summary by house type is below.

House Type A

In this house type the construction elements measured were located in a bedroom, with a normal occupancy pattern. The measurements were taken on west facing construction elements (it was not possible to monitor the north facing wall element as this is a separating party wall). Analysis of the measurement data indicated a 22% and 31% improvement over design U-values of the wall and roof elements respectively. The design U-value target was already an improvement over the then current maximum U-values in the Building (Scotland) Regulations and achieved a 53% (wall) and 45% (roof) improvement over these backstop values.

As described in the methodology, thermography was used to ensure the elements under test were representative of the wall construction and avoided placement of HFP on thermal bridges. It was revealed that this house type is subject to repeating thermal bridges at joist ends in addition to large areas of the first floor ceiling that appear to have missing or ill-fitting thermal insulation (non-repeating thermal bridging) (discussed later in this report). Whether the thermal bridges are due to poor detailing or workmanship they compromise the integrity of the insulated envelope by increasing heat loss from the dwelling and present a risk to the building fabric due to risk of condensation and mould growth. However, it could be questioned whether the areas of tested building fabric, particularly the roof, was a representative sample for measurement due to the extent of thermal bridging.

The data logger used for the U-value measurement malfunctioned during the two week testing period, where compatibility with the actual date and time was lost. It was therefore impossible to determine the date and time measurements were taken. The fact that the data logger continued to log chronologically and receive data from all test apparatus simultaneously meant the raw data was of sufficient quality to attempt analysis. Data that displayed continuous readings were selected for three (apparent) consecutive days for analysis. The analysis demonstrated the tests were 'passed' by the 'results averaged' method of analysis, however, there was an insufficient quantity of data for analysis using the more rigorous 'results corrected' analysis method. Due to the equipment malfunction there is naturally uncertainty over the validity of the results. It was decided at the time not to repeat the test due to the inconvenience already caused to the occupant.

House Type B

The apparatus was set up in a heated east facing bedroom, with normal occupancy patterns. Wall measurements were taken on a north facing wall and on an east facing section of the warm roof. The analysis confirmed the measured wall U-value to yield a 15% improvement over the design intent and 23% improvement over the Building Regulations backstop U-value of 0.30W/m^{2}K. Interestingly, the architects' original design intent drawings provide detail and specification for the external wall construction, noting a U-value of 0.19W/m^{2}K (refer to Table 3:3). However, on review of the architects' drawings there is a discrepancy between the architects' section and specification. The section details an insulated layer to the outer side of the timer frame, presumably to minimise thermal bridges. The written specification replaces the insulation with 10mm OSB, which does not have a comparable thermal conductivity to insulation. It is likely that the resulting design U-value is poorer than the architects' design intent as the discrepancy was not identified during the design stage.

The roof revealed a result 12% lower than the design intent. At the design stage the prediction for roof U-value was to achieve a 30% improvement over the Building Regulations maximum back-stop U-value. Although the actual measurement was poorer than the design intent the measured result still is 20% better than the Building Regulation maximum U-values.

House Type C

The apparatus was set up in a bedroom that is occupied overnight and heated by an electric panel heater operated on an intermittent basis. The equipment was set up on 17th December and demounted on 7th January 2014. During the measurement period the internal space temperature dropped to 10°C. This corresponds to the dwelling being unoccupied and unheated for extended periods over the Christmas and New Year period. This resulted in the temperature difference ('Delta T') between inside and outside dropping to less than 10°C (Figure 3:5), which affected the rate of heat loss through the building fabric and corresponding accuracy of the measurements.

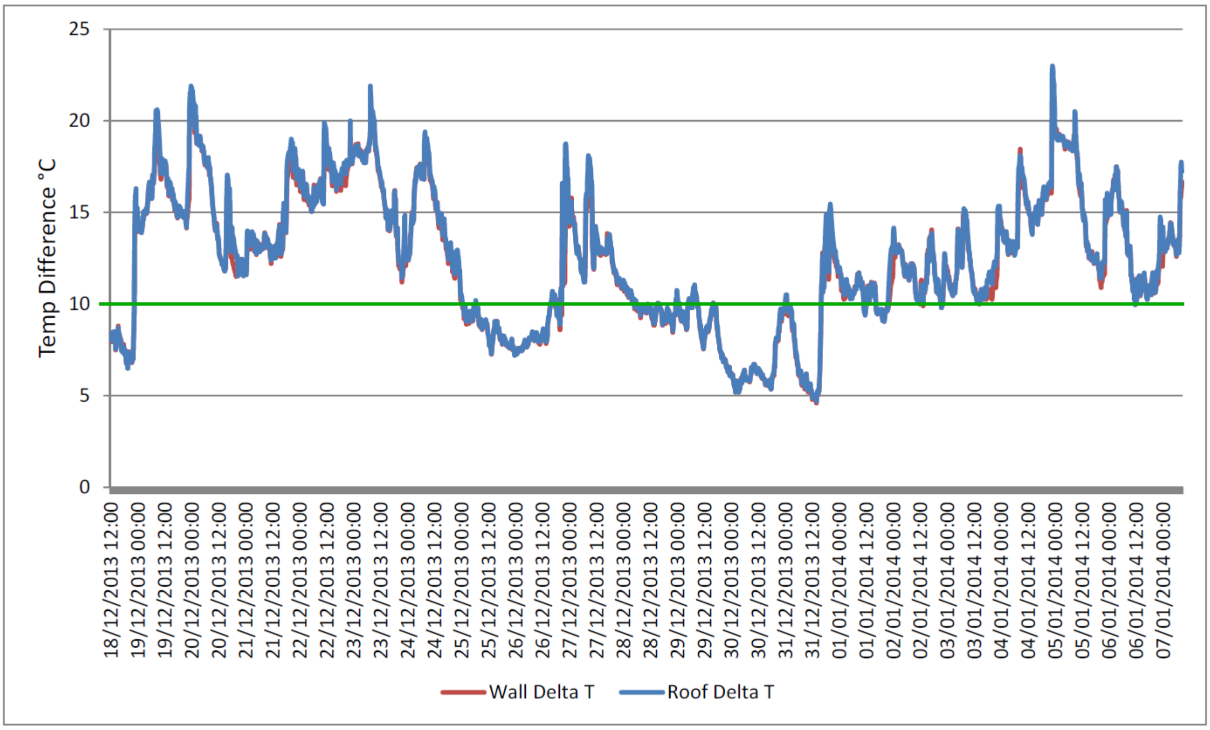


Figure 3:5: Temperature difference between inside and outside during the measurement period, data below the green line correspond to reduced analysis accuracy.

Analysing the data using the ISO 9869:1994 ‘results average method’ revealed a very good in-situ U-value of circa 0.07W/m^{2}K for both the external wall and roof elements. However, these lie outside of the ±5% error criteria stipulated in the ISO document, but fall within a ±20% error. Analysis using the more rigorous ‘results corrected method’ includes for thermal storage effects of the building fabric and requires a continuous 96 hours of data within the ±5 error criteria. This method failed to return U-values within the ±5% and ±20% error and therefore the analysis technically failed to return a result. However, the differences between the calculated U-value and design U-value were considered significant and also unrealistic for the element build-ups.

As noted in section 2.4, an error was identified with the SAP documentation for the roof element that was submitted to the Local Authority to demonstrate compliance with the Building Regulations. The SAP sheet for the roof simply copied the wall construction layers, except for a reduction in insulation thickness. As there was effectively no design U-value calculation for the roof, a manual elemental U-value calculation was undertaken using the roof build-up and layer thicknesses noted in the architects’ drawings; the resulting U-value was 0.22W/m^{2}K. This U-value is 10% poorer than the Building Regulation maximum permitted value at the time of design.

After careful analysis of the data with ISO 9869, it was considered the U-values derived for the building elements subject to measurement were not representative of the construction build up and the low results produced were more likely from fluctuations in internal space temperature, which have affected the results. The fluctuations were due to frequent unheated periods within the dwelling and significant periods where the ambient air temperature difference between inside and outside were lower than 10K (Kelvin), as demonstrated in Figure 3:5.

House Type D

The apparatus was set up to provide two measurements on the north facing external wall of this timber frame dwelling. A heated bedroom with normal occupancy pattern was selected for the measurement. As this property is a flatted dwelling without access to the roof, the test undertaken compared the difference between U-values in areas with and without a thermal bridge, on the same wall. The equipment remained in place for a two week period.

The thermography (Figure 3:6) indicated an area of wall at high level with a thermal bridge, which potentially identifies missing or ill-fitting insulation within the wall, HFP B was set up in the vicinity of the thermal bridge. HFP A was located in an area representative of the wall construction. The results indicate HFP A to have achieved a U-value 6% better than the design U-value and 53% better than the backstop value of 0.30W/m^{2}K. In contrast, the test at the thermal bridge revealed a U-value 62% poorer than the design intent and 33% poorer than the Building Regulation backstop U-value. This highlights the effect missing or ill-fitting insulation can have on heat loss from a wall element.

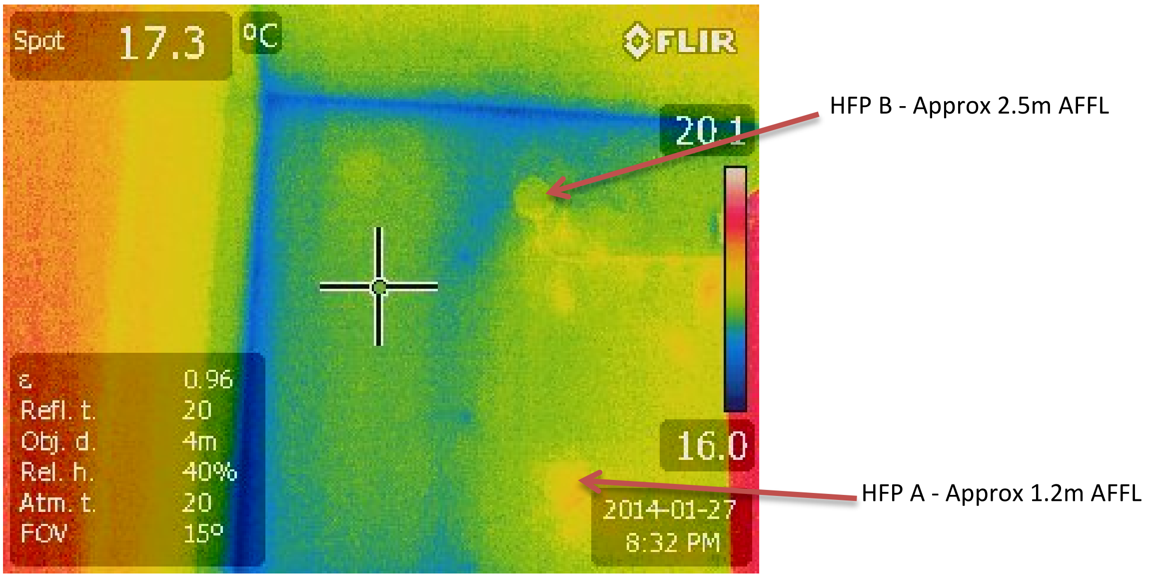


Figure 3:6: Thermal image of wall under test, highlighting location of HFPs mounted at 1.2m and 2.5m above finished floor level (AFFL).

Challenges

There were a number of challenges faced during the monitoring period, including:

- Lack of concise initial set-up instructions and procedures from the equipment supplier for the two sets of new monitoring apparatus. The apparatus was returned to the supplier on a number of occasions, which resulted in the supplier updating their set-up instructions. Initial testing of the new equipment alongside trusted instrument indicated an error in data collection with the new equipment. The equipment was returned to the supplier. Once the equipment was producing valid results and ready for monitoring the first winter period had passed. Test were undertaken during the second winter period (2013-2014).
- Unusually warm external temperatures through the winter period (2013-2014) required extended measurement periods to account for HFP stabilisation and to increase the probability of capturing robust data for analysis using methods described in the ISO document.

- The data logger on one set of equipment failed twice during testing. It became necessary to repeat the measurement in one dwelling as insufficient data was obtained to undertake meaningful analysis. In the second house there was insufficient data due to the data logger circuit board being found to be faulty; this was subsequently replaced. However, the data was used for analysis as it was too much of an inconvenience to return to the dwelling, due to hospitalisation of one of the children.
- The equipment has many wires that, once installed, trail across floors and walls. There was concern over how these should be installed so the equipment wouldn't intrude and cause a trip hazard or risk becoming tangled with a small child. The installation required use of masking tape and non-marking fixings in an attempt to fix wires to wall surfaces. Wireless external temperature sensors were purchased to avoid placing wires through windows and potentially becoming damaged in the window seals.
- Each dwelling was fully furnished at the time of measurement. There was difficulty in placing equipment in the rooms due to items of furniture and occupants' belongings. The available floor area in some of the bedrooms was not large enough to erect step ladders to assist the set-up of apparatus.

Lessons Learnt

There were several lessons learnt through this process, including:

- Evidence of a general lack of quality assurance and checking procedures for design information that has the potential to affect, in this case, U-values stated in the design intent. This study raised an awareness of this occurring in two of the house types where incorrect drawing/specification material was produced by the architect, SAP assessor, Local Authority and the contractor.
- Occupants were not adequately briefed by the research team. In so far as the principle of the test was explained participants were not specifically requested to keep their properties heated through the test. This meant that internal temperatures in one property fluctuated significantly which affected overall test results.

3.1.2 Thermography

Infra-red thermographic surveys were undertaken on a sample dwelling for each of the four house types. The execution of the surveys was problematic due to external weather conditions consisting of unusually high external temperatures combined with prolonged periods of sunshine and rain. This led to the surveys being postponed on a number of occasions in an attempt to wait for more suitable weather conditions. The surveys were carried out during the winter/spring period of 2013/2014 under conditions which were not considered completely ideal. When the surveys were undertaken there had been minimal solar insolation, relatively high wind speeds and there was limited cloud cover. As the night sky has the potential to reflect off the building surfaces and high wind speeds quickly cool the façade (which gives false thermographic readings) it was decided to restrict the surveys to dwelling interiors. A few external images were taken of building elements positioned in sheltered locations.

The aim of the survey was to detect whether any areas of the building fabric is at risk of condensation or mould growth due to defects in the construction which may cause excessive heat loss and low internal surface temperatures.

Methodology

The surveys were undertaken in the late afternoon and evenings on 27th January 2014 and 2nd April 2014. The surveyors worked systematically around the dwellings capturing internal and external images (both infra-red and digital) of areas of potential defects and equipment heat gain. The internal and external conditions at the time of the survey are provided in Table 3:4. The testing was undertaken by Prof. T Sharpe and Mr. C Morgan while both are non-members of UKTA they have significant knowledge and experience in undertaking thermography in accordance with the requirements of TSB monitoring protocol, BPE IP1/06 and BSRIA 39/2011.

Date:	**27th January 2014**	**2nd April 2014**
House Type:	House Type A Houe Type C	House Type B House Type D
Weather:	Dry with extensive cloud	Dry with slight cloud
Ext Temp:	4°C	4°C
Ext RH:	87%	94%
Int Temp:	circa 20-22°C	circa 20-22°C
Int RH:	32-34%	34-40%

Table 3:4: Internal and external conditions at time of thermographic survey of each house type.

Discussion

The thermography revealed increased heat loss at window frames and seals, unsealed skirting boards, door thresholds and building services penetrations. There were also instances of increased heat loss in areas that may have ill-fitting insulation or no insulation. Heat gains from equipment in all of the properties surveyed were similar, with principle heat sources identified such as fridge/freezers, artificial lighting, stove flue (House Type C) and the building services such as un-insulated domestic hot water pipework, boilers and the heat exchange units in House Type D. These equipment gains contribute towards overheating of the indoor environment during periods of warmer weather, as noted in Chapter 7 of this report. A brief summary of the thermography findings in each dwelling type follows and full reports are located in Appendix F.

House Type A

The survey of House Type A revealed several repeating thermal bridges due to poor sealing of joists ends (Figure 3:7). There were non-repeating thermal bridges at window frames, unsealed skirting boards, door seals and thresholds and penetrations in the building fabric for pipes and ducts. However, the most significant non-repeating thermal bridge was, in the first floor ceiling, where there were areas of ill-fitting or missing insulation, (Figure 3:8). Many of these thermal bridges could have been avoided with good on site workmanship.

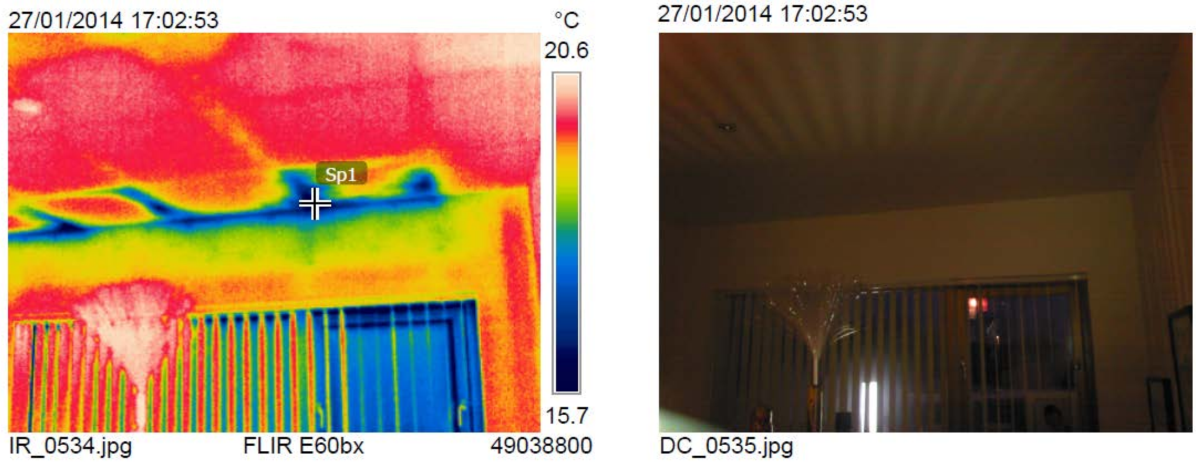


Figure 3:7: Thermal image of wall under test, highlighting location of repeating thermal bridge in living room ceiling.

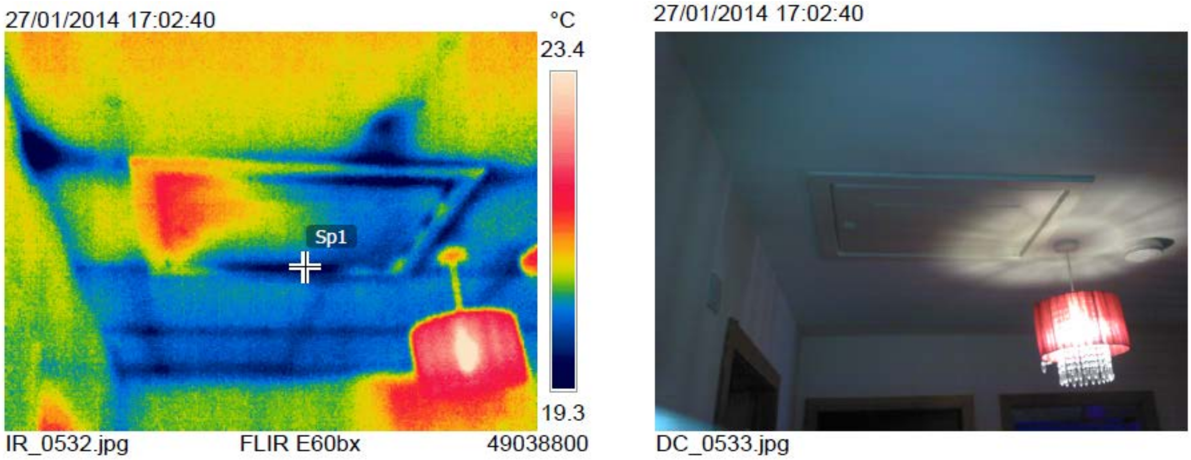


Figure 3:8: Thermal image of wall under test, highlighting location of non-repeating thermal bridge in first floor hall ceiling.

House Type B

In House Type B there appeared to be ceiling insulation missing in the ground floor WC (Figure 3:9) and around all roof lights in the dwelling. Whilst it is common building practice to increase timber stud thickness to form structural openings, this practice causes thermal bridging and puts the building fabric at risk. There was evidence of increased heat loss around the front door seals and extensive thermal bridging at timber wall and roof studs. The architects' external wall drawings detail an external layer of insulation over the outside of studs in an effort to reduce repeating thermal bridging, however the specification on the same drawing makes no reference to this layer of insulation and notes a 10mm OSB layer instead. In the roof an attempt to limit thermal bridging has been made by specification of timber 'I joists', however the architects specification (and drawing) excludes an additional insulated layer over these joists to reduce thermal bridges (Figure 3:10) as noted for the walls.

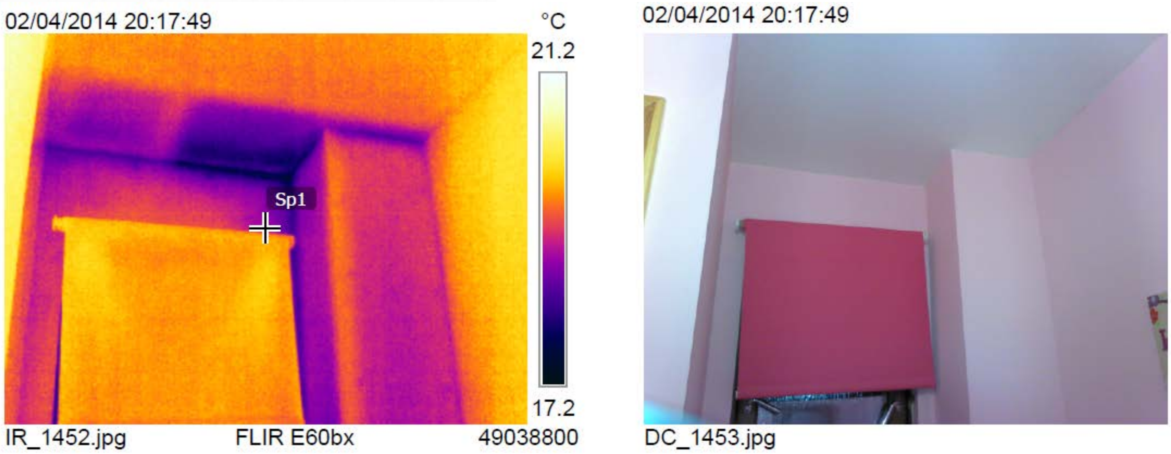


Figure 3:9: Thermal image of wall under test, highlighting location of non-repeating thermal bridge in ground floor WC ceiling, missing insulation is suspected.

Draughts were detected around building services penetrations for extract grille, water and waste pipes located in the kitchen and bathroom. Other infiltration paths were found around inadequately sealed wall mounted trickle vents and through the extract hood above the cooker, which is ducted directly to outside. WC cisterns in this house type are ceramic close-couple type with non-insulated water tanks. The WC cisterns fill with cold water (around 10°C) fed direct from the mains where due to the temperature difference between the cistern and the room, the outer surface of the cisterns have the potential to form surface condensation, but the cisterns can also reduce surface temperatures of surrounding construction elements, creating a risk for condensation or mould growth on nearby wall surfaces.

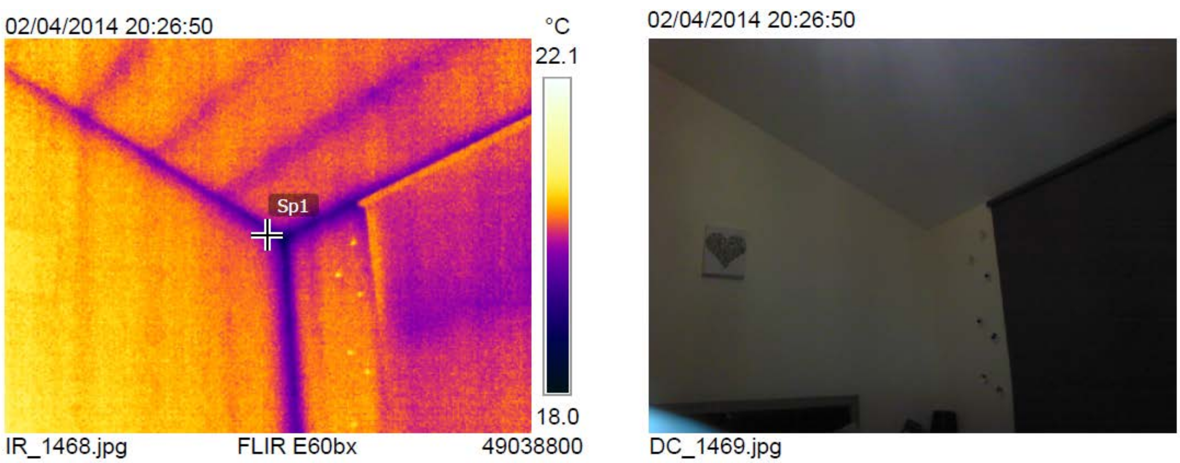


Figure 3:10: Thermal image of wall under test, highlighting location of repeating thermal bridge roof and to some extent walls. An additional layer of insulation over the studs and joists would have reduced this.

House Type C

Principle heat losses in House Type C were identified as draughts at skirting level, around the front (Figure 3:11) and rear door, stove flue ceiling penetration and its proprietary regulation plate/fire collar. Non repeating thermal bridges were identified within the walls where insulation was suspected to be poorly fitted. The design drawings and specification did not specify a layer of insulation over the wall studs and consequently excessive heat loss was visible at the joints in the prefabricated panels. These were more pronounced in the bedrooms. Areas were noted where ceiling insulation may be poorly fitted (Figure 3:12) and the side hung windows allowed draughts at the high and low level pivot points.

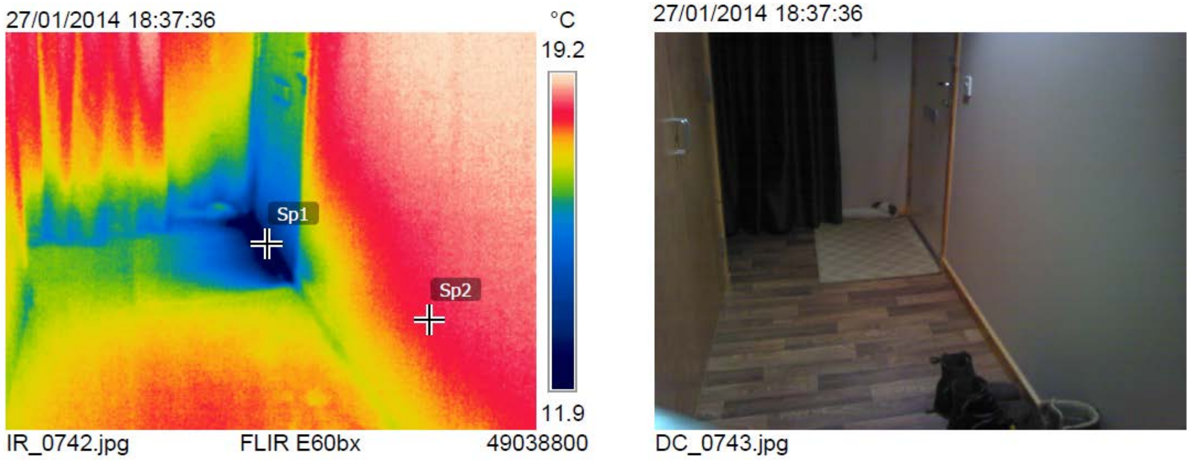


Figure 3:11: Thermal image of draught detected at main entrance door to the property.

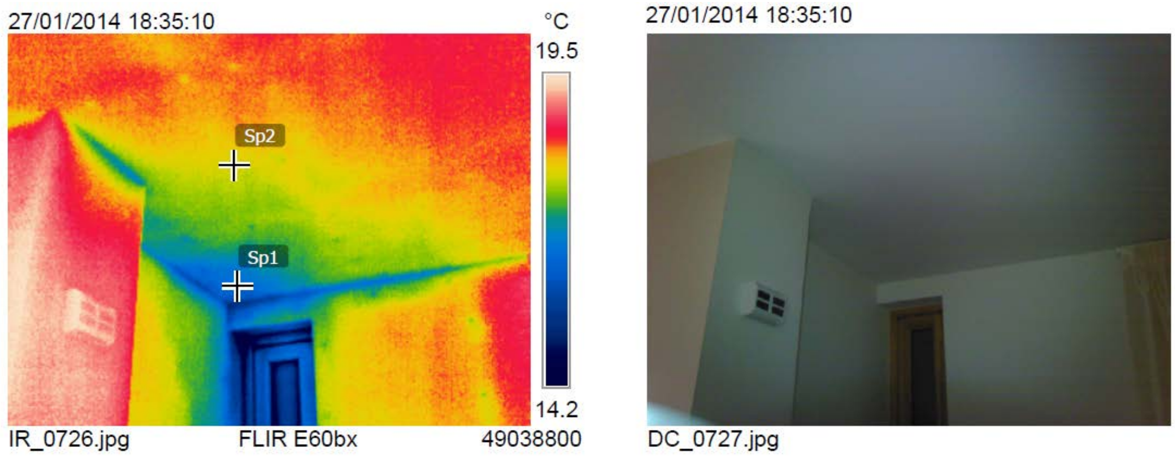


Figure 3:12: Thermal image of wall and ceiling, an area of non-repeating thermal bridge is detected at the ceiling and to the left of window.

House Type D

In House Type D thermal bridges were mainly identified at skirting level (Figure 3:13) and window frames and seals. The finding of thermal bridges at skirting level was also detected by the airtightness testing where significant air leakage under the floor was discovered. There were small temperature differences at ceiling joists, however the thermography taken at the time of the airtightness testing revealed large areas of ceiling that may have missing insulation (refer to section 3.3 for airtightness summary). There were areas of external wall in the sunspace where insulation may be ill-fitting or missing. The sunspace had significantly cooler surface temperatures than the adjacent living/kitchen (Figure 3:14) which would cause a heating energy penalty in the dwelling. (Sunspace design is discussed in chapter 2 and 7 of this report). Poor sealing at penetrations for installation of extract fan units was also detected.

In this house type the occupants reported that the bedroom is unheated as it is warm throughout the year. The thermography revealed heat gains from the fridge/freezer and the living room radiator were warming the separating wall to a level where the bedroom wall was providing radiant heat into the room and acting like a large radiator. Whilst this may be advantageous in the winter months, however, during the summer the heat rejection from the fridge/freezer could contribute to overheating of the bedroom.

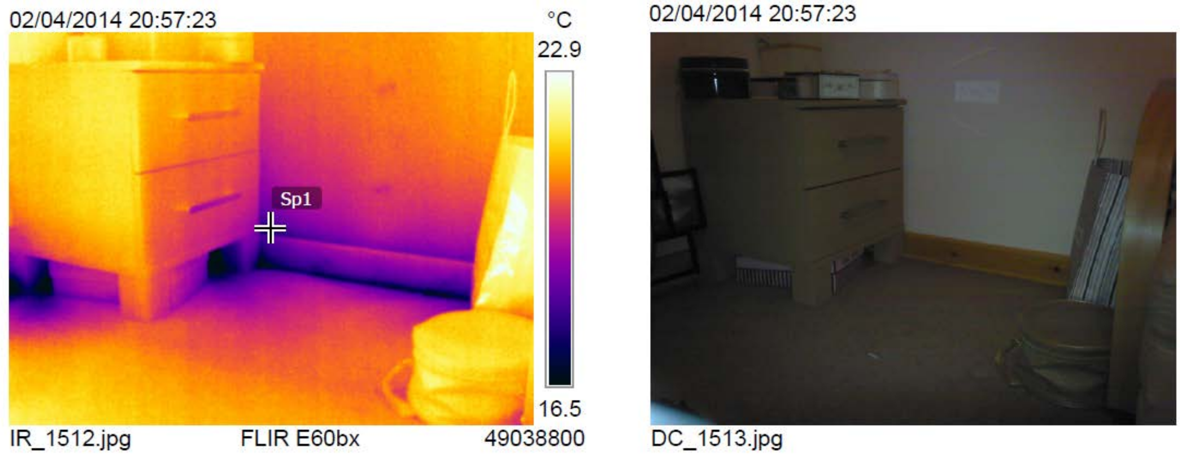


Figure 3:13: Thermal image of wall/floor junction. An area of non-repeating thermal bridge is detected above and below the skirting.

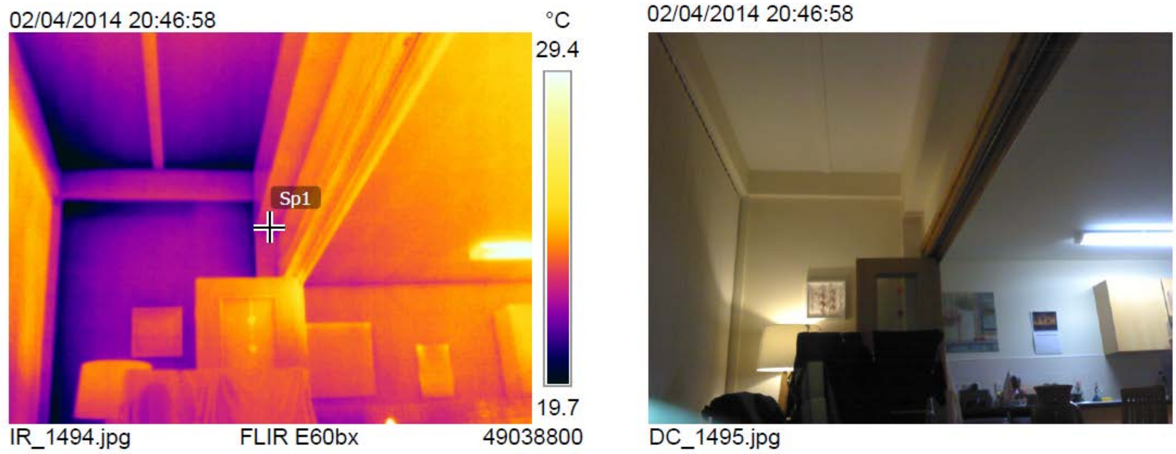


Figure 3:14: Thermal image of wall/ceiling junction in sunspace (within insulated envelope), an area of non-repeating thermal bridge is detected at the junction, also note cooler sunspace surface temperatures essentially cooling the adjacent living space.

Challenges

There were a few challenges faced in regard to the infrared thermography, these include:

- Due to the site being located 180 miles from the research team there was a reliance on weather forecasts to predict suitability of weather conditions. As the site is in an elevated position it also has slight difference in climate conditions than the MET office weather station. In addition its location is in Highland Scotland, where weather conditions during the course of a day can vary considerably.

- The furniture placement of the occupiers caused difficulty to work around for the thermographic survey. A view was taken not to ask the occupiers to move furniture and pictures placed near external walls, as tests had been abandoned on previous occasions due to poor weather conditions. In reality some of the households would have difficulty in moving the furniture to a location remote from the external wall. The surveyor decided to work around the furniture.
- For the occupants to understand and follow through with the extended heating time prior to the survey.

Lessons

There were limited lessons learned through the study, these were:

- Many of the defects found could have been avoided by good design and workmanship on site.
- A relationship between the research team and occupants had built up over the course of the monitoring period, and a phone call was usually made for organising access for various tasks. As the occupants were normally busy and access arranged a week in advance, the occupants could easily forget what they have been requested to do. A standard document posted to the occupants in advance of the test to confirm date and time of survey, with an explanation of the test and the preparations needed would have been useful to fully prepare the occupants of the testing process, assuming the letter was opened.

3.1.3 Air Permeability Testing

Air permeability testing is performed on buildings to determine the extent of uncontrolled air leakage (infiltration) through the gaps and cracks in the building fabric; these affect internal comfort conditions by increasing heat loss and causing draughts (in winter and increase energy demand) and heat gain (in summer). In Scotland air permeability testing on dwellings is currently not mandated through the Building Regulations unless a target lower than $10m^3/(h.m^2)$@50Pa is specified in the SAP documents.

In order to achieve an air tight dwelling it is imperative to ensure, attention to detail in design by inclusion of airtightness targets in specifications and for the airtightness layer to be clearly identified on drawings. Good workmanship is required by the contractor as well as coordination between trades. It is not easy to visually detect infiltration pathways and as such testing is required to ensure internal comfort conditions (winter and summer) and to reduce energy demand for space heating.

Testing involves the creation of a pressure differential between inside and outside, by using a portable variable flow fan temporarily installed in a doorway. The total flow through the fan and the pressure differential are recorded through a range of pressure differentials. The resulting infiltration rate is computed from these readings and is expressed in air leakage (m^3/hour) in or out of the building, per square meter of building envelope at a reference pressure of 50 Pascals ($m^3/(h.m^2)$@50Pa). In order to detect the location of infiltration pathways a smoke pencil is routinely used, together with thermography.

In line with TSB BPE mandatory requirements, air permeability testing was undertaken on all eight dwellings at the beginning of the BPE monitoring period on 1st November 2012, and repeated towards the end of the project on 20th and 21st May 2014.

Methodology

The testing was carried out in accordance with ATTMA (Air Tightness Testing and Measurement Association) TS1 (Technical Standard for air permeability testing of dwellings) which is broadly based on BS EN 13829:2001. The following summarises the methodology for each test.

- Building was measured to determine floor area, building envelope area and volume.
- All trickle vents, windows and external doors were closed; none were sealed.
- Internal doors propped open.
- Mechanical ventilation sealed and switched off where applicable.
- Portable fan and frame installed in front entrance door, creating an airtight seal.
- Infrared thermography undertaken to detect areas where infiltration paths could exist (second test).
- Buildings depressurised to an internal/external pressure difference of at least 50Pa.
- Infrared thermography undertaken to detect possible infiltration paths (second test).
- A series of air flow measurements recorded at varying indoor/outdoor pressure differentials.
- Fan set to positively pressurise the dwelling to an internal/external pressure difference of at least 50Pa (second test).
- A series of air flow measurements were recorded at varying indoor/outdoor pressure differentials (second test).
- Results computed through regression analysis of recorded measurements.

Results

The figures in Table 3:5 (and graphically in Figure 3:15) represent the negative pressure (depressurisation) results. Negative pressure testing was selected for the comparative analysis as positive testing was not undertaken or reported as part of the initial air permeability tests. Table 3:6 provides results for positive, negative and mean air permeability and air change rates for each dwelling for the second testing carried out towards the end if the study.

Dwelling Ref	Target Air Permeability at 50Pa ($m^3/h.m^2$)	Initial Test Air Permeability at 50Pa ($m^3/h.m^2$)	Final Test Air Permeability at 50Pa ($m^3/h.m^2$)
A1	10.00	3.82	3.50
A2	10.00	4.21	4.20
B1	10.00	5.82	5.73
B2	10.00	6.07	5.43
C1	10.00	5.93	5.47
C2	10.00	6.00	4.78
D1	10.00	5.71	6.06
D2	10.00	4.53	6.64

Table 3:5: Initial and final air permeability results (dwellings depressurised).

Dwelling Ref	Negative Air Permeability at 50Pa ($m^3/h.m^2$)	Positive Air Permeability at 50Pa ($m^3/h.m^2$)	Mean Air Permeability at 50Pa ($m^3/h.m^2$)	Mean Air Changes Per Hour (ACH)
A1	3.50	3.63	3.57	3.54
A2	4.20	4.41	4.31	4.27
B1	5.73	5.35	5.54	5.55
B2	5.43	5.22	5.33	5.34
C1	5.47	5.34	5.40 (5.77*)	6.61 (7.07*)
C2	4.78	4.72	4.75 (5.03*)	5.82 (6.16*)
D1	6.06	6.06	6.06	8.31
D2	6.64	6.34	6.49	8.90
* Slightly leakier results were obtained when the tape over the flue/regulation plate in the ceiling above the stove was removed				

Table 3:6: Negative, positive and mean air permeability results 20-21st May 2014.

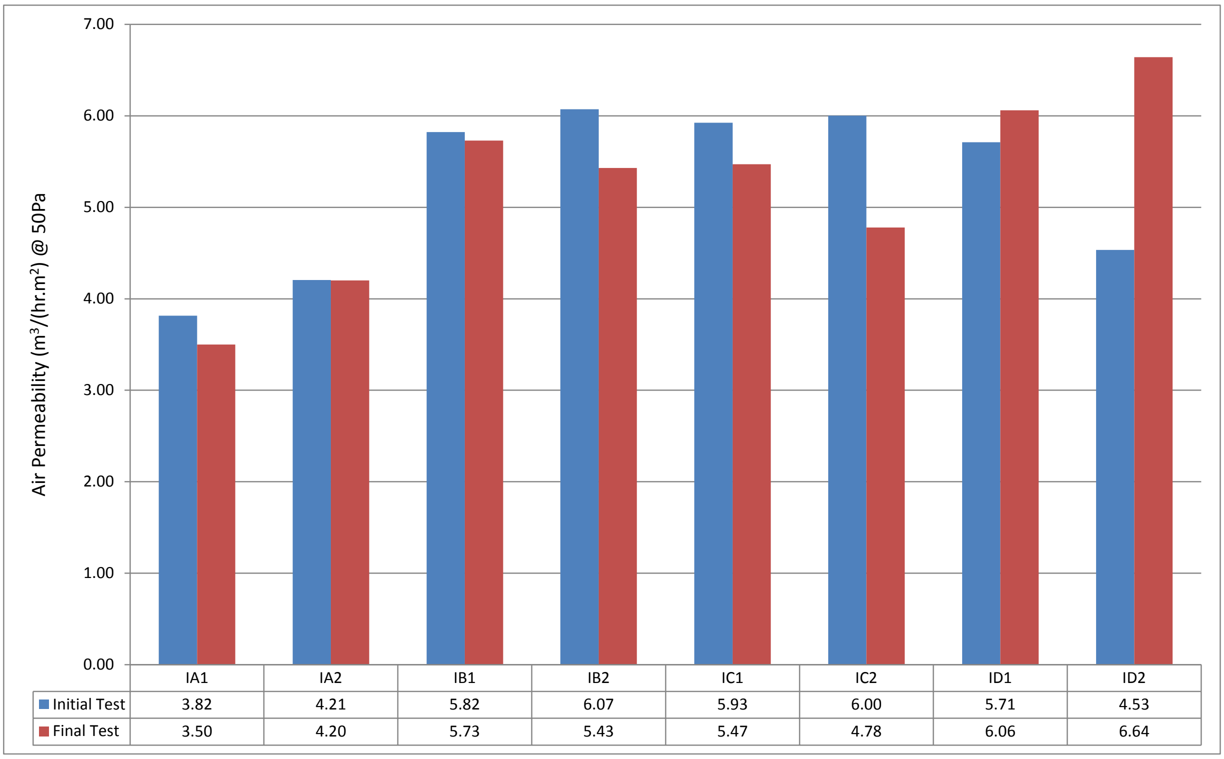


Figure 3:15: Comparison of Initial and final air permeability results (dwellings depressurised).

Discussion

The contractors that completed the testing provided air permeability test reports for each dwelling. In addition the contractor who undertook the testing in May 2014 provided a thermographic survey report and videos of the smoke pencil testing as well as a combined summary of the results and main findings. These are summarised herein and the contractors' reports are located in Appendix G.

Unlike the English Part L document, the Scottish Building Regulations in force at the time of initial design (2007) of the dwellings did not mandate air permeability testing of dwellings. At this time air permeability testing was required on a sample number of dwellings in a development if the target specified at Building Warrant stage was less than $10m^3/(h.m^2)$@50Pa. Testing was not considered necessary for dwellings designed and constructed to the Accredited

Construction Details (Scotland) and a value of $10m^3/(h.m^2)$@50Pa could be inserted by default within the SAP calculation. In the case of the four pairs of dwellings in this study, their respective SAP calculation sheets declared air permeability targets of $10m^3/(h.m^2)$@50Pa, thus assuming the intention for the dwellings to be designed and constructed to Accredited Construction Details (Scotland), this negated the requirement for post construction air permeability testing.

It should be highlighted that comparison of the results is made using data from air permeability testing with the dwellings tested under negative pressure. This is due to the omission of positive pressure testing during the initial tests. Despite TSB requirements being made clear to the contractor, the first tests adhered to the procedure in the ATTMA technical standard, and thus are valid. It is common for a dwelling tested under negative pressure as (normally) it exhibits a leakier envelope than when tested under positive pressure (refer to Table 3:6) thus outcomes of these cannot be compared. In order to clear up ambiguity in interpretation of air permeability results the ATTMA testing methodology, clearly, needs to be more prescriptive and identify one method for compliance for a valid test; this should be the mean of a negative and a positive test.

The tests in November 2012 confirmed all eight of the dwellings achieved air permeability rates that were better than their design target of $10m^3/(h.m^2)$@50Pa. Both dwellings in House Type A (A1 and A2) and one other dwelling, D2, had infiltration rates less than $5m^3/(h.m^2)$@50Pa; the level at which current (2013) Building (Scotland) Regulations recommend additional ventilation measures should be made (normally through mechanical means) to avoid internal air quality and condensation issues. However, there appear to be no moisture related issues in these three dwellings. There is an issue with excessive moisture in bathrooms which is linked with under-performance of intermittent extraction fan units (discussed in Chapter 6).

The final tests in May 2014 confirmed the air tightness of each dwelling remained below their initial air permeability targets and similar to the rate of the first tests in 2012. The air permeability of five of the dwellings improved, indicating a lower infiltration rate; while the air tightness of two dwellings deteriorated and the air permeability of one dwelling (A2) remained static. The testing revealed the most significant areas of infiltration in all dwellings were similar. These were found around bath panels, behind kitchen cabinets, pipe penetrations for water and drainage services, heating pipes, boiler flues, extract fans, trickle vents, above and below skirting boards, socket outlets, below floors (in flatted dwellings), door seals and settlement cracks.

The reason for the improved air permeability rates in House Type A and B over the intervening period is unknown. While the decrease in air permeability rates in House Type C is linked to sound insulation works and floor coverings being fitted in dwelling C2 during the intervening period. These works have provided a 25% and 8% air leakage reduction in dwellings C2 and C1 respectively. The cause for the deterioration in air permeability in House Type D (9% in D1 and 31% in D2) is unknown. It was of particular note to witness vinyl floor coverings throughout D2 being pushed upwards by air leakage from the sub-floor. However it is unlikely this infiltration is the principle cause for the overall increase as the same floor coverings were in place prior to the first test in 2012. The air leakage in this dwelling (D2) intensified in the bathroom with toilet paper being blown (not normally witnessed) and air temperature being noticeably cooler (relative to the rest of the property). Air leakage in these areas in D1 existed but were not as prevalent. This may be due to the occupants having fitted ceramic floor tiles in the bathroom and engineered timber floor coverings elsewhere in the property during the intervening period.

Challenges Met

The challenges associated with the air permeability testing included:

- The occupants have varied occupancy patterns; some are shift workers with working patterns varying each week. This created a logistical challenge for organisation of successive access to each of the eight households.

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

- The requirement for air permeability results to be measured with the building held under both negative and positive pressure. The contractors did not see the value of both sets of test results, as only one is required for compliance with ATTMA TS1.

Lessons Learnt

The lesson learnt from the air permeability testing included:

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

3.2 Conclusions and key findings for this section

While the in-situ fabric testing revealed the dwellings were generally constructed to a better standard than the then current Building (Scotland) Regulations, it should be noted the Building Regulations are progressively being updated to reduce heat loss through the thermal envelope. The target wall U-value for House Type B is already below the current (2013) Building Regulation backstop value of $0.25W/m^2K$. In the not too distant future it is anticipated thermal transmittance of other building elements will become borderline with the revised backstop U-values.

There appears to be familiarity with constructing with timber frame, however, evidence of thermal bridging due to poor design detailing and workmanship was found in each of the dwelling types. Backstop air permeability targets have improved since the construction of these dwellings, while a result of $6m^3/(h.m^2)$@50Pa may be an achievement over the then target of $10m^3/(h.m^2)$@50Pa this is now close to the current backstop value of $7m^3/(h.m^2)$@50Pa (if designing to approved details) and is still relatively draughty. It was noted for the design and construction review (Chapter 2) design teams had not set specific airtightness targets and the contractors (after procurement changes) did not add this to their new scope.

It would appear these houses are not 'future proof' and as thermal efficiency improves and fuel price increase they may become less desirable to future tenants or owners. Recommendations for future projects would include for design teams to actively design in air permeability barriers to exceed the minimum standard for air tightness. This would help to improve construction quality however, the architects drawings and specification need to clearly present this information, targets and testing methodology. Thermal bridge free design should also be considered early in the design process and thermographic testing should routinely take place once the building envelope is sufficiently weather tight.

Finally, for air permeability testing we would recommend for a revision to the ATTMA standard for valid resting results to be through a mean of tests conducted under negative and positive pressures. This would reduce ambiguity in comparing results.

4 Key findings from the design and delivery team walkthrough

4.1 Introduction

A semi-structured interview was developed from TSB Guidance documentation and took place during March and April 2013. For each of the four house types the architects, main contractors and housing associations were interviewed separately in the office of each interviewee (it was not possible to conduct interviews for each plot collectively). The structure of the interviews allowed individual experiences to be gathered from those involved in the delivery of the project. The main objective of the process was to develop an understanding of whether design changes (if any) had been made to the original design intent, and if so at what stage changes had been made, why these had been made, who made the change and to understand the main challenges in delivering the project. As built drawings and operation and maintenance manuals (where available) were used as aids. Design team survey responses were recorded in bullet point fashion and are located in Appendix H.

House Type A

Design Intent: From the architects perspective the original concept of the competition "*was to demonstrate sustainability and new* [innovation in] *energy"* systems. The dwellings were originally designed to provide a sense of space, high levels of insulation, breathing walls, sophisticated heating systems and to maintain a connection with the garden from principal living spaces.

Project Delivery: The contract changed part way through the design process from a traditional contract to a design and build, a value engineering process followed which resulted in design changes from the original architectural intent. When asked what changes had been made the contractor acknowledged the design had been "*dumbed down a bit…following the start of the recession and the reality of the market but it* [House Type A] *was generally unaffected by the value engineering that took place*". The housing association maintained a different viewpoint stating the value engineering process "*was a changing feast*" as the properties on this plot were over the cost benchmark for Scottish Government funding, the housing association needed "*to keep cutting until the benchmark was met, there was a lot of compromise.*"

The value engineering process reportedly involved the architect, contractor and housing association where thermal insulation in the walls changed to a more mainstream insulation product which negated the breathing wall concept; the housing association instigated a change in heating system, from a heat pump to a simple gas fired combination boiler; healthy materials and green aspects were deemed unaffordable; omission of garden sheds; and the total floor area of the dwellings was reduced. The housing association and the architect are in agreement that the overall aesthetics of the dwellings are unaffected but materials and overall concept changed considerably.

All involved commented on the very short time frame for delivery of the dwellings, this was described as "*bonkers*". The deadline to complete before the planned Expo event and delays experienced necessitated long working hours and contractors to share equipment and site facilities. From the interview with the contractor was apparent the pressure to deliver on time was their main driving force over anything else, as "*no-one wanted to fail*". While keeping up with the fast pace, the main contractor revealed one of their largest learning curves on the project was the attention to detail required to achieve the specified airtightness which had "*focused their minds*" as "*these were the first houses we had pressure tested*". Chapter 3 details this House Type to have the lowest air permeability.

Energy targets for the project were high priorities for both the architect and client (housing association), however the contractor was unaware of any energy targets for the project. The contractor appointed a sub-contractor to design the building services but as the contractor was unaware of any targets the project ethos was not passed down to the sub-contractor designing heating, ventilation and piped services. Towards the end of the project, the building services sub-contractor went into receivership which caused some issues during the snagging process; the contractor would not elaborate on these.

Weather conditions were harsh and stated by the contractor and media as the "*worst winter in the region for thirty years*". One of the biggest challenges highlighted by the client and contractor was the location of the site, being "*above the snow line*" there were regular occurrences of severe snow delaying progress, even on the first day of construction. These weather conditions delayed the pouring of foundations which had the knock on effect for many subsequent trades.

House Type B

Design Intent: The intention of this house type was to adopt a 'fabric first' approach "*originally specified to include products that* [the architects] *perceived to be 'healthy', avoiding oil based paints and* [specifying] *natural paint and insulation*" products. The dwellings were designed to be simple to operate and avoid the use of "*renewable and fancy technologies*". High energy and SAP ratings were pursued throughout the design.

Project Delivery: The contract changed part way through the design process from a traditional contract to a design and build, a value engineering process followed which resulted in design changes from the original architectural intent. While the initial design concept had been successfully communicated from the architect to the housing association, the project ethos had stopped there and hadn't filtered down to the contractor's site manager, whose involvement in the build began on the first day of site construction.

After the contract had changed there were many changes to the original specification we were informed these were agreed between the housing association (client) and the contractor's quantity surveyor. The housing association admits that in the pursuit to adapt the design to meet their budget "*the health thing became a misnomer as we* [housing association] *had compromised a lot of what the architect had designed in*." There were numerous changes to the original specification including the omission of a brise soleil; stone floor and clay wall for thermal mass "*this was one of the first things to go, as we* [housing association]*weren't precious about it*"; healthy insulation changed to a vapour barrier construction, timber roof materials omitted, as the contractor was not willing to build a timber roof; cladding materials changed; "*the healthy non-toxic paint specification was just lost*" although oil based paints were not used. The contractor stated "*most of the tricky stuff came out so it was quite simple and straightforward*." The architect expressed disappointment with the loss of the health and energy conscious aspect and commented that the final result was very different to original design intent but "*at least it's still the same shape*." The architect supposes that after the omission of the healthy materials the "*next big challenge is the liveability in terms of the air quality*." This will be explored in Chapter 7.

On site there were issues with severe snow but as the contractor had applied early enough for staged building warrants this hadn't delayed the laying of foundations. The contractor quickly realised that many of the materials for the whole Expo site would be ordered from the same suppliers, which had the potential to cause delays with deliveries. Their policy was to place orders early. Even after having done this the contractor still found the "*timescale ridiculous*" admitting "*the work could have been done better but time was tight*."

The housing association thought that the space in one bedroom was compromised by the step beneath the window to meet building control requirements "*effectively it makes the room a single not double and the step creates a trip hazard, next time we would change the window design to avoid the need for a step*." The occupants also commented they thought the bedrooms were small.

House Type C

Design Intent: To provide affordable housing that promotes well-being by using benign materials and breathing walls. The dwellings were designed using a fabric first approach with high insulation levels and minimal glazing to the north, with larger glazed areas to the south and west façades. Designed with a passive stack ventilation system it is a "*modernist design idea with a central services core*".

Project Delivery: The architect was linked to the housing association (client) from the outset, but after the project contract changed to a design and build contract some of the original elements specified were lost, despite "*attempts made to urge retention of design ideas* [that were] *not supported by contractor or client*".

The contractual involvement of this particular housing association was short term as their "*role was to take the properties and sell them on…we have no further involvement in them once they are sold*." The housing association commented that a "*fundamental flaw*" of the Expo process was their lack of involvement in selection of winning entries for their plots. They considered "*the design to be way out there, bold and whacky; way beyond our standard benchmarks for affordable housing.*" The housing association were not complementary or supportive to the original intentions of the design competition.

The client stated their involvement in value engineering process "*was in a peripheral way*" it was left to the designers. The architect reported the project had a few minor changes from original design intent that resulted in layout and materials specified being largely unaffected. The contractor recalled the largest change to be the omission of prefabricated bathroom pods based on "*a previous bad experience*". The wall floor and roof panels were manufactured offsite and "*were quick and simple to crane into position*".

On site there were issues with severe snow and cold temperatures, but the contractor had obtained a building warrant early and managed to lay the foundations without causing a delay to the project. A further challenge was with the installation of the EDPM roof which developed numerous bubbles beneath the finished surface. The contractor was uncertain whether this defect was a result of severe weather conditions or poor workmanship by the sub-contractor.

There were sound transmission issues between flats, which was later identified as being a result of the relocation of woodstove flues to outside of the central service duct, due to lack of space. The contractor believed there to be a remedy for this issue and was attending site to remedy the situation.

When the housing association was asked about the handover process, they acknowledged "this is an area where we are all underperforming, about informing residents how a building should be managed" and couldn't recall whether the systems were demonstrated to the new owners and added "*the system is a modest electric heating system with a wood burning stove*". The closing remark from the interview with the housing association was "*we are not responsible for these properties and are not interested in the way the occupants run their homes. We do need to do better as it is important to educate, instruct and provide assistance if needed*."

House Type D

Design Intent: There were no specific energy targets but the project was designed with large amounts of cellulose insulation, thermal mass in the buffer space to "*regulate temperature extremes*" and orientated to harness solar gains in the main living spaces (refer to Chapter 7 for details on internal conditions). "*The idea was to include passive systems to avoid 'plug-in' and 'bolt-on' systems"*, the roof *"was designed to accommodate PV*", which was later omitted.

Project Delivery: The architect entered the design competition with the contractor as a design and build from the outset and "*feels there was a good relationship with the contractor*". The architect had liaised early on with the housing association to determine their design requirements and designed to meet these. During the value engineering process to meet housing association benchmark costs the properties were altered from one bedroom to two bedroom properties. The result was a compromise in the living space which causes the occupants to live in a way that conflicts with the original design intent.

The architect commented the contractor was aware of the "*good insulation levels and solar gains*" but raised concerns over the contractors understanding of the sunspace principles as internal glazed doors to the sunspace became single glazed and opening high level windows were omitted during the value engineering process. The contractor maintained opening windows were on the drawings that the architect had signed off prior to order. However, somehow these were missed and as a result the sunspace contributes to overheating of the indoor environment. The architect had thought the occupants wouldn't understand the concept of a sunspace and thought perhaps it could be opened up to the living space to create a dining area (which is what has happened for space reasons).

On site the contractor had instigated a change of roof material from EDPM to a similar glued system they were familiar with using, this was based on the unsatisfactory experience from another dwelling type (House Type C) the contractor was constructing at the same time. Ceilings in the entrance hall of each property required to be lowered as the contractors hadn't appreciated that the 42mm communal heating pipework would require insulation and space to be installed. The void space wasn't large enough to accommodate the pipes. The contractor had proposed these changes in discussion with the architect.

The floor was constructed of cassettes which "*were insulated with cellulose on site to help keep up with the programme*". The contractor also ordered materials early, especially the windows, as most of the plots were using the same window manufacturer.

The heating system is a communal biomass heating system, the contractor had said he had heard a rumour that the biomass system is not working and heat is being supplied through a back-up condensing gas fired boiler.

The architect didn't think that the build on this house type was rushed as it was completed a month before the Expo event. The housing association couldn't remember the handover process provided to the occupants. However, the occupants report they had no formal demonstrations of the systems, are unaware of how to use the sunspace and that the biomass boiler had frequently broken down. They also stated that the housing association are unable to assist with their queries as the flats are shared ownership between the occupant and the government.

4.2 Conclusions and key findings for this section

Although each house type was designed with 'fabric first' principles with an emphasis on high levels of benign thermal insulation, the air tightness of the dwellings seemed to be more of an after-thought, with relatively little importance on design detailing (refer to Chapter 3). It seems odd that the airtightness would be given low priority as the building fabric and airtightness are inextricably linked in a fabric first approach. The change in the form of contract to design and build affected the materials used for each of the house types, where the contractor omitted materials and concepts unfamiliar to them. The short time frame for the build and the poor weather conditions meant there were delays and as a result work was rushed to meet the deadlines for the Expo event. From the various fabric testing (Chapter 3) and internal conditions (Chapter 7) it transpires the quality of construction was affected. This is confirmed by the occupants who have also expressed dissatisfaction with elements of the build quality (Chapter 5).

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

This section discusses occupant surveys and other occupant evaluation conducted over the monitoring period. The TSB mandatory elements of the occupant handover process were designed to understand the level of information provided to the occupants when they moved into their homes, and the outcomes of the BUS evaluation undertaken across the development. The occupants were invited to keep diaries for two one week periods in the 2013/2014 winter period and the 2014 summer. Results from the diary periods these were analysed and a summary presented.

5.1 Occupant Handover Process

Semi-structured interviews were developed to discuss the handover process with the occupants, these aimed to understand the level of advice and support each household had received when moving in to their homes and to understand issues the occupants worried about. In particular, they were questioned over their ability to operate and control the heating and hot water systems to provide comfortable living and whether the heating is affordable. The questionnaire prompted discussion over sound performance and ventilation systems. The final questions aimed to establish, and attempted to assess, whether there were any instance of asthma or health problems considered to be associated with the living environment. The questionnaire responses are summarised below and full questionnaires for each dwelling uploaded to Appendix I.

House Type A

The housing association handed over the dwellings to the tenants with tenant information packs containing user manuals for the buildings operation. The housing association advised the research team that their handover document focuses more on their procedures rather than the practicalities and technical aspects of moving into a new home, however after the process the housing association confirmed they would revise their handover process in the future. The tenants confirmed on their moving in, they received a booklet and a quick run through of the systems and controls. They both reported being comfortable with control of the boiler, although one household found setting the heating programmer difficult. The ground floor heating is provided by an underfloor heating circuit and the upper floor is heated by radiators with thermostatic radiator values TRVs; these systems have separate programmers, which was initially confusing. Both households reported they found the heat output fairly effective and liked having underfloor heating but noted bedrooms could sometimes be too hot. The shower is fitted with a thermostatic mixing valve (TMV) where one household commented the water temperature is too cool and thought the thermostat maybe set too low. The occupants reported there were snagging issues in relation to the building services installations for a faulty living room thermostat (still not resolved), leaks from pipework, inadequate sealant in shower, failure of lighting circuits and inadequate ventilation in shower rooms.

Although marketed as low energy homes, both households find fuel bills expensive where the cost was considered to be similar to where they had previously lived; these were homes that were not considered low energy. They both stated they would reduce the time heating operated if they found fuel unaffordable; one household switched their payment method to a pre-payment card meter shortly after moving in, which has a higher tariff than direct debit. In regard to ventilation, the occupants both felt extract fans in the bathrooms and kitchens were ineffective, this was confirmed during the air flow measurement procedure (Chapter 6) which identified three out of four fans in this house type were extracting air at flow rates lower than the Building Regulation recommendation.

On the whole, the occupants like their homes, they particularly like the open layout and the larger than average room proportions. The housing association is responsible for repairs and has a reporting procedure in place, although they feel the response time is a little slow. During the monitoring period we found the housing association to be proactive in replacing shower room extract fans after the air flow measurement results were reported to them.

Since the survey the occupants have commented on the poor drainage in the gardens where the gardens are sodden for days after rainfall. They feel the cost saving exercise was extended to omit garden drainage and landscaping.

House Type B

The housing association provided a handbook to each of the tenants, one dweller was given a walk round to explain the systems, which the occupant found too quick and would have welcomed more detailed advice and demonstration on the operation of the heating system. The other household felt they needed more handholding at first as they had never lived in a house connected to mains gas before; after an uncertain start they quickly understood how to set the timers for space heating and hot water. Both found the heating (gas boiler serving radiators with TRVs) to be effective but although the temperatures were initially reported as being comfortable, the occupier in house B1 found all of the rooms to be a little on the cool side.

Domestic hot water is stored in a hot water cylinder and is heated by a coil fed from the gas boiler. The occupants reported confidence in heating their water in this way, but neither had set the programmers for water heating to be done automatically. It transpired one dwelling (B1) preferred to use the electrical immersion heater instead of setting the gas programmer, as it was thought to be a cheaper method of heating hot water, this is discussed later in this report in Chapter 7. Although the cost of heating was considered affordable, one householder thought the cost was similar to a previous home and the other thought the cost to be much less expensive than previously, due to the switch from electric heating to gas. This household informed us they would find a way to keep the heating on (if expensive) and the other would reduce the time heating is on. With regard to draughts only one household reported feeling draughts from doors, despite the relatively high infiltration paths around patio doors and beneath kitchen cabinets in each of the houses. On the whole the occupants are very appreciative of their homes but were critical in terms of limited fridge/freezer space and the small bedrooms. The bedroom size was commented on by the housing association and reduced during the value engineering.

Although there is a procedure in place for reporting issues, the occupants find the housing association slow to respond. The systems have been reliable the housing association have been called out to repair leaking uPVC guttering, handrails on stairs, sticking rear door and on-going faults with electrical circuits.

House Type C

The occupants of his house type were given manuals on the various systems in these dwellings. One of the occupants interviewed confirmed the systems were not demonstrated on moving in and expressed uncertainty of operation of the heating system, as well as the cooker hood and kitchen extract. The occupant revealed that the user manual provided with the property was incomplete and did not cover all of the equipment installed in the dwelling. The electric heating was found to be slow to react and expensive, which causes one of the household to use their wood burning stove more often than the electric heating panels. In one household the hot water cylinder provided was considered to be too small due to limited hot water storage capacity being insufficient for a bath, the other household doesn't have baths as it is considered that the hot water temperature is too low, there are TMVs fitted on the bathroom taps. Both households had differing opinions on the affordability of heating their respective homes. Those who use their wood burning stove thought the heating to be cheap for electric, while the other household that heated using the electric radiators found the heating expensive. They both had concerns over the draughts from the front doors, also identified during thermography (Chapter 3) and had sound transmission problems between properties, which the research team were informed had been resolved.

The occupants in flat C1 changed part way through the BPE programme (September 2013), the new occupant was provided instruction on how to use the systems by the previous occupant and was handed user manuals which were found to be helpful. This occupant reported more detail on hot water heating would have been useful. The new occupant preferred to use the wood stove rather than the electric heating and hasn't set the timer. The occupant finds the heating to be affordable, mainly due to access to a free supply of wood from a family member who owns a croft nearby. The tenant identified the acoustic issue between flats still exists but isn't as pronounced as before the remedial works. The occupant pointed out an issue with water ingress into the property (at a junction over a door in living room) but was unable to determine exactly where the water was entering. The front door seals were also raised as an issue. The fire alarm was found to be too sensitive and frequently sounds when the oven is being used. The occupant also expressed a dislike at the short bath. In common with the other neighbour who uses the wood stove as their primary heating source suggested an external wood store would have been useful, as well as a bin storage area. The occupiers organise any maintenance and organise repair of any break downs as they own their flats.

House Type D

The occupants of this house type reported they were provided with a user manual from the housing association. There were no demonstrations of the setting and operation of specific appliances and the heating system. However, the manual provided information on the dwellings' appliances and contained details of heating system operation, but this was considered complicated. The heating and hot water in this house type is provided by a communal biomass boiler, with back-up gas fired boiler. When the occupants were asked about the heating system, we were informed of a break down over their first Christmas period due to lack of wood pellets. Residents in both dwellings find the controls easy to operate a the dwellings have standard panel radiator heat emitters with TRVs and wall mounted thermostat. However, one household finds the system ineffective at maintaining comfortable internal conditions. The occupant who finds the heating comfortable sets their thermostat to 23°C. The occupants in dwelling D2 report an inability to operate living room and bedroom radiators simultaneously and therefore the bedroom radiators are not operated. They had commented that they were the first occupants to take up residency in the block and at this time the heating worked perfectly, suggesting there could be issues with the system output or the distribution of heat on the landlord side of the heat exchanger. The domestic hot water at the bath tap outlets is found to be too cool in one dwelling, the occupants informed the research team that they use a kettle to raise the water temperature when taking baths. In the summer they report that the living/kitchen is too hot, as identified through thermograph (Chapter 3) the fridge freezers produce significant internal heat gain and the sunspace (Chapter 7) contributes to overheating of this space.

When asked about affordability of utilities, one household reported the heating to be more expensive their previous home, especially as a management fee to the operator of the communal heating is now paid on top of the fuel. These occupants have expressed their dissatisfaction in how the heating is charged and have recently (summer 2014) commented that they are considering about finding out whether there is a possibility of installing their own gas-fired boiler and be removed from the communal system. The other occupants were unable to compare and comment on cost of the heating as they were first time buyers and had not previously been utility bill payers.

One household reported they found their home to be draughty, particularly from the sunspace. The second airtightness tests found this house type to have the highest air permeability rate of the eight dwellings.

One respondent commented on the poor sound performance of the dwellings and at that time were unaffected as their upstairs neighbour was relatively quiet. Since the interview, both sets of occupants have alerted the researchers to sound transmission issues and described how they have fallen out with neighbours over this, and are both considering moving out in within two years (by 2016).

One occupant requested that the operation of the sunspace was better explained so it can be used better. The research team designed and provided a 'quick start guide' (Chapter 8) individual to each home which explains the operation of the sunspace and the occupant also requested further information on the sunspace during the exit interview. The research team observed that the occupants use the sunspace to extend their living space and consider the living space to be too small without permanent use of the sunspace (refer to Chapter 2 for design changes).

One occupant identified that the flats were all designed to be wheelchair accessible but there is no lift in the building to access the upper floor levels, in addition all flats are designed with a shower in the bath which would not be accessible to a wheelchair user. The Police also visited the dwellings and advised residents to fit blinds over the sunspace glazing for their security, we are unclear whether this house type was designed to 'Secured by Design' guidance.

5.2 Building User Survey (BUS)

BUS is an established method of evaluating occupant satisfaction and for benchmarking buildings against a large database of details for similar buildings across a development. This survey formed a mandatory requirement of the TSB BPE study and it took place over a two day period, 23rd and 24th October 2013. This time of year was specifically selected as it was considered to be more neutral in terms of climate (being autumn), which would have reduced potential for influencing respondents' comments.

One week before the planned survey a letter was posted to each address in the development to request participation in a doorstep survey. A consent form was included in the letter which was subsequently collected from willing participants prior to the survey. The survey team consisted of three people, working in two teams, each team was assigned specific addresses to contact. Each survey was conducted in the home of the respondents where the researchers completed the questionnaire by transcribing comments made by the respondent.

Figure 5:1: Researcher completing BUS survey with participant.

Figure 5:2: Researcher completing BUS survey with participant.

The final response rate was for 64% of the developments residents to have participated in the survey. The details are:

- 45 properties targeted to participate.
- 29 responded.
- A further 2 surveys were completed and returned by post after analysis had been undertaken. These were not included in the Arup analysis but the comments made have been considered and included in this summary.

After the survey, responses were entered in to the standard BUS spread sheet template and emailed to Arup for analysis. This allowed the results for this development to be benchmarked against other BUS responses, these were presented in two reports. One report sets out the quantitative data and the second report itemises the occupants' responses to the survey questions. As part of the analysis, Arup provide a web link to a standard report, located at http://portal.busmethodology.org.uk/Upload/Analysis/yp2nevx2.214/index.html. A brief summary of occupant profiles is listed to provide an overview of the respondents who participated in the survey:

- Survey response rate 64%.
- 44% were male and 55% of were female.
- 68% of the respondents had lived in the development for more than one year.
- 68% were over thirty years of age.
- 44% were tenants, while 55% of dwellings were owner occupied.
- 24% of respondents live in detached houses, 27% in semi-detached houses, 20% in flatted dwellings and 27% in other accommodation which was terraced houses.

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

Quantitative BUS Survey Results

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

The results were grouped in the following categories:

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

The summary of BUS variables presented in Table 5:1 indicate the majority of the variables were ranked with an average benchmark (amber circles). While the variables scored higher than the benchmark are represented by green squares and the variables lower than benchmark are indicated with red diamonds.

These results need to be carefully considered, as although noise from neighbours is ranked with a green square (indicating it is better) this result could be misleading, as a third of respondents described too much neighbour noise. Internal noise issues due to 'open plan' living was also discussed where these residents praised the bright airy spaces but complained of high noise levels from inside the house. The noise sources cited included: television, music and kitchen appliances e.g. extract fans, washing machines, fridge/freezer and a heat pump.

The absence of draughts in the dwellings during winter should be considered a good result (indicated by a red diamond) in terms of airtight dwellings. The lack of draughts is in keeping with the relatively good result from the airtightness tests conducted on the dwellings forming this BPE study. However, the summer equivalent of this variable also scores lower than the benchmark. Almost, two thirds of respondents (62%) stated they found their homes hot during summer this suggests poor air movement perhaps due to design (large windows without shade from summer sun), inappropriate window design to allow purge ventilation, combined with and occupant behaviour for window opening. A frequent comment made during the interviews was to inform of a lack of ventilation; this was owing to a number of reasons such as lack of control, safety concerns or window type.

In regard to the lighting variables, most of the occupants commented positively towards natural light and praised the large windows, there could be some glare issues associated with the windows. However the mixed reviews in regard to artificial lighting could have pulled down the overall lighting benchmark.

The control of the building services was scored with an average benchmark, lighting was considered easy to control in terms of using local 'rocker' switches. However, there were some issues discussed in relation to the positioning of lighting controls and the quantity of lamps wired to one switch. Most of the respondents use task/mood lighting (plugged in to the small power circuit) more often than ceiling mounted fittings. None of the dwellings are fitted with mechanical cooling systems and provide cooling through shading and ventilation. It was interesting to note that while some occupants linked cooling with window opening and cross ventilation, 37% of respondents stated that they had 'no control' of cooling systems as there weren't any provided. The control over heating was also mixed, 33% of occupants considered there to be 'no control'. However, due to the varying types of heating systems through the development, it appeared those with gas-fired boilers and radiators were more confident in controlling heating systems than the dwellings with underfloor heating, heat pumps and wood burning stoves.

Overall comfort, building design and user needs all score highly with building occupants, but remain within the midpoint benchmark. It indicates that while there are individual issues with the development generally the residents' satisfaction levels are high. The occupants like the individual design, location with close proximity to the city centre, major trunk road and forested walks nearby, which are easily reached on foot from the development.

Green Squares	Amber Circles	Red Diamonds
Issues scoring better than the benchmark and scale midpoint	Issues scoring between the benchmark and the scale midpoint	Issues scoring poorer than benchmark and scale midpoint
• Air In Summer: Fresh/Stuffy • Air In Winter Overall • Appearance From The Outside • Control Over Lighting • Health (Perceived) • Lighting: Artificial Light • Noise From Neighbours	• Air In Summer: Odourless/Smelly • Air In Summer: Overall • Air In Winter: Dry/Humid • Air In Winter: Fresh/Stuffy • Air In Winter: Odourless/Smelly • Comfort: Overall • Control Over Cooling • Control Over Heating • Control Over Noise • Control Over Ventilation • Design • Layout • Lighting: Overall • Location • Need • Noise: Noise From Other People • Noise: Noise From Outside • Noise: Overall • Space • Storage • Temperature In Summer: Hot/Cold • Temperature In Summer: Overall • Temperature In Winter: Hot/Cold • Temperature In Winter: Overall • Temperature In Winter: Stable/Varies • Utilities Costs For Electricity • Utilities Costs For Heating	• Air In Summer: Dry/Humid • Air In Summer: Still/Draughty • Air In Winter: Still/Draughty • Lighting: Natural Light • Temperature In Summer: Stable/Varies

Table 5:1: Summary of results and BUS benchmark.

Individual Feedback Comments

Scotland's Housing Expo was an architectural design competition which aimed to showcase innovative ideas in architecture to create a housing development for comfortable 21st century living. As such the comments received during the BUS survey were from respondents residing in differing house types of very different form and construction. The Table 5:2 lists the comments a selection of the comments most frequently made during the survey the full list is located in Appendix J. There were areas where the project was considered by the occupants as being successful in aligning with the competition goal. For example the development location with its proximity to woodland ranked highly (69 Percentile); this was highlighted by frequent comments relating to ability to walk to local woodland to exercise dogs and for physical exercise such as cycling and running.

BUS Variable	Work well	Hinder
Windows	• High ceilings, natural light, views and long windows. • Love the big windows, bright and airy and good light. • Love the huge windows in lounge. • Really different - like the long thin shape and the tall windows. • Big windows make you feel happier as there is more light. • Extremely good amount of natural light due to many windows (large and small). • Double height space and open plan works well for our lifestyle.	• As it was a design competition with various architects involved with different plots there is an issue with privacy between properties through windows. • Difficult to regulate heat and the high windows in the sunspace do not open. • Big windows make it difficult to furnish small rooms. • The solar space does not work as it should because someone forgot [to install] the opening system in some of the windows. • Don't get a draught [through the house] even with windows on both sides, as [opening] windows are low down. • There are sky lights we can't reach so we are unable to open them. There are no blinds on them and we found we had to fit a shade over them.
Temperature	• Do need to use the heating less and the flat heats up quickly. Never have heating on in bedroom as it is very well insulated. • Heat stays put reducing heating costs. • Quite good with heating we hardly use any heating - even in winter. It's a really warm house. • Have radiators turned off upstairs as not required. • Not had a heating season in the house, but we believe that we will get much free heat from solar gains. • Really warm hardly need the heating on even when sunny in the winter we still don't need the heating on. • The sun heats the house really well and I need to turn off the heating on sunny winter days. • Wood burning stove is a very good addition. • Heating good but condensation is a big issue due to cost cutting and removal of extract fans. • The heating works well. • Front of house warms up in sunlight. • We do use the heating less as the sunspace warms the flat. • Due to the position of our plot we gain in summer due to no solar gain [in living room].	• Energy system overcomplicated. • Don't have good control over underfloor heating. • Boiler should have outside [weather] compensation. • The house is designed with added insulation, but the orientation is not beneficial to provide heat gains in winter, so the running costs for heating and hot water are very high. • Fire is uncontrollable, would rather central heating!! • Can't control the fire. House is either too hot when on, or too cold (in winter) when off. • Heating doesn't react fast enough. The heating stays the same but rapid changes in external temperature are more of an issue - it's cosy but at a cost. • Lose out on solar gain in the living room due to the orientation of windows. • The air source heat pump is not good for this area. It gets warm upstairs but it is hard to heat downstairs, we needed to get draught excluders and have to wear zipped up jumpers downstairs. • The heating system is not great and the boiler is located in our child's bedroom and it is noisy. • Can't put food in low cupboards or on the floor due to the underfloor heating. • Heating is sporadic and we have been different advice on how to operate the system. • The windows make it too hot. • Too hot in summer, especially between 1-5pm. We have to close our windows as well due to smoke from people below having a barbeque. So unable to cool down our flat.
Air	• I can smell a slight smell of the sheeps' wool insulation. • Because of the ventilation system providing good indoor air quality it is better than a normal house. • I like the void in the house because…it helps circulate heat and fresh air.	• When cooking in summer it is hard to get rid of smells. • Smells relate more to cooking smells. • Too airtight if anything.
Lighting	• Love the big windows, bright and airy and good light. • Big windows make you feel happier as there is more light. • Light (day) has a positive effect on sense of well-being. • Extremely good amount of natural light due to	• Daylight can be an issue in the evening in summer e.g. on TV. • Poor artificial lighting. • Lights consume too much energy and are expensive to replace with LEDs. • There are too many lights for example there are 15 lights on three switches, these are not low energy

Lighting cont.	many windows (large and small).	and are too high to reach safely to replace them. • Artificial lighting isn't bright enough…bulbs are too high. • Might invest in blackout blinds for bedroom as there is so much natural light. • Issues with wiring – lights don't all work. • Not enough daylight in the hall, I have to have the light on during the day. The lights are halogen and use lots of energy. • Too much street lighting shinning in.
Noise	• Impact noise an issue but not important. • Location is quiet. • Not much noise from neighbours. • Very peaceful.	• Internal noise control poor. • External metal stair for access to upstairs flat, the noise wakes up my children. • Can't control noise of heating. • Extract fan makes more noise than extracts air. • I can hear noise from pipework when I turn on kitchen tap. • Music through the walls from next door and above. • Walls are thin, for example I can hear noise in pipes when I turn on kitchen tap. The downstairs neighbour complains as they can hear us walking on the floor – we have laminate. We can hear voices from downstairs. • Open plan living, but we need a snug room to get away from TV noise. • Can hear the TV through the [entire] house due to open plan layout and door undercuts. Also can't do anything in private. • The heat pump is located in the open plan living space, it is constantly humming. • Washing machine in the open plan living space makes too much noise.
Control	• Use curtains and blinds to control solar gains.	• As the heating is communal we don't have any control of buying the fuel or our tariff. • Heating system extremely complicated. • Impact noise is an issue. • No way of cooling. • We have control of the heating system, but no control of the air source heat pump. • We choose not to use timers as we work shifts. • Underfloor heating controls are not user friendly. • Fire is uncontrollable, would rather central heating. • Can't control fire, house is either too hot when on, or too cold (in winter) when off.
Design/Needs	• Design is good, however poor finishes • Great design. • I love the houses in the street being different. I hate to see streets that look like Legoland with identical houses all with cars parked in front of the house. • It's not perfect but good, especially when comparing to other homes built today. Much better quality. • Different way of living with living space upstairs. • Closer to countryside and easier for walks. • I try to do gardening as I have a garden now. • Gardening vegetables has added to my activities. • More healthy environment. • I am a member of the residents association that we created. We have formed a close nit small community.	• It's too hot and the layout is poor in the kitchen. • Layout is good but more integrated storage would have been useful. • Like living here but open plan isn't great for a family. • We would change the size of rooms and make the hall smaller. • Feel isolated up here...it is hard to find this address as SATNAV doesn't recognise the address yet.

Table 5:2: Summary of respondents comments to each of the BUS variables.

There were limitations of the BUS survey which affected the data collection and subsequent analysis of the results received from Arup, these are:

- **Sample Size**. There are some limitations of this methodology which suggest 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 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 52 dwellings), and it was necessary to go 'door-to-door' to elicit surveys. This is time consuming and has limited success rates. The other related issue is that there are 27 different house types in this development, with different situations in the (e.g. mid and end terrace, semi-detached, detached and upper and lower flats) where occupants may have very different experiences. The BUS tool may be of more usefulness 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. Thus 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 associations with temperature ('it's 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 occupant prior housing experience. It is possible that responses are therefore conditioned to a certain extent by the nature of the prior experience, which in relatively new housing, are likely to be positive. A more longitudinal approach to satisfaction may therefore be more appropriate.
- **Useability of the data**. The final issue how use the Association can make use of the data. The BUS was survey designed for larger buildings with corporate clients and user groups with greater understanding of statistical analysis. Notwithstanding any methodological issues, the nature of the data and its presentation were of limited use to the housing association who reported that it was not a user friendly document and has limited value when compared with their in-house surveys

5.3 Occupant diaries

The purpose of the diaries was to gather fine grain data on occupancy and activity patterns in the dwellings, and to analyse these against the monitored environmental and energy data. A standard booklet was developed in-house by MEARU to capture specific data and issued across all projects with completion guidance for occupants, refer to Appendix K for a sample of a blank diary.

Detailed data from the diaries showed the daily routine for each occupant, by room and when they were at home over the seven day period. The information collected 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 (to capture hob cooking only).
- Laundry: detail of laundry washing and method of drying.
- A subjective assessment of comfort and indoor air quality for each occupant.

The diaries were undertaken across all MEARU TSB projects over one winter week, Monday 3rd – Sunday 9th February 2014; and one summer week June 30th to July 6th 2014. The return rate for the winter diaries was 100%, while summer diary return rate was poor, at 25%. The winter diaries were specifically handed to an occupant in each household, the completion was explained to the occupant and a stamped addressed envelope (SAE) was provided to return to MEARU on completion. In addition, the occupants were given a financial incentive to complete these which would be handed to them once their diary was returned. In contrast, the summer diaries were posted to the occupants with a SAE and detail of the same financial incentive. Two (25%) diaries were returned. Having spoken to occupants on the telephone to remind them to return the diaries we were advised either they didn't receive a diary, didn't have time to complete it or keeping track of a large number of occupants in a dwelling proved too difficult.

Internal conditions for two bedrooms have been used to illustrate high internal space temperatures, high CO_2 levels and window opening patterns (Bedroom 2 only) that were recorded during the diary weeks. The charts also illustrate when the room is reported as being occupied for sleeping there were numerous instances of high CO_2 levels that are indicative of bedroom occupancy. The data illustrates that due to differing lifestyles bedrooms are occupied for extended periods during the daytime for leisure and in the case of Bedroom 2 below or for sleeping during the day after shift working.

Bedroom 1: The winter diary week for east bedroom in dwelling B2 was selected for analysis as it was known to have high CO_2 concentrations, be occupied by one single occupant of teenage years who keeps the window in a closed position at all times. The hours when the occupant indicated they were in the bedroom are represented with grey shading in Figure 5:3. It indicates that there were times that the bedroom was occupied prior to retirement for bed on at least four occasions. The night of 5th February the occupant indicated presence in the bedroom, however, the CO_2 peaked around 3000ppm which was and similar to the night of 7th February when the bedroom was unoccupied. The occupant indicated that the bedroom door is normally 'open' through the night. The CO_2 concentrations through the week were continually over 1000ppm and space temperature rarely fell lower than 20°C,. This indicates the room is under ventilated and continually heated, these conditions could affect sleep patterns of the occupant and cause headaches. The reason for CO_2 peaks when the bedroom was unoccupied and occupant absent from the dwelling are unclear, however it is clear the occupant spends long periods in the evening in the room and the family have a large dog which could be sleeping in the room.

Occupant feedback for this family was not provided until the spring (April), when our findings were reported to the parents, who actively encouraged more frequent window opening in this bedroom. During April 2014, although the bedroom window was initially opened frequently after the occupant feedback session the high internal temperature and peaks in CO_2 remained the same.

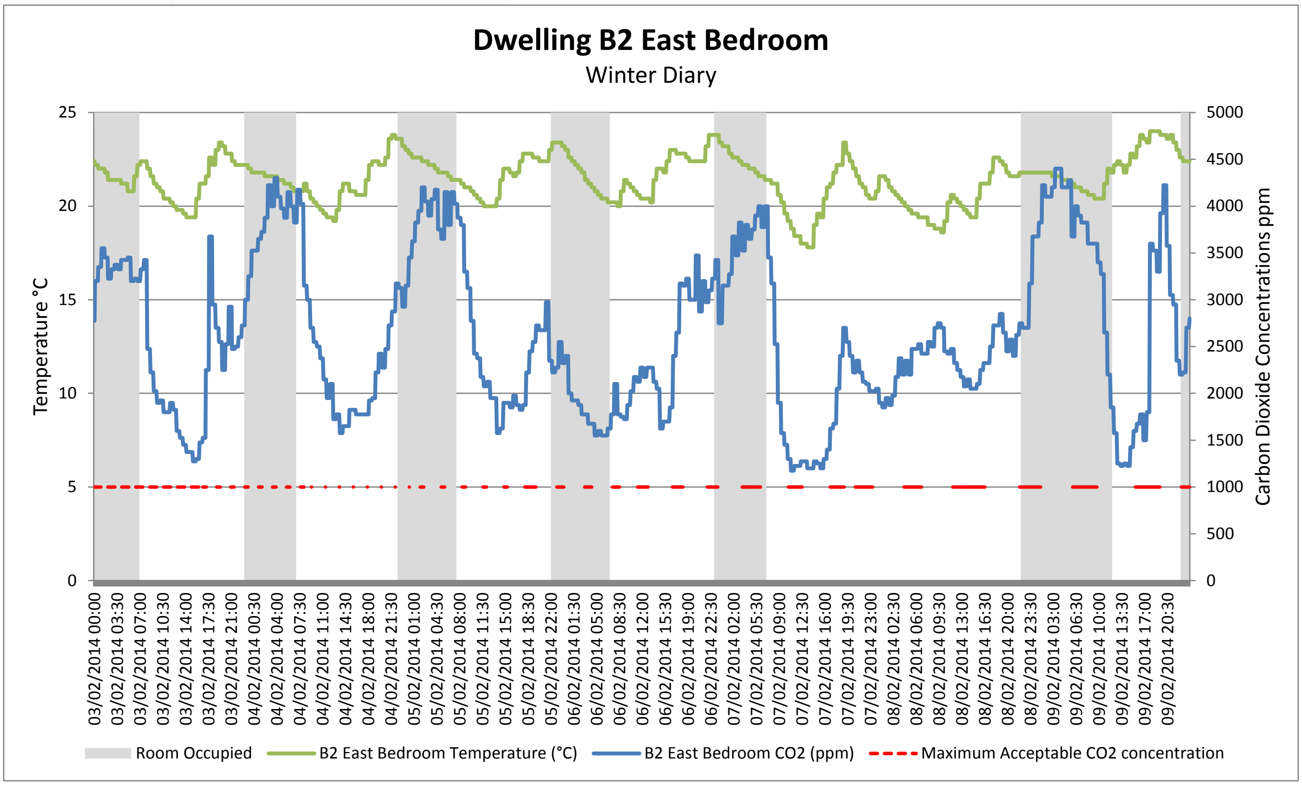


Figure 5:3: Plot of east bedroom environmental conditions against winter diary data for Dwelling B2.

Bedroom 2: Dwelling D1 returned both diaries, the data for winter and summer are plotted in Figure 5:4 and Figure 5:5 respectively. The bedroom is occupied by two adults, they sleep with the door closed and have seasonal window opening patterns. During both seasons the bedroom temperature is maintained between 20 and 25°C, there is however a drop in temperature in the winter when the window is opened. During the night when occupied (indicated in grey) CO_2 concentrations consistently rise to above 1000ppm, this is seen in both winter when the window is closed and in the summer when the window is open.

During the summer it was also evident that the bedroom is occupied during the daytime one at least four occasions where the CO_2 concentrations rise to around 1000ppm, this is thought to be one of the occupants sleeping during the day as one occupant rises at 04.30hrs during the weekday in the summer diary week. There are frequent lower night time CO_2 peaks during the summer week which could be due to higher external wind speeds; however this data was not collected due to a failure of the external weather station. During both diary periods the room CO_2 concentrations decay to below 1000ppm.

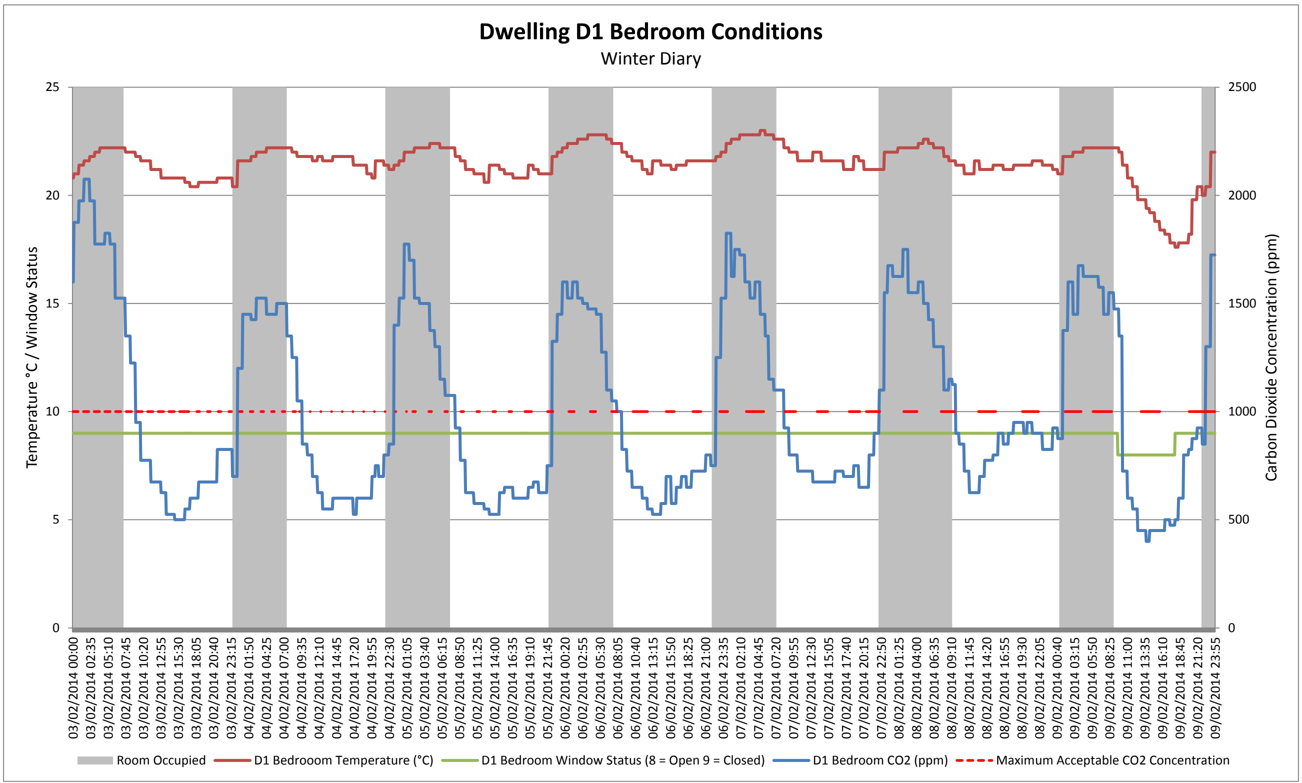


Figure 5:4: Plot of master bedroom environmental conditions against winter diary data for Dwelling D1.

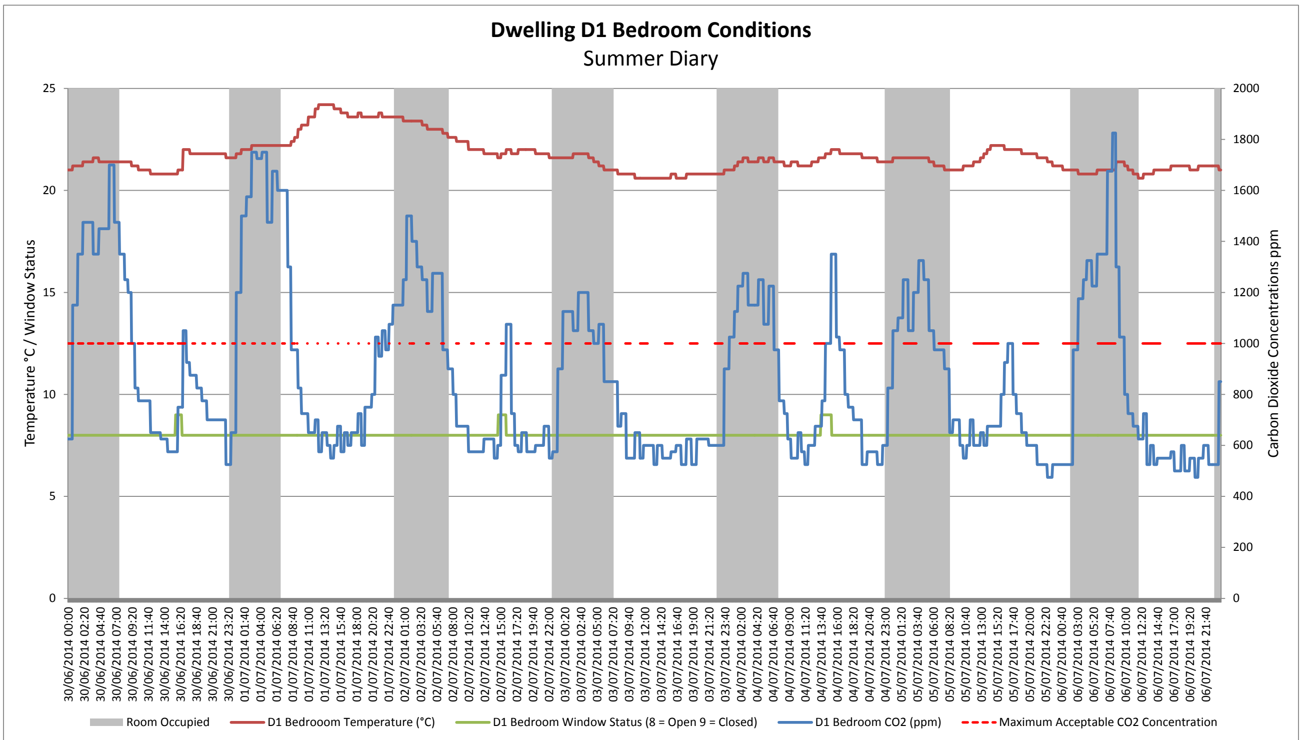


Figure 5:5: Plot of master bedroom environmental conditions against summer diary data for Dwelling D1.

5.4 Exit Interviews

Although not part of the BPE the research team undertook an exit interview with the participants on 11th and 12th September 2014 to obtain occupant feedback for the BPE project. This was to establish whether the various activities undertaken were disruptive and whether the BPE process was how they had imagined at the beginning.

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.

The interviews were conducted over the telephone, it was not possible to contact all of the participants and therefore this analysis is based on responses from four of the households that we were able to contact (copies of the interviews are located in Appendix L). Overall three out of the four surveyed found the process to have been straightforward and awarded a score of '5' for the project as a whole, one participant scored the BPE project a '2' because the project wasn't made clear at the start and there were far more visits made than anticipated. The breakdown of scores for individual process are illustrated in Figure 5:6. The scores 0-5 relate to how disruptive a task was considered, '0' represents very disruptive and '5' represents the task wasn't problematic. The chart indicates some occupants found the process less disruptive than others. Minor disruption was caused with the airtightness tests. DomEarm audit and the BUS questionnaires. While the installation of equipment scored low with two of the households. This was due to the requirement to be off work while this was being installed which was exacerbated by unexpected technical issues relating to an overloaded mobile telephone mast.

All respondents considered the equipment in use didn't cause them any problems. None of the occupants were keen on completing the diaries, as either they were unable to recall the information required each day or it was said to be causing tension in the household between the person completing the diary and the others living in the dwelling. The individual quick start guides scored lower than expected it was discovered the occupants found the content useful but they were provide too late and should have been provided when they moved into their homes.

Thermography (undertaken on two of the four properties) which was well received in other projects, scored well with one occupant it was poorer with the other. The poorer scoring household admitted while the survey was fascinating the timing of the survey was not convenient for them, due to the need to retire to bed early for an early start the following day (the occupant retired to bed while the survey was being undertaken and asked for the bedroom to be surveyed first). This same occupant scored U-value testing process low, it was this dwelling where equipment malfunctioned and a second measurement period was necessary to obtain results.

It was surprising that the occupant residing in dwelling D2 found the BPE project problematic, it transpired they hadn't realised that there would be as much contact as there was, they thought the equipment would be set up and then removed after the two year period. The occupant stated the various testing tasks and their time requirements were not clearly explained to them in the beginning. However, the occupants were friendly and welcoming to the research team.

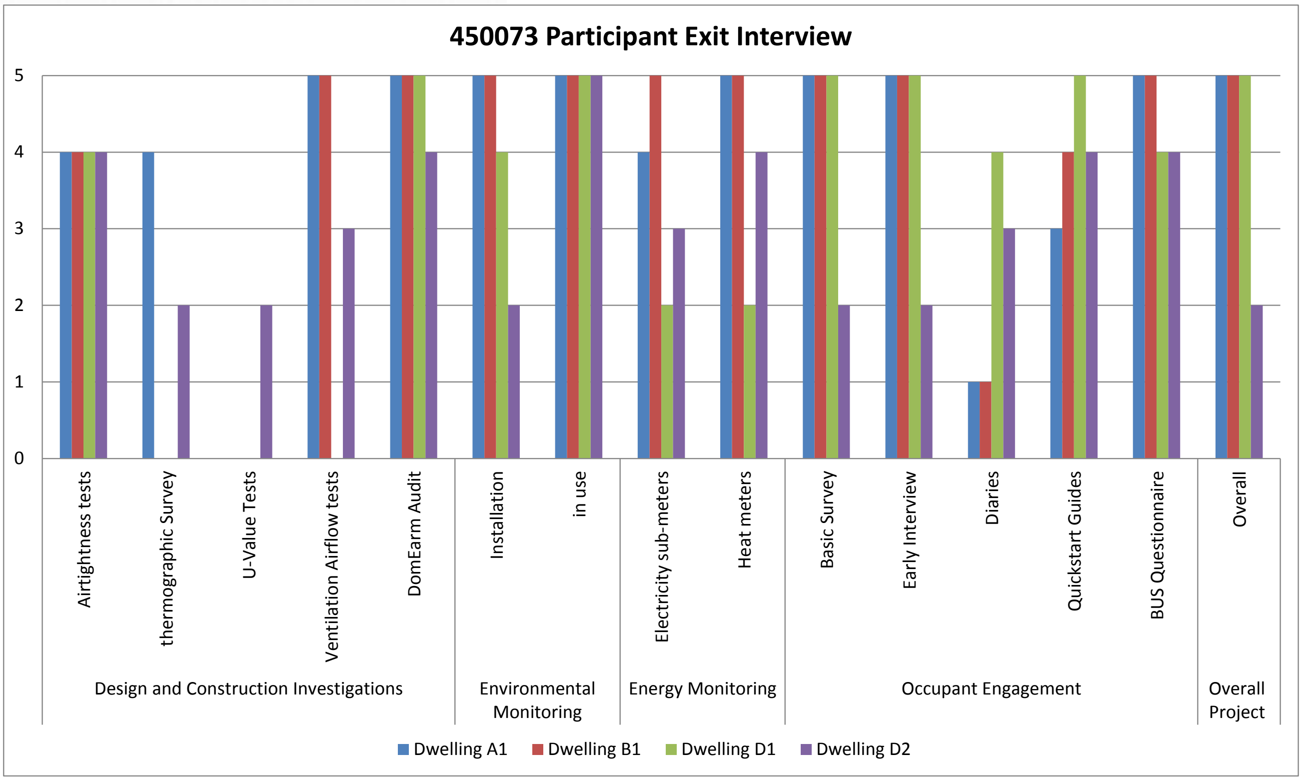


Figure 5:6: Results of occupant exit interview by task and overall.

When asked whether they had made any changes to the way they operate their dwellings as a result of the BPE project, three of the four respondents confirmed they had. The changes were as follows:

- Changed the way the domestic hot water is heated and the house is aired more often especially the bedrooms.
- Another started opening the bedroom window more often, interestingly the occupant stated that they did not feel it had made any difference. This bedroom was discussed in the winter/summer occupant diaries where there wasn't a discernible difference in internal conditions.
- The third household also reported more frequent opening of doors and windows, and stated they had noticed a positive difference.
- The aspects of the study the occupants reported they found particularly interesting or useful were:
- No sound proofing in the side of the house – the research team are not sure where the occupant had learned this as soundproofing in this house was not included or reviewed as part of the study.
- How much heating hot water costs using an electric immersion compared with gas boiler.
- Liked meeting the architect and learning about the original design concept and the changes that took place.
- Found the information on our electrical consumption interesting and the indoor air quality.
- Thermal imaging camera, it was interesting to find out the fridge/freezer helps to warm our bedroom and also learning about indoor air quality in our bedroom.

Two of the dwellings reported that their landlords engagement hadn't changed through the process, they had thought that the landlord would take more of an interest in the study. To conclude, the occupants were relatively satisfied with the overall BPE project and found they had learnt more about the operation of their homes. Although the contact with the occupants was tailored around the occupants working patterns, they would have preferred more consideration is made for those who are working as holidays needed to used to allow the initial set up. They were all unclear about what the project involved and would have welcomed more detailed information at the beginning with a timetable of events (however many of the tests are dependent on ideal weather conditions and therefore timetabling may not be realistic).

5.5 Conclusions and key findings for this section

The aim of this chapter was to evaluate occupant survey information gathered through the course of the BPE project. The initial occupant walkthrough was designed to capture the occupants' experiences in the handover process of their homes. This was undertaken through a semi-structured interview with a series of questions that aimed to understand the level of support each household received in moving into their homes and whether they heating and hot water was easy to control and affordable. None of the householders found the support on moving to be sufficient and felt that more handholding would have been beneficial. They had raised there are so many other issues to consider when moving home and taking in how to operate systems was difficult. The user manuals provided to the occupants were considered too technical and in one house type was incomplete. Most occupants learned how to operate their systems through trial and error and for many these homes were the first homes they had lived in that were connected to a gas supply or communal heating in the case of House Type D. The individual quick start guides developed as part of the BPE study were considered to have been handed to the occupants too long after moving in, although they were found to have been informative and better than the technical manuals provided.

While the occupants found their homes affordable to heat they all complained about the heating and hot water costs (from SAP) that were displayed to them as the real costs were considerably higher than the SAP costs. One occupant stated that they are seeking legal advice over this as they believe they were misled and that it is a trade description issue. The residents in House Type D remain unclear on how the costs are broken down for the communal biomass system and are keen to discover whether the heating through gas (first four years) was cheaper than through the wood pellets. Occupants in House Type C remain dissatisfied with the electric panel heaters and continue to use the wood burning stoves as their principal heating source, they would have welcomed a dedicated storage area for seasoning and storing their wood fuel.

The BUS survey was designed to capture and benchmark satisfaction levels of the complete development. For this particular site with 27 different house designs that are a mix of terrace, semi-detached, detached and flatted dwellings it made comparison very difficult to determine overall satisfaction levels. The occupants were satisfied with the area and the external appearance of the dwellings. The BUS survey indicated that noise issues to score well, when in reality they scored poorly.

Occupant diaries were undertaken on two separate occasions, these assisted in analysing data in fine grain data against occupancy and provided comfort for analysis of the environmental data reviewed in Chapter 7.

The exit interviews revealed that all occupants had found various aspects of the study beneficial however, they found the initial technical issues on equipment set up to have caused them inconvenience, this affected the researchers approach in organising tasks around the occupants and most visits were done in the evenings. One occupant was never won over and initially had withdrawn from contact with the researchers. This occupant moved out after a year of monitoring but became the landlord of the new tenant and reluctantly gave permission for the research team to contact the new occupant as they had expressed an interest in participating in the project.

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

6.1 Building Energy Related Systems

Following the omission of the proposed site wide district heating system, the design of the building services systems for each house type became contractor design. The main contractor sub-contracted this element of the design to a local building services company for 'design and build' of the systems. The exception to this process was House Type D which has a communal biomass (wood pellet) heating system, with back-up gas fired condensing boiler, providing heating and domestic hot water; this serves six dwellings and was designed by local consulting engineers. During interviews with the design and delivery team details surrounding building services system commissioning were vague. We were informed the building services sub-contractor that installed the building services had gone into receivership at a time that coincided with the commissioning of the building services systems. The delivery team inferred there were snagging issues with the building services systems that, owing to the situation, took some time to resolve. Despite attempts to identify the snagging issues, no specific details were divulged by the design and delivery teams. However, some occupants confirmed some snagging issues during occupant interviews.

Since 2010, Approved Document Part F in England mandates the inspection and testing of intermittent extract fans. There are no similar testing requirements in the Building (Scotland) Regulations for domestic extract systems. However as part of the study the testing of extract systems in each property was undertaken to determine extraction rates. The findings indicated deficiencies exist with the ventilation strategies used in the development which are characterised by frequent under-performance of mechanical extraction units. This makes a case for further investigation by the housing association and owner occupiers to ensure indoor air quality is not affected. Table 6.1 provides a summary of the measured extraction flow rates alongside Building Regulation minimum flow rate recommendations, these systems are described by House Type below. However, the results indicate three mechanical fans out eleven tested (27%) complied with Building Regulation recommendations. The testing also highlighted inconsistencies in flow rates in those dwellings installed with Passive Stack and Continuous Extract Systems as grilles were found not to activate or fan speed to boost on detection of increased humidity.

Dwelling	Fan Location	Extract System	Average Measured extract rate (l/s)	Design extract rate (l/s)	Pass/Fail Measurement test
A1	Kitchen	Extract Fan	25.6	60	Fail
	Utility	Extract Fan	29.4	30	Pass
	Shower	Extract Fan	7.5	15	Fail
	Bathroom	Extract Fan	7.5	15	Fail
A2	Kitchen	Extract Fan	34.5	60	Fail
	Utility	Extract Fan	31.9	30	Pass
	Shower	Extract Fan	3.7	15	Fail
	Bathroom	Extract Fan	4.6	15	Fail
B1	WC	Passive Stack	3.2	7	n/a
	Bathroom	Passive Stack	4.9	15	n/a
B2	WC	Passive Stack	5.2	7	n/a
	Bathroom	Passive Stack	4.0	15	n/a
	Kitchen	Extract over hob	62.6	30	Pass
C1	Kitchen	Continuous Extract (humidity activated boost)	5.8	60	n/a
	Bathroom	Continuous Extract (humidity activated boost)	7.3	15	n/a
C2	Kitchen	Continuous Extract (humidity activated boost)	8.5	60	n/a
	Bathroom	Continuous Extract (humidity activated boost)	5.9	15	n/a
D2	Kitchen	Extract Fan	26.1	60	Fail
	Bathroom	Extract Fan	6.9	15	Fail

Table 6:1: Air Flow Measurement of Extract Fans against Design Flow Rates recommended in the Building Regulations.

The building services systems, including ventilation, are described separately by House Type below.

House Type A

Heating System

The dwellings in this house type are fitted with individual gas-fired condensing combination boilers, these are sized to meet hot water requirements and are located in the respective utility rooms. The ground floor space heating is met with underfloor heating circuits and radiators are fitted for space heating to serve the first floor level. These two circuits operate using different water temperatures and one is considered to be a long lag system, therefore there are two programmers. One is located adjacent to the boiler, this allows the heating timer to be programmed for the first floor radiator circuit. The heating programmer for the underfloor heating is located in the hall. Underfloor heating system has separate zone (room) thermostats fixed to the walls in individual rooms. Thermostatic radiator valves (TRVs) are fitted to individual radiators on first floor, to provide individual control in each room.

<u>Domestic Hot Water</u>

The domestic hot water is heated by the boiler on demand.

<u>Ventilation</u>

The dwelling is naturally ventilated via opening windows located in each room and trickle vents at the head of the windows. Mechanical extract ventilation is provided in the ground floor shower room, kitchen, utility room and first floor bathroom, air is extracted to exhaust to outside. The fans are operated intermittently with manual control for the kitchen and utility rooms and light switch controlled in the bathroom and shower room.

The decorative surfaces on the walls and ceilings of the ground floor shower rooms in both dwellings were damaged, presumably as a result of high humidity. Occupant numbers in both households are high (six) and all occupants prefer to take showers, the project participants commented on the perceived poor performance of the extract fans. In Scotland the Building Regulations do not mandate flow measurement or a specific commissioning procedure for these type of mechanical fans. The shower room fans were flush mounted in the ceiling around two metres from the external wall where the exhaust point is situated. It was not possible to inspect the duct type and route as it was enclosed behind plasterboard. The fan was light switch controlled, and was found to have no run-on after use, the occupants informed us that as there is a window in the room they do not always use the light in the room due to sufficient daylight levels, therefore the fan is sometimes not operated when showering. The air flow rate was measured and found the fans to be extracting at 4.9 litres per second (l/s) and 3.7 l/s for dwelling A1 and A2 respectively. The Building Regulations recommend a minimum flow rate of 15 l/s. The underperformance of these instigated flow measurement for the remainder of extract fans in each dwelling. The findings are reported in a separate report located in Appendix M, however in summary of the four extract fans in each dwelling, only the utility room extract fans were extracting the recommended air flow rate.

Figure 6:1: Volume flow measuring equipment (without extension hood attachment) in ground floor bathroom in A2. Note extent of peeling decorative paint.

Figure 6:2: Replacement extract fan in ground floor shower room in dwelling A1.

The findings were reported to the Housing Association, with recommendations for investigation. The Housing Association was reactive to this and replaced the fan unit in one of the dwellings (access was being arranged for the second dwelling). The replacement unit was surface mounted, light switch controlled with a fan run-on of 20 minutes. The flow measurements made confirmed an extract air flow rate of 22 l/s. The occupant reported that the unit "*sounds* *like an aeroplane*" and because of the noise they now operate the fan using the isolator switch. This is located at high level outside the shower room, not all of the household occupants are able to reach the isolator and therefore the correct operation of the fan is doubted.

Lighting

The SAP assessment assumed 50% low energy lights to be fitted in each dwelling. The dwellings were fitted with a mix of 35 Watt (W) tungsten halogen spot lights, light fittings containing compact fluorescent light bulbs and fluorescent light tubes in the kitchen. The living room light fitting in dwelling A2 has been replaced with a fitting that requires three tungsten halogen lights.

Snagging

The occupants reported original snagging issues for the building services installations as faulty thermostats for underfloor heating system (still not resolved), leaking pipework, inadequate sealant around the shower tray, failure of lighting circuits and inadequate ventilation in ground floor bathrooms.

House Type B

Heating System

These dwellings are fitted with individual gas-fired condensing boilers, these are located in the kitchens. The boiler generates hot water to serve radiators with individual TRV controls. The boiler programmer is located adjacent to the boiler and permits operational times to be set for the space heating.

Domestic Hot Water

A single coil, domestic hot water tank is located in a cupboard off the first floor landing, its contents are heated by the boiler to a temperature dictated by the setting of the thermostat on the hot water tank. The tank is fitted with factory fitted insulation. A programmer, located adjacent to the boiler, allows pre-determined times to be programmed for hot water heating. The hot water tank is fitted with an electric immersion heater to allow water heating in the event of a boiler failure.

Ventilation

The dwelling is naturally ventilated via opening windows located in each room and trickle vents at the head of the windows and through wall mounted trickle vents. Mechanical extract ventilation is provided by manual control in the kitchen, this is an extract canopy over the hob which when operational exhausts outside of the dwelling. The ground floor WC and bathroom (first floor) are ventilated using passive stack ventilation. The grilles for the passive stack system are humidity activated.

A visual inspection of the passive stack extract system serving the ground floor WC and first floor bathroom in each dwelling was made. Grilles are wall mounted and were found to be moderately soiled, particularly in the first floor bathrooms where access for cleaning requires use of a step ladder. All but one grille was found in a partially open position and providing a contract extraction rate. Duct routes were not inspected due to being boxed in. Mould growth on tile grout and silicone sealant was identified in the bathroom of dwelling B2. Flow measurements indicated that this bathroom has lower extract rates than the neighbouring property. The roof mounted exhaust points on dwelling B2 are slightly sheltered from the wind by the neighbouring roof. This could affect extract performance in this bathroom. It is of concern available guidance states there is no requirement to test or commission passive stack systems as BRE studies have concluded a well-designed passive stack system could be ruined by poor installation.

Figure 6:3: Outlets of passive stack ventilation systems.

Figure 6:4: Typical inlet grilles of passive stack ventilation system, humidity activated. (WC in B2).

Lighting

The SAP assessment assumed 50% low energy lights to be fitted in each dwelling. Although more than 50% of light fittings remain low energy lighting lamp types in both houses have been changed. In dwelling B1 the replacement lamps are LED, while in dwelling B2 incandescent lamps have been used. Both households tend to use floor or table mounted lamps which are operated off the unregulated small power circuit.

Snagging

The systems have been reliable however the housing association have been called out to repair leaking uPVC guttering, faults with electrical circuits and to replace the handrails on the staircases in both dwellings.

House Type C

Heating System

These dwellings are heated with electric panel heaters fitted with integral thermostatic controls. The panels were installed in the living room, bedroom, bathroom and kitchen. A timer, located in a cupboard off the hall, enables the occupant to set the timer for operation of the radiators but this is not used. The dwellings are fitted with wood burning stoves, which provide a secondary form of space heating.

Domestic Hot Water

A single coil, domestic hot water tank is located in a cupboard off the hall, the tank is an unvented type and is fitted with factory fitted insulation. Cold water is heated in the tank by an electrical immersion element to the temperature dictated by the thermostat setting, located on the hot water tank.

Figure 6:5: Uninsulated pipework serving bathroom wash basin. Note inadequate sealing around pipe penetrations and also excess solder flux on pipe elbows, indicating poor workmanship.

Figure 6:6: Heating programmer at rear of cupboard housing domestic hot water tank out of view (dwelling C1), note items stored on top of the domestic hot water tank restricting access to the control panel.

<u>Ventilation</u>

The dwelling is naturally ventilated via opening windows located in each room (except bathroom) and trickle vents at the head of the windows and through wall mounted trickle vents. A ducted mechanical extract ventilation system serves the kitchen and bathroom, the unit is located in a service core and is accessible through an access hatch located in the bathroom. The system extracts continually in a trickle mode, and boosts flow rates in individual rooms on detection of raised humidity.

The bathrooms in this house type are internal and are reliant on the performance of the extract system for removal of excessive moisture from cooking and bathing. Bathroom grilles were relatively clean, while kitchen inlets, which were more difficult to access, were found to be soiled. The flow measurements were made in trickle mode as despite creating significant moisture production, through running of hot water, boiling the kettle in the vicinity of the grille and running the shower for 15 minutes, neither bathroom or kitchen grilles detected an increase in humidity and did not boost. The average flow rate for bathroom extracts operating in trickle mode was 7.3 l/s and 5.9 l/s in dwelling C1 and C2 respectively. Due to the absence of mould growth the conclusion was that the system was operating effectively in trickle mode. The residents have not commented any problems with moisture removal from the bathrooms.

Figure 6:7: Soiled extract inlet grille in kitchen, dwelling C1.

Figure 6:8: Flow measurement in kitchen, dwelling C1, access to grille above wall mounted cupboards with measurement apparatus was difficult.

Lighting
The SAP calculation assumed all light fittings would be fitted with low energy lamps. The fittings surveyed as part of the project indicated lamp types were a mix of 35 W tungsten halogen spot lights, incandescent lamps, compact fluorescent and LED. One occupier had commented he was informed before moving in that all the lighting would be LED however, there was one LED lamp, which was in the living room on moving in. There SAP calculation does not specifically highlight what lamps were to be installed.

Snagging
No specific building services snagging issues raised by the residents, however the focus for snagging issues for this house type had been on a resolution for improving acoustic separation issues.

House Type D

Heating System
All heat for this house type is generated by a communal biomass boiler located in an out-building adjacent to the main entrance of the building. Hot water is generated and stored in a buffer tank before being pumped through an insulated pipe network to heat exchange units in a hall cupboard in each property. The heat is metered and is fed to radiators with TRV control to provide space heating. A heating programmer, located in a cupboard off the hall, enables the occupant to set the timer for operation of the radiators.

Domestic Hot Water
The domestic hot water is supplied from the heat exchanger to draw off points (taps) on demand. There are no hot water storage tanks in this house type. However, the SAP calculation has stated a 110 litre insulated hot water cylinder.

Ventilation
The dwelling is naturally ventilated via opening windows located in each room and trickle vents at the head of the windows. Mechanical extract ventilation is provided in the kitchen and bathroom, where air is extracted and exhausts directly outside. The fans are operated intermittently with manual control for the kitchen and light switch control in the bathroom.

Air flow measurements were made for kitchen and bathroom extract fans in dwelling D2. The kitchen extract unit is located in a position away from the hob and is manually switched, the measurements of 26 l/s, 56% lower than the Building Regulation recommendation. The bathroom extract unit is light switch controlled and has been set with a run-on time of around two minutes. The average air flow rate of this unit was 6.9 l/s, 54% lower than the extract rate recommended in the Building Regulations. The occupants advised the daylight levels in this room were frequently sufficient to allow showering without switching the light on and they are unable to reach the handle to open the window. The bathroom trickle vent was found to be broken and airtightness testing indicated a significant amount of air leakage from this room, it is therefore the infiltration in this room which is helping to keep it mould free.

The occupants advised of their intention to read their owners handbook to establish if the run-on of the fan could be increased and to fit a replacement screw in the trickle vent.

Figure 6:9: Flow measurement testing in kitchen, dwelling D2. Note how the apparatus just fits.

Figure 6:10: Broken trickle vent in bathroom, dwelling D2.

Lighting

The SAP calculation assumed all fixed light fittings would be fitted with low energy lamps. An energy survey undertaken during the project revealed low energy lamps in bedroom ceiling fittings had been replaced with 60W incandescent lamps, in both dwellings. The occupants stated they do not use the living area ceiling lights often, except for the fluorescent tubes in the kitchen area, as they prefer to use floor and table mounted lamps.

Snagging

No specific issues reported by the occupants.

6.2 Lessons Learned

There were many lessons learned through the review of the installed building services, these include:

- From contractor interviews it became clear the energy efficiency ethos behind the project was not passed down from the main contractor to their sub-contractors. An inspection highlighted inadequately fitted pipe insulation, when fitted, and inadequate sealing around pipes and extract fans to reduce infiltration pathways.
- A lack of a statutory testing and commissioning procedures (in Scotland) for mechanical and passive stack ventilation systems were highlighted through extract flow measurements showing most of the mechanical fans to be underperforming, and kitchen extract fans were found to be undersized by 50% in all house types, except for House Type B.
- Some extract grilles were installed in locations that were not easily accessible to allow for cleaning without climbing ladders and these locations (as well as those fitted close to corners and window heads) proved difficult to access for taking flow measurements using a powered flow hood. There seems to be little thought around the physical location of grilles and diffusers.
- Extract fans in kitchens were not always used by occupants for extraction of moisture produced through cooking; the occupants' preference is to open windows rather than use a fan.

- Many occupants use local isolator switches to control bathroom extract fans. It was observed that extract fans in bathrooms are not operated if they are considered 'too noisy' and if daylight levels are sufficient artificial lighting is not used and therefore the fans are not operated.
- The humidity activated grilles were not activating on an increase of humidity, while these systems were operating in a trickle mode there is increased risk of condensation and mould growth issues in 'wet' rooms such as bathrooms.
- The roof mounted exhaust outlets for a passive stack ventilation system may have been installed in a sheltered position. Minor mould growth was observed in the bathroom of this dwelling.
- Ceiling light fittings and low energy light bulbs were replaced with more energy intensive lamps. Which has an impact on the 'regulated' lighting loads and perhaps the overall SAP energy performance prediction.
- Occupants in two House Types had communicated various (and on-going) issues with electrical installations, where socket outlets and lighting frequently fail.
- The hall ceiling in House Type D was lowered to accommodate heating pipework. High heat gains were observed from the boxed in pipework and the heat exchange unit in the cupboard.
- Households with electric heating do not use the programmer to set the heating, they consider electric heating to be expensive. This impacts internal space temperature and presents a risk to the occupants and building fabric (refer to Chapter 7 for details on internal environments).
- Domestic hot water cylinders are installed in cupboards where household items such as vacuum cleaners, ironing boards, clothes horses etc. are stored. The space is tight and pipework could easily become damaged. Some cupboards are overloaded where overflows and controls are not easily accessible.

6.3 Conclusions and recommendations for future homes

The project ethos for innovation and energy efficiency was not adequately communicated through the project. However, the heating, hot water and ventilation systems installed were varied for each house type but there were common themes emerging, such as lack of (or poorly fitted) pipework insulation and unsealed penetrations in the fabric, leading to an increase in infiltration pathways. It was of particular note that those dwellings fitted with domestic hot water tanks in hall/landing cupboards (House Type B and C) use these cupboards for storage of household items. Pipework installation within the cupboards serving the tanks is unsupported and is in locations where pipes could be knocked against and easily damaged. It appeared that adequate space provision was not allowed for installation, maintenance and storage of large household items such as ironing boards, vacuum cleaners and clothes horses. It should be that a dedicated airing cupboard is provided for domestic hot water tanks and the pipework and electrical controls are well designed prior to installation. More attention needs to be paid for installation of the building services.

All of the dwellings are naturally ventilated through opening windows and trickle vents with additional means of ventilation in kitchens and bathrooms. All households expressed their preference to ventilate the kitchens using the opening window, rather than the mechanical extract fans, mostly due to increased noise from these. However, in the bathrooms there were three different types of ventilation system in the four house types, it was noted that none of these were installed and performing adequately. This could in part be remedied by introduction of system commissioning and testing by an independent contractor and inspection by the Local Authority. However, if the

Building Regulation guidance is based on those adopted in England, it should be extended to include methods of control and include measurement of passive stack systems.

Most of the occupants forget to clean the extracts grilles on a regular basis, it was noted that most were cleaned prior to the research team arriving to undertake flow measurements. In House Type C there is a MEV unit behind a propriety access hatch, this assists in access to the unit, however, there was no access to the control box on the unit to switch it off (for airtightness testing). The unit also appears to be too large to be replaced through the access hatch provided and if needed to be removed the plasterboard will need to be cut. Wall mounted fans, in theory should be relatively straightforward to replace, however the ducted installations proved more difficult. A replacement bathroom fan in House Type A proved to be unsatisfactory to the occupant in terms of noise production and aesthetics, as a result the bathroom fan is not operated as intended.

Different trades should coordinate and be made more aware of issues arising from poor workmanship i.e. airtightness, dust inside ductwork, uncapped pipes, excess solder flux, poorly fitted pipe insulation etc. Their work on site should be actively and routinely inspected for quality by a trained professional such as an independent consulting engineer or clerk of works and condemned if necessary.

7 Monitoring methods and findings

The Scotland's Housing Expo consists of dwellings of varied design and construction. The monitored properties were from four different house types ranging from terraced housing, semi-detached housing and one and two bedroom flatted dwellings. Two dwellings, with similar occupancy profiles, from each of the house types were monitored. 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 dwellings in each house type.

7.1 Background

The monitoring of environmental conditions and metering of energy and water consumption of the eight houses in the study was developed 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. The equipment suppliers attended site on during July 2012 to survey the properties. A series of further discussions were made to refine the project requirements, and orders placed for a wireless data capture system with the capability to transmit data over GRPS (General Packet Radio Service) networks to a central off-site server. This method of data collection was considered better suited to domestic situations as sensor placement is less restrictive (no need for adjacent power sockets) and more robust (less risk of equipment being accidentally unplugged). The system also provided better security to reduce risk of data loss and the access requirements to each of the houses was reduced.

The data repository was accessed through a password protected web portal, which allowed online viewing of data and creation of graphical displays, data was also downloadable from the repository. The initial intention was to provide project participants with remote access to their data, following a pre-determined period, of around one year, with each household operating in a 'natural' pattern. However, it was later discovered that the external company (t-mac) were unable to permit access to individual households without charging a significant cost.

Equipment suppliers selected for this project were t-mac Technologies Ltd. (t-mac) for sub-metering and environmental monitoring and ORSIS UK Ltd. for metering of the households primary supplies. t-mac supplied a combined wireless solar powered temperature, relative humidity (RH) and carbon dioxide sensor (CO_2) as shown in Figure 7:1, these were used to monitor environmental conditions in selected rooms in each dwelling. This equipment was used in conjunction with solar powered door/window contact sensors (Figure 7:2) to monitor window opening patterns. All data was transmitted wirelessly to a central t-mac unit, which was hard-wired via a fused spur to a meter board (Figure 7:3). At the meter board up to six electrical sub-circuits were monitored via CT (current transformer) clamps, connected to the t-mac unit (Figure 7:3). Monitoring of hot water consumption was provided through pulsed output heat flow meters plumbed into hot water systems; these transmitted data to the central t-mac unit. A weather station was fitted with t-mac logging equipment (Figure 7:4) and secured in the rear garden of one of the monitored dwellings.

Metering and monitoring

5 minute meter reading intervals

House Type	Utilities	Sub-metering	Environment
A - 4-bed house	Gas Electricity Mains Water	Cooker Kitchen Sockets Downstairs Sockets Upstairs Sockets Downstairs Lighting Upstairs Lighting	Living Room Bedroom Bedroom
B - 3-bed house	Gas Electricity Mains Water	Cooker Kitchen Sockets Downstairs Sockets Upstairs Sockets Downstairs Lighting Upstairs Lighting Immersion Heater	Living Room Bedroom Bedroom
C - 1-bed flat	Electricity Mains Water	Cooker Kitchen Sockets Other Sockets Lighting Electric Heating Electric Shower Pilot	Living Room Kitchen Bedroom
D - 2-bed flat	Electricity Mains Water	Cooker Kitchen Sockets Other Sockets Lighting Communal Heating Controls	Living Room/Kitchen Sunspace Bedroom

Table 7:1: Metering and monitoring by house type.

ORSIS provided data capture from existing gas and electricity fiscal meters. New water meters were installed on the incoming cold water main to allow water consumption to be monitored (water meters in Scotland are currently not installed in domestic dwellings as water metering is not a requirement of the domestic Building (Scotland) Regulations and water charges are made in the Council Tax for each dwelling). Data from each of these meters was collected wirelessly and transmitted to the ORSIS data portal, from here the data was streamed to the t-mac repository.

Equipment was delivered to site week commencing 27 August 2012 and installation commenced that week, further commissioning and testing was carried out during September 2012. Table 7:1 details the monitoring and metering equipment installed in each dwelling.

Figure 7:1: Combined temperature, relative humidity and CO_2 sensor.

Figure 7:2: Window contact sensor.

Figure 7:3: CT clamps on consumer unit (middle) and central t-mac unit (top left). Electrical Orsis meter top right of image.

Figure 7:4: Weather station installed in rear garden of one of the monitored dwellings.

7.2 Equipment Issues

Over the course of monitoring there were several issues with the operation of the equipment, these included:

- Due to the remote nature of the site, mobile telephone signal was found to be weak and some of the houses were unable to log to the remote portal. An electrical booster was installed in each dwelling to boost the signal to the central t-mac unit. In addition to this, it emerged the local mobile telephone mast was overloaded; this was upgraded and a more reliable network provider serving the rural area was sourced. This provided a solution for a period of around one year with few interruptions. However some of the issues emerged while examining the data. A brief summary of the type of issues follows:

- Communication with the on-site external weather station was lost in July 2013. Despite several attempts to restore connectivity the signal was never restored.
- Data collection for some of the dwellings was sporadic and equipment in some dwellings did not log for extended periods. In the case of dwelling B2 the gas meter battery failed, this was eventually identified and the battery replaced. There were no low battery warnings and raises questions for the longevity of batteries in meters for long term monitoring. Data collection in House Type C was sporadic throughout.
- It transpired that t-mac had not connected heat meter sensors to cold water pipework, these were left loose in the cupboard. This affects the heat metering calculation as the air temperature in the cupboard is warmer than the incoming cold water.
- Window opening sensors had been removed and/or damaged in some dwellings.
- There were issues with validity of readings from CO_2 sensors, readings were unrealistically low and the level of accuracy queried with t-mac. t-mac have been unable to respond to this query and are consulting the sensor manufacturer.
- The research team discovered an issue with monitoring the specific energy consumption on a sub-metered circuit. It emerged that t-mac had installed 100 Amp CTs which are oversized for domestic consumption. This means that the sub-metered data is not accurate but can provide an indication of electrical usage in each dwelling.

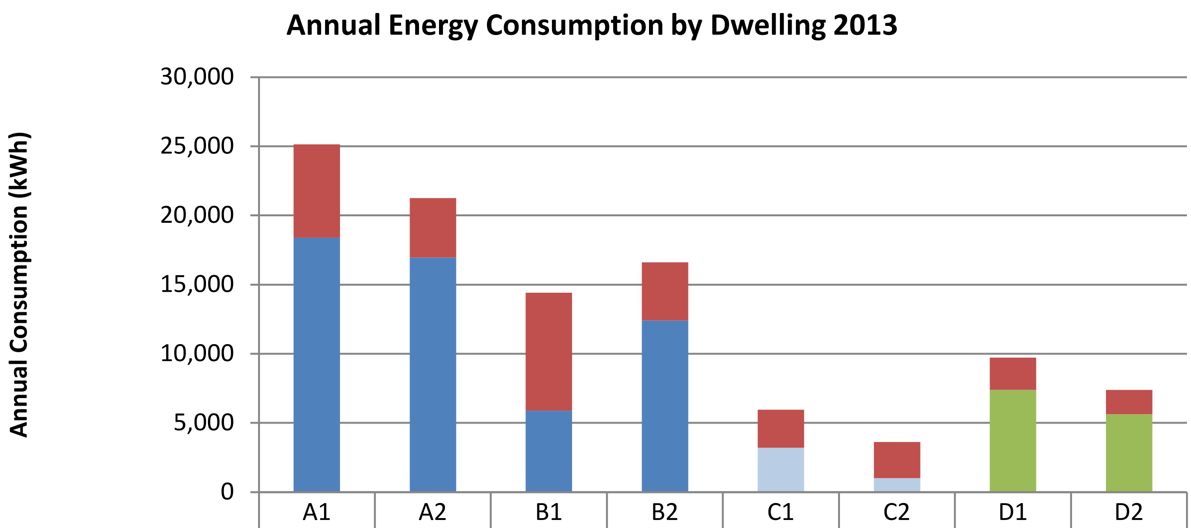
7.3 Energy Summary

The site is connected to mains gas and electricity. All of the monitored dwellings are connected to the mains electricity grid via a meter; none of the dwellings have on-site renewable energy generation for electricity. Four out of the eight dwellings are connected to mains gas for heating and hot water demand, two dwellings are heated using electrical radiators and their hot water is electrically heated. The heating and hot water demand for the remaining two dwellings is supplied via a heat exchanger linked to a communal biomass wood pellet system. Each of these systems are described in more detail in Chapter 6 however are summarised by house type in Table 7:2.

House Type	Electricity	Heating	Hot Water
A - 4-bed house	Grid connected	Gas-fired condensing combination boiler serving underfloor heating (ground floor) and radiators (first floor).	Gas-fired condensing combination boiler generating hot water on demand.
B - 3-bed house	Grid connected	Gas-fired condensing system boiler serving radiators.	Gas-fired condensing system boiler heating water for storage in a hot water cylinder.
C - 1-bed flat	Grid connected	Electrical panel heaters. A wood-burning stove (located in the living rooms) provides a secondary heat source.	Electrical immersion heating water for storage in a hot water cylinder.
D - 2-bed flat	Grid connected	Communal biomass boiler with buffer tank serving heat exchange units in each property.	Communal biomass boiler with buffer store serving heat exchange units domestic hot water on demand. Back-up provision is made via gas-fired condensing system boiler.

Table 7:2: Energy summary by house type.

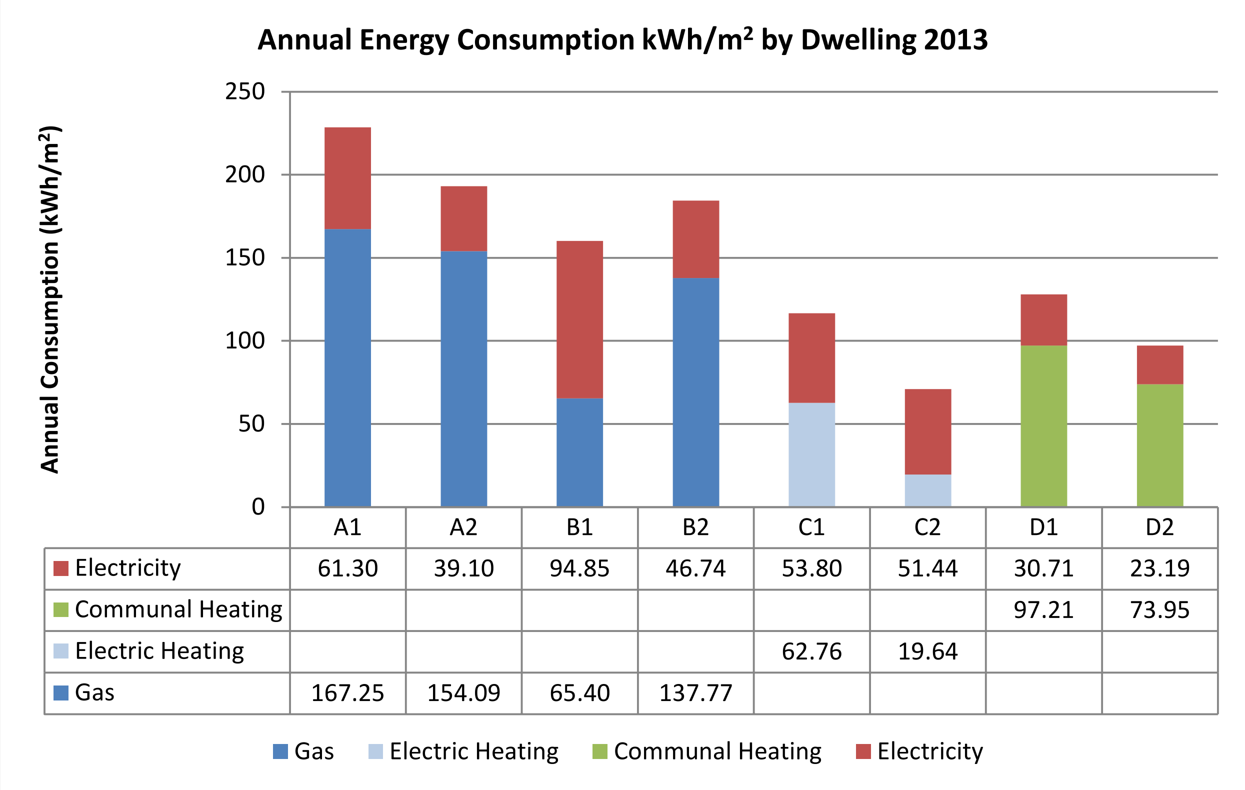
Due to initial technical problems (described in section 7.2) the monitoring for some of the dwellings commenced later than anticipated, it was therefore not possible to collect two full years of data for each dwelling type. With this in mind, the annual energy consumption presented in Figure 7:5 reflects the actual consumption from 1st January to 31st December 2013. The chart illustrates slight consumption variations between the pairs of dwellings and illustrates distinct consumption differences between each House Type (discussed separately). What is noticeable is the overall annual measured energy consumption increases as floor area and number of bedrooms in each house type increases. It is recognised energy consumption varies depending on a range of factors including house type, heat loss parameters, airtightness and orientation as well as other factors such as occupancy patterns, number of occupants, user behaviour and energy efficiency of appliances. These factors make it difficult to compare the energy demand in each of the eight dwellings, therefore annual energy consumption is compared in dwellings per unit of floor area in kWh/m^2 as illustrated in Figure 7:6. These charts illustrate dwelling B1 to have the highest total electrical consumption and consumption by floor area due to misunderstanding the hot water heating. Per unit of floor area the one-bedroom flats of house type C use significant amounts of electricity per floor area. Consumption for the pairs of dwellings is discussed later.



	A1	A2	B1	B2	C1	C2	D1	D2
Electricity	6743	4301	8536	4207	2744	2623	2334	1762
Communal Heating							7388	5620
Electric Heating					3201	1001		
Gas	18397	16950	5886	12400				

Gas | Electric Heating | Communal Heating | Electricity

Figure 7:5: Annual Energy Consumption by Dwelling 2013.



	A1	A2	B1	B2	C1	C2	D1	D2
Electricity	61.30	39.10	94.85	46.74	53.80	51.44	30.71	23.19
Communal Heating							97.21	73.95
Electric Heating					62.76	19.64		
Gas	167.25	154.09	65.40	137.77				

Figure 7:6: Annual Energy Consumption kWh/m^2 by Dwelling 2013.

The annual consumption reviewed concentrates on both 'regulated' and 'unregulated' energy consumption, as termed by the Building Regulations. Regulated consumption refers to energy consumed for space heating, hot water, lighting and fans and pumps, while unregulated consumption refers to all other energy users in a home that the occupants typically plug in.

As noted in Chapter 2, the Standard Assessment Procedure (SAP) is the Governments methodology for comparison of energy and environmental performance of dwellings. The assessment focuses on regulated loads and assumes standard occupancy patterns to provide an estimate of the energy consumption of a dwelling. Figure 7:7 plots carbon dioxide emissions for regulated energy for actual consumption and compares this against those in the SAP predictions. (Individual breakdown for each dwelling is discussed in section 2.3.) This indicates with the exception of one property, C2, the actual CO_2 emissions are greater than the predictive tool. In dwelling C2 we are aware of the use of a secondary heat source (wood burning stove) but are unable to quantify the amount of fuel used. However assuming the wood fuel is sustainably sourced the carbon emission factors are low and would not make significant difference to the overall dwelling emissions.

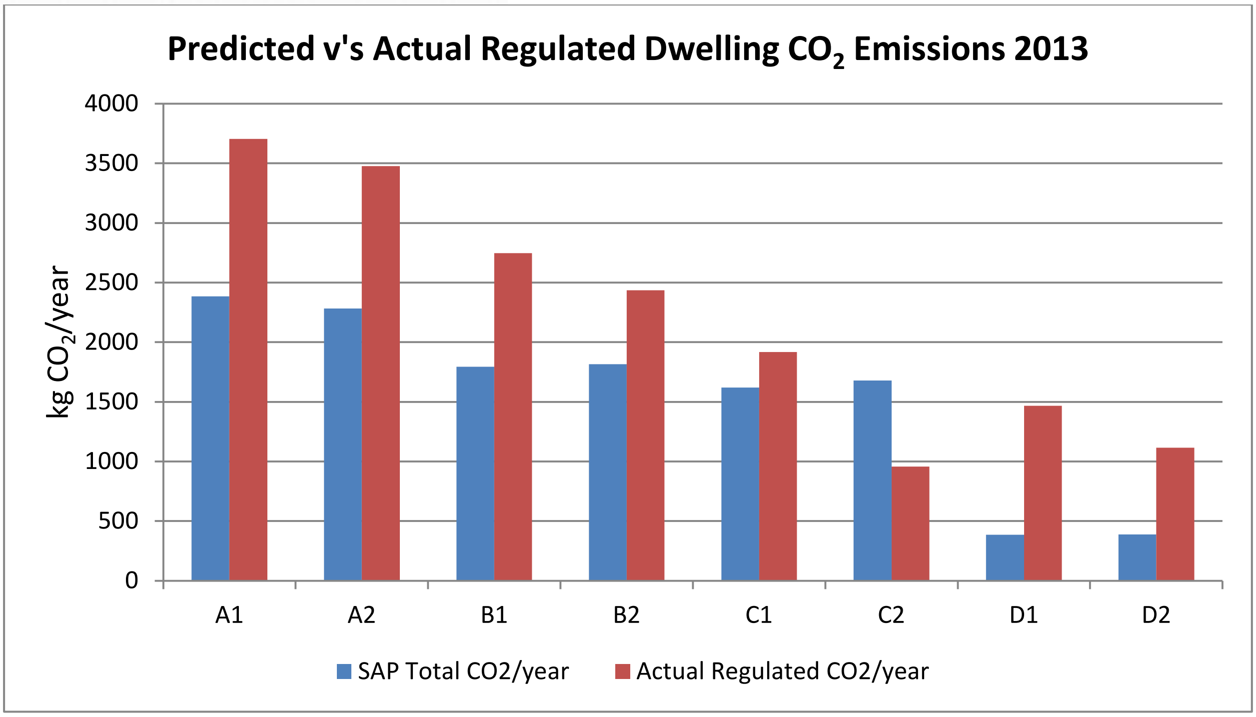


Figure 7:7: SAP predicted v's Actual Dwelling CO_2 emissions 2013.

A mandatory element of the project was for undertaking a DomEARM (Domestic Energy Audit and Reporting Method) survey. The survey work was carried out by MEARU staff in September 2013 for six units and January 2014 for the remaining two dwellings. The process involves an audit of every item drawing electricity in the home, from regulated use such as immersion heaters and lights to non-regulated use such as washing machines, kettles, TVs and mobile phone chargers. This information is fed into a standard spread sheet (provided by TSB) which takes – in this case – accurately monitored energy consumption and derives graphical indications of the actual consumption of the dwelling compared to typical and best practice consumption in the UK. The resultant outputs are included in Appendix N.

The DomEarm is discussed by dwelling below however overall most of the dwellings consumption is around the Part L Compliant benchmark prediction. Dwelling B1 and C1 were both found to have high electrical consumption for incorrect understanding of boiler operation in B1 and electrical heating in C1. Overall dwelling D1 appeared to be the dwelling that exceeded benchmark data but it was noted that the occupants have few electrical items outside of the kitchen (which is unusual) and they are unable to operate all of their heat emitters simultaneously.

However, it is of note is that the benchmark figures are based on idealised, rather than actual measured data. Thus the Part L compliant is based on a calculated consumption (rather than benchmarks of actual consumption of Part L houses). Additionally the benchmark data used in DomEARM relates to English dwellings and is not specific to Scotland where it is significantly colder and a large proportion of the dwellings are older stone housing stock and are rural.

House Type A

Comparison of the annual energy consumption of the two House Type A dwellings, Figure 7:8 indicates total energy consumption in dwelling A1 to be greater than the neighbouring property A2 for both gas and electrical energy consumption during 2013. Both dwellings have similar occupant numbers and occupancy patterns and therefore it is likely that the increase in dwelling A1's gas consumption could be as a result of its end of terrace position, the high set point of the broken living room heating thermostat or a combination of both. Figure 7:8 represents two years energy consumption for both dwellings and is plotted against four current UK benchmark data sets for domestic energy consumption. The data indicates gas consumption in the dwellings to compare well with the benchmark for Building Regulation Compliant dwelling, however electrical consumption of both dwellings is higher than the UK benchmark. Figure 7:9 illustrates gas consumption profile of both dwellings and indicates the occupants of dwelling A1 have reduced their summer time gas consumption and appear to have altered their habits in year 2 of monitoring, compared to the previous year. The consumption pattern in dwelling A2 indicates a decline in gas usage during the summer which is presumably a result of the reduced requirement for space heating, due to warmer external temperatures. It is clear that dwelling A2 usually consumes slightly higher quantities of gas than dwelling A1 during the heating season, however, now dwelling A1 appears to be adjusting their space heating seasonally their gas consumption for 2014 is likely to be lower than the neighbour.

Electrical consumption for a two year period for both dwellings is plotted in Figure 7:10, this indicates consumption in dwelling A1 to consistently be higher than A2 through the monitoring period. The sub-metering of both dwellings revealed dwelling A1 (Figure 7:11) to consume significantly more electrical energy on their cooker, kitchen and downstairs sockets. In dwelling A1 there was a significant reduction in monthly consumption for the downstairs sockets from August 2013, where the mean 12 month value for year 1 was 165kWh, compared with 115kWh mean during year 2, the reason for this reduction is unclear. From February 2013 there is also a large increase in kitchen socket consumption and continues unit May 2014. This coincides with the wet summer of 2013 and 2014 winter period. It appears the consumption on this circuit reduces considerably with weather improvements and therefore it is supposed the rise in kitchen socket consumption is linked with tumble dryer use.

Lighting consumption is taken into account within the SAP assessment as a regulated load and consumption is low in comparison to other circuits (unregulated loads) within the dwelling. A review of the lighting indicates dwelling A2 (Figure 7:12) to be the greater consumer, particularly on the ground floor. It is of note that, in dwelling A2, the ceiling pendant, with energy efficient light bulb, has been replaced with fitting containing three tungsten halogen lamps. The neighbouring dwelling has maintained the original pendant and low energy compact fluorescent bulb.

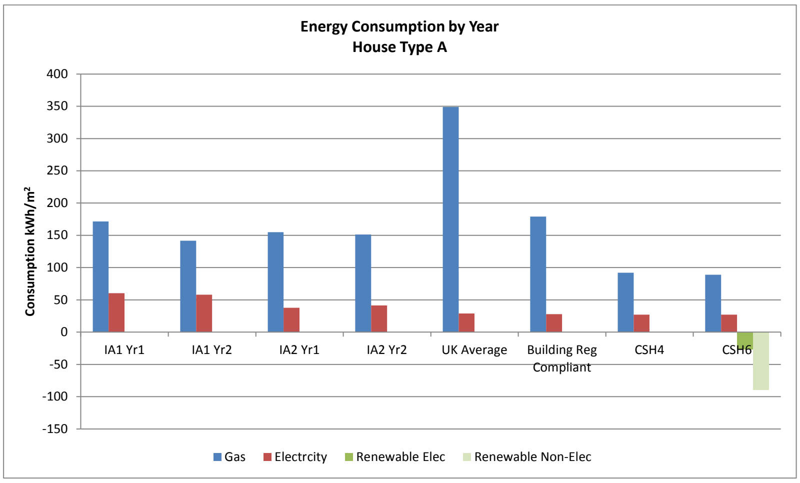


Figure 7:8: Gas and electrical energy consumption of two dwellings in house type A for two years.

This indicates the gas consumption in dwelling A1 has reduced in year 2, while gas and electrical energy consumed in A2 remained relatively constant. For gas usage both dwellings are around the Building Regulation Compliant benchmark, both have increased electrical consumption compared to standard benchmarks.

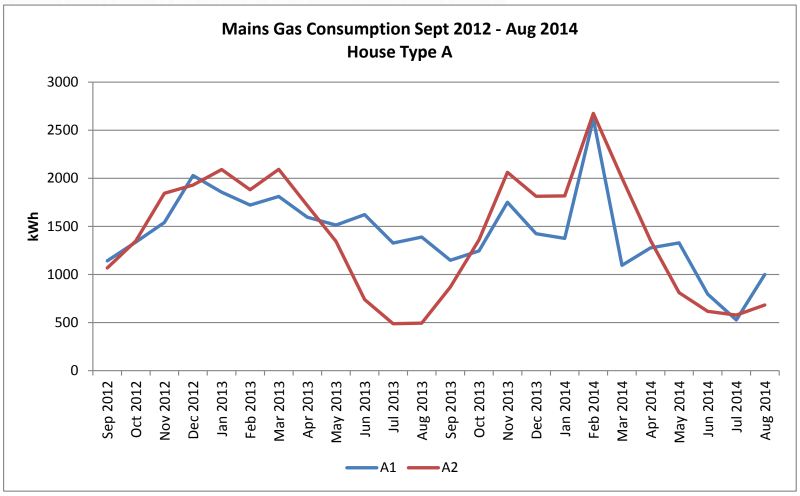


Figure 7:9: Gas consumption for two monitored dwellings in House Type A.

A clear summer/winter pattern of useage is noticeable in dwelling A2 while this pattern emerges in the second year of monitoring for dwelling A1.

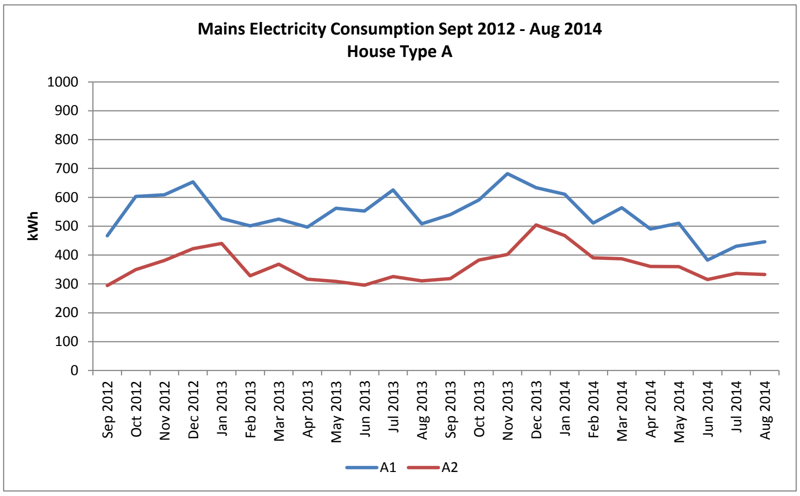


Figure 7:10: Electrical consumption for two monitored dwellings in House Type A.

The data indicates dwelling A1 maintains a higher average consumption of 37% in year 1 reducing to 28% in year 2.

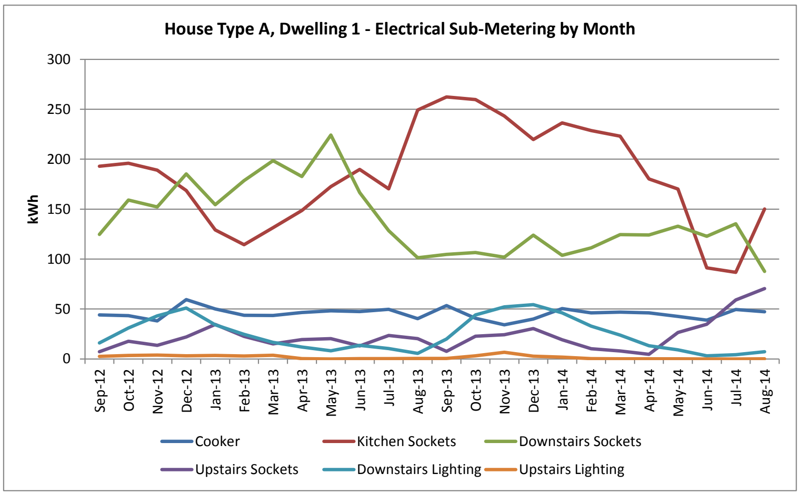


Figure 7:11: Electrical consumption by sub-circuit for two years in dwelling A1.

This indicates the downstairs and kitchen sockets are the greatest electrical consumers in this dwelling. Energy for cooker remains almost constant however a summer/winter pattern is identified in the downstairs lighting circuit.

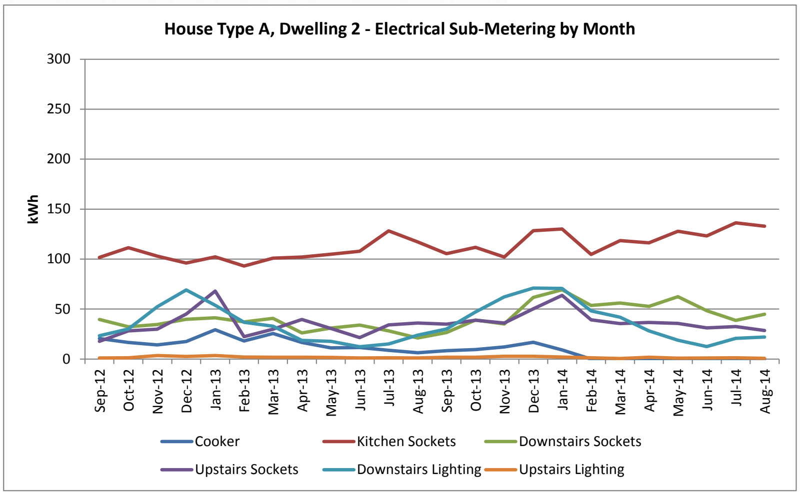


Figure 7:12: Electrical consimption by sub-circuit for two years in dwelling A2.

The data indicates the kitchen sockets to consume the highest energy consumption. clear summer/winter usage pattern is identified in the upstairs sockets and downstairs lighting. However this may be indicated of the special needs of the family.

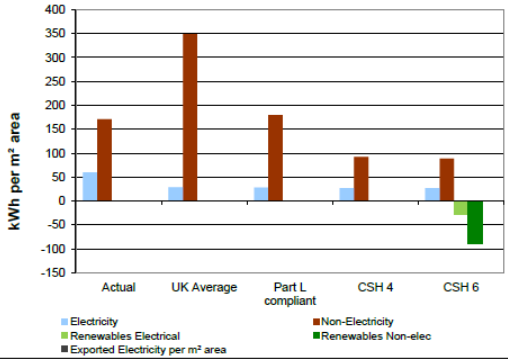
DomEarm

Select basis for results: 1

Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kWh per m² area	60	29	28	27	27
% Difference between actual and benchmark		+105%	+114%	+124%	+124%
Non-electricity kWh per m² area	172	349	179	92	89
% Difference between actual and benchmark		-51%	-4%	+86%	+93%
Renewable Electrical kWh per m² area	0	0	0	0	27
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non-Elec kWh per m² area	0	0	0	0	89
% Difference between actual and benchmark		NA	NA	NA	-100%
Exported Electricity per m² area	0	0	0	0	0



***Annual Emissions compared with benchmarks**

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kgCO2 per m² area	31	15	15	14	14
% Difference between actual and benchmark		+105%	+114%	+124%	+124%
Non-electricity kgCO2 per m² area	34	69	36	18	18
% Difference between actual and benchmark		-51%	-4%	+86%	+93%
Renewable Electrical kgCO2 per m² area	0	0	0	0	14
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non Elec kgCO2 per m² area	0	0	0	0	18
% Difference between actual and benchmark		NA	NA	NA	-100%
Balance kgCO2 per m² area	65	84	50	32	0

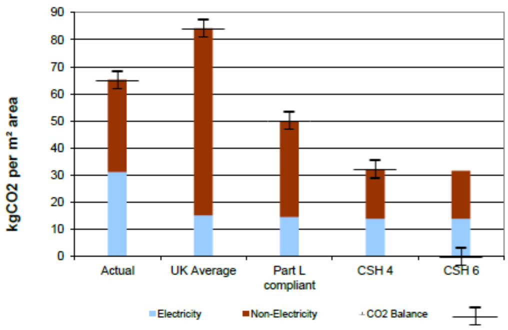


Figure 7:13: DomEARM results output dwelling A1.

The DomEARM survey for dwellling A1 (Figure 7:13) indicates this dwelling is performing above the benchmark data for electrcity and has correspondly high annual emissions ($kgCO_2/m^2$) which are more than 100% greater than the benchmark data. In respect to the gas consumption the DomEARM indicated gas consumption is greater than the Code for Sustainable Homes benchmarks (although this assessment is not applicable in Scotland) and is lowere than the UK average and is similar to the predicted benchmark for a Part L Compliant home.

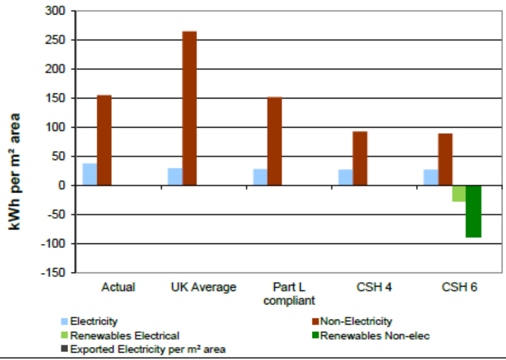
Consumption in neighbouring dwelling A2 (Figure 7:14) are lower however the electrical consumption remains greater than the UK benchmark data. As with dwelling A1 the gas consumption is lower than the UK average significantly above the English Code for Sustainable Homes benchmark but similar to Part L Compliant benchmark data.

Select basis for results: 1

Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kWh per m² area	38	29	28	27	27
% Difference between actual and benchmark		+28%	+34%	+40%	+40%
Non-electricity kWh per m² area	155	265	152	92	89
% Difference between actual and benchmark		-41%	+2%	+68%	+75%
Renewable Electrical kWh per m² area	0	0	0	0	27
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non-Elec kWh per m² area	0	0	0	0	89
% Difference between actual and benchmark		NA	NA	NA	-100%
Exported Electricity per m² area	0	0	0	0	0



*Annual Emissions compared with benchmarks**

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kgCO2 per m² area	20	15	15	14	14
% Difference between actual and benchmark		+28%	+34%	+40%	+40%
Non-electricity kgCO2 per m² area	31	52	30	18	18
% Difference between actual and benchmark		-41%	+2%	+68%	+75%
Renewable Electrical kgCO2 per m² area	0	0	0	0	14
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non Elec kgCO2 per m² area	0	0	0	0	18
% Difference between actual and benchmark		NA	NA	NA	-100%
Balance kgCO2 per m² area	50	68	45	32	0

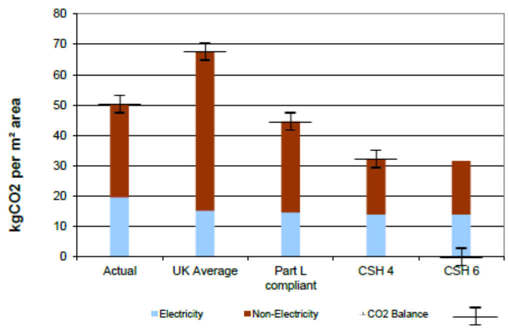


Figure 7:14: DomEARM results output dwelling A2.

House Type B

During 2013 the number of occupants was similar in both households with differing occupancy patterns. In B1 there is a home worker as a result the dwelling is normally occupied for extended periods. With differing occupancy patterns in mind the overall lower energy consumption (Figure 7:5) in dwelling B1 is therefore surprising. However, electrical consumption dwelling B1 is very high in comparison to its neighbouring dwelling and the remainder of the dwellings in this BPE study. In dwelling B1 Figure 7:15 indicates the gas consumption to have increased and electrical energy consumption reduced in year 2. The gas consumed in dwelling B2 indicates a large reduction in year 2 consumption compared with year 1. In Figure 7:16 the change in dwelling B1's gas consumption is identified due to observation of summer demand by comparing 2013 with 2014. This increase during summer 2014 is linked to the occupants using the gas boiler for hot water heating. In dwelling B2 the chart illustrates high peaks followed by a drop to zero consumption in March 2014. This was due to the failure of the battery in the monitoring equipment.

The comparative electrical consumption for two years plotted in Figure 7:17 indicates the dramatic decrease in dwelling B1's electrical consumption. This is linked to the occupants' previous habit for heating hot water with the electrical immersion, instead of setting the gas boiler to do this. During the occupant feedback session at the end of January 2014 this was highlighted to the occupant who informed the research team her water heating habit was formed after being told by a plumber (who visited the house) using the immersion was the cheapest and best way of heating the hot water. However, both Figure 7:17 and Figure 7:18 illustrate the significant drop in electrical energy immediately after the feedback session with the research team. What is interesting is the occupant continues to use the immersion sporadically for heating hot water. The other higher electrical consumers in dwelling B1 are the kitchen and ground floor sockets closely followed by the upstairs sockets. Figure 7:19 illustrates consumption of the sub-circuits in the neighbouring property B2 where the downstairs sockets are continually the highest consumer followed by kitchen sockets, upstairs sockets, the cooker, downstairs lighting and upstairs lighting.

Both these dwellings have occupants in their teenage years that frequently use computer equipment, stereos and games consoles these devices are contributing to the electrical load. The consumption monitored for the two lighting sub-circuits indicate these are the lowest consuming electrical circuits in both dwellings, these are the regulated loads.

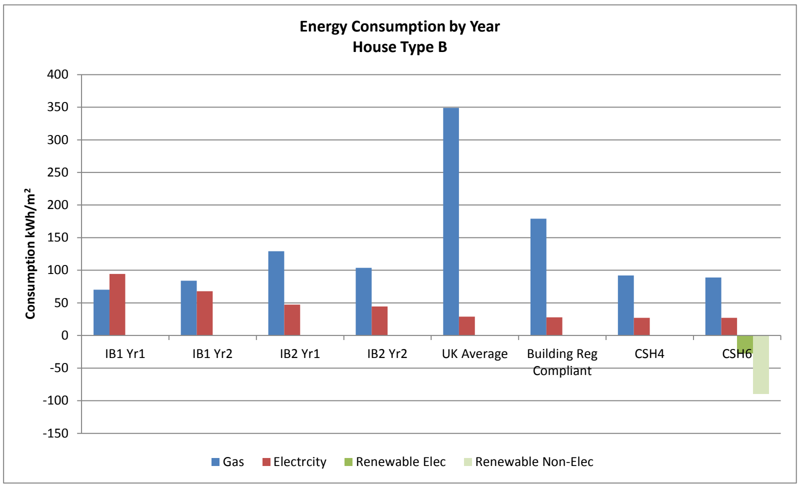


Figure 7:15: Gas and electrical energy consumption of two dwellings in house type B for two years.

This indicates the gas consumption in dwelling B1 has increased slightly during year 2 and B2 has reduced . Both dwellings fall below the Building Regulation Compliant benchmark and dwelling B1 is comparable to the code for sustainable homes benchmark figures. Electrical consumption in both dwellings is higher than the current benchmarks.

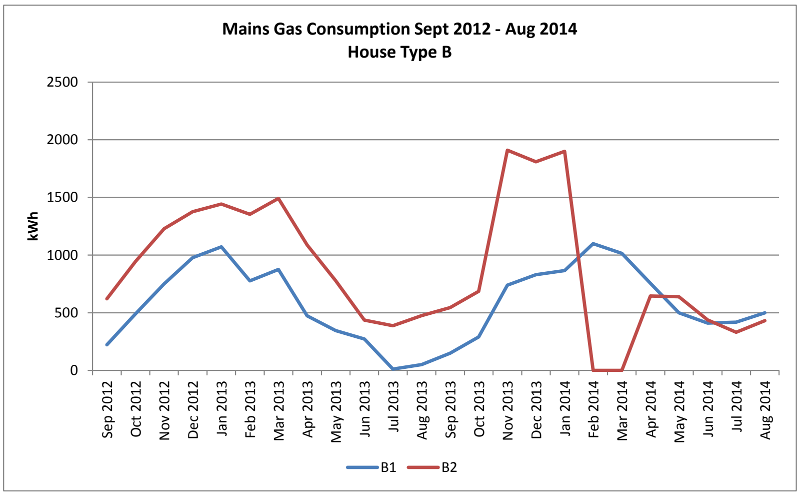


Figure 7:16: Two years gas consumption for two monitored dwellings in House Type B.

There is a clear summer/winter pattern of useage in both dwellings, however year two data for dwelling B2 is erroneaous due to battery failure around November 2013, battery was replaced during March 2014 once the fault was detected.

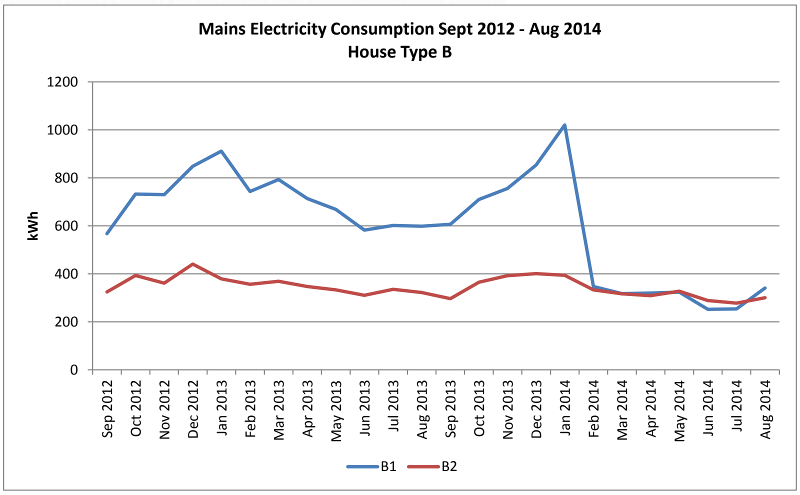


Figure 7:17: Electrical consumption for two monitored dwellings in House Type B.

The data indicates a near constatant electrical demand for house B2. However the electrical consumption for dwelling B1 has reduced significantly due to the reduction in heating hot water with the immersion.

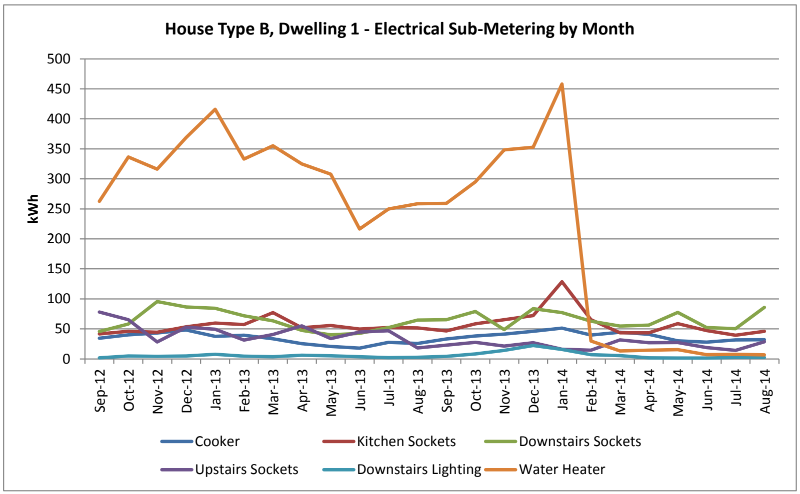


Figure 7:18: Electrical consumption by sub-circuit for two years in dwelling B1.

The chart clearly illutrates the time when the electrical heating of hot water ceased. The downstairs, kitchen and upstairs sockets are used most frequently and the cooker consumption drops during the warmer months.

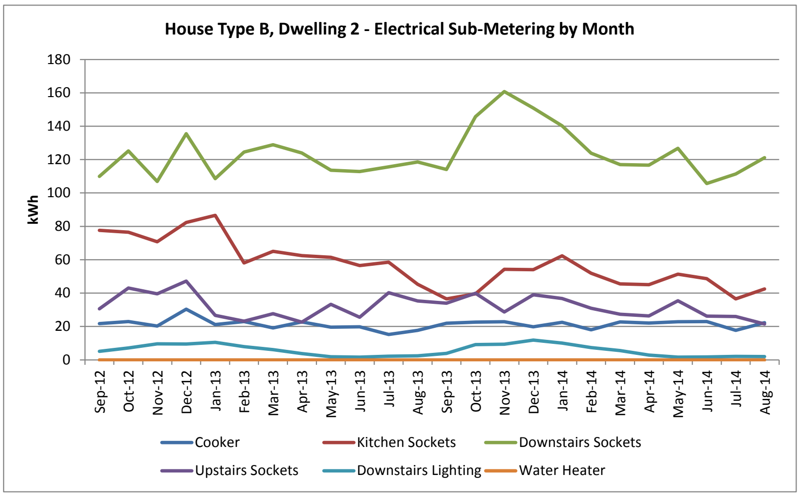


Figure 7:19: Electrical consimption by sub-circuit for two years in dwelling B2.

The data indicates the downstairs sockets to be the highest energy consumer in the dwelling. There is a distinct consumption hierachy in this dwelling with the regulated lighting consumption showing clear summer/winter patterns with low consumption. The electric immersion for water heatering has not been used in this dwelling over a two year period.

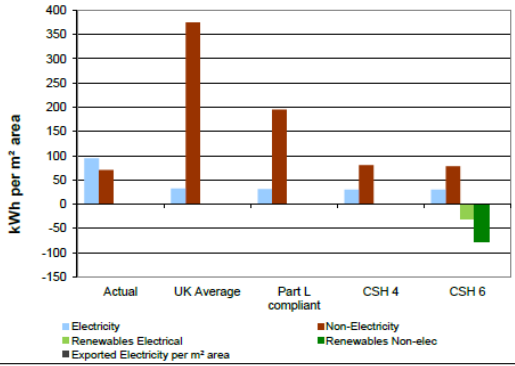
DomEarm

Select basis for results: per m² area

Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kWh per m² area	94	32	31	30	30
% Difference between actual and benchmark		+192%	+203%	+216%	+216%
Non-electricity kWh per m² area	70	375	195	81	78
% Difference between actual and benchmark		-81%	-64%	-13%	-10%
Renewable Electrical kWh per m² area	0	0	0	0	30
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non-Elec kWh per m² area	0	0	0	0	78
% Difference between actual and benchmark		NA	NA	NA	-100%
Exported Electricity per m² area	0	0	0	0	0



*Annual Emissions compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kgCO2 per m² area	49	17	16	15	15
% Difference between actual and benchmark		+192%	+203%	+216%	+216%
Non-electricity kgCO2 per m² area	14	74	39	16	16
% Difference between actual and benchmark		-81%	-64%	-13%	-10%
Renewable Electrical kgCO2 per m² area	0	0	0	0	15
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non Elec kgCO2 per m² area	0	0	0	0	16
% Difference between actual and benchmark		NA	NA	NA	-100%
Balance kgCO2 per m² area	63	91	55	31	0

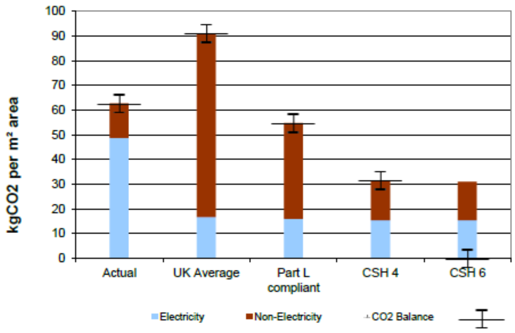


Figure 7:20: DomEARM results output dwelling B1.

In dwelling B1 (Figure 7:20) the electrical consumption was found to be significantly higher than all benchmark data used in DomEARM, while the gas consumption was lower than the benchmark data. It was later discovered while reviewing sub-metered data that the dwelling occupants were heating their domestic hot water using the electrical immersion heater, which has also impacted the overall annual dwelling emissions.

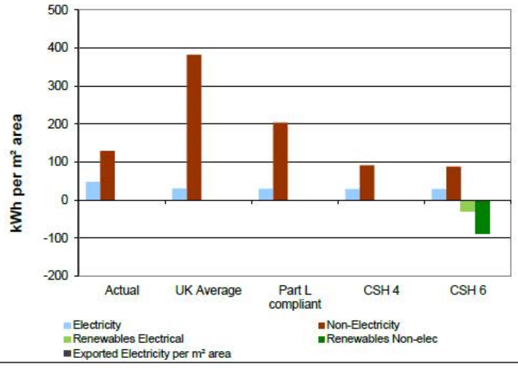
In comparison, the DomEarm assessment for dwelling B2 (Figure 7:21) indicates a lower electrical consumption, yet it remains higher than the standard benchmarks used for the assessment. Gas consumption is lower than both the UK average and the Part L Compliance prediction. Similar to the dwellings A1 the emission split is around 50/50 for electricity and non-electrical uses.

Select basis for results: per m² area

Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kWh per m² area	48	31	30	28	28
% Difference between actual and benchmark		+55%	+61%	+67%	+67%
Non-electricity kWh per m² area	129	382	203	92	88
% Difference between actual and benchmark		-66%	-36%	+41%	+46%
Renewable Electrical kWh per m² area	0	0	0	0	28
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non-Elec kWh per m² area	0	0	0	0	88
% Difference between actual and benchmark		NA	NA	NA	-100%
Exported Electricity per m² area	0	0	0	0	0



***Annual Emissions compared with benchmarks**

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kgCO2 per m² area	25	16	15	15	15
% Difference between actual and benchmark		+55%	+61%	+67%	+67%
Non-electricity kgCO2 per m² area	26	76	40	18	18
% Difference between actual and benchmark		-66%	-36%	+41%	+46%
Renewable Electrical kgCO2 per m² area	0	0	0	0	15
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non Elec kgCO2 per m² area	0	0	0	0	18
% Difference between actual and benchmark		NA	NA	NA	-100%
Balance kgCO2 per m² area	50	92	55	33	0

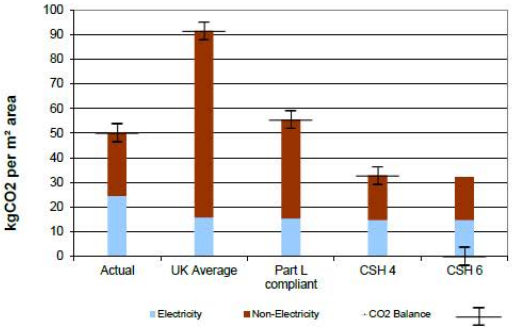


Figure 7:21: DomEARM results output dwelling B2.

House Type C

Throughout the monitoring period the signal from both dwellings was frequently lost, this affected the quality and granularity of data collected. However, there was sufficient data available to allow direct comparison of the pair of dwellings. Figure 7:5 plots data for the calendar year of 2013 and provides an indication electrical consumption in each dwelling is broadly similar, while energy used for electrical heating is greater in dwelling C1. In 2013, this dwelling was occupied by a single occupant for a 9 month period, following this new tenants (two occupants) moved, it was after this time consumption of the electric heating reduced. The reduction in total electrical energy consumption in year 1 compared to year 2 in dwelling C1 is evident in Figure 7:22. The consumption in this dwelling is now similar to the neighbouring dwelling of this house type where both occupants prefer to use their wood burning stove (secondary heating source) more frequently. However, as reported in Chapter 3 the way in which the occupants heated their homes affected the outcome of the in-situ U-value testing. The internal space temperature is noted to have large daily swings in both dwellings, this is reviewed in the environmental section of this chapter.

Figure 7:24 illustrates the significant impact electrical heating can have on electrical consumption and associated cost. The newer occupants in C1 prefer to use the wood burning stove due to a free supply of wood, and the occupants of C2 use a mix of electric heating and the wood burning stove. However, both occupants complained over lack of external storage for the wood fuel.

The sub-circuit monitoring for dwelling C1 (Figure 7:25) is interesting as it allows comparison between different sets of occupants and clearly highlights the impact user patterns/behaviour have on electrical consumption. The initial year of monitoring illustrates consumption related to the first occupancy (single occupant) and the second year of monitoring plots data recorded from the second tenancy (two occupants) however there have been technical issues in receiving data from April 2014. The electric shower is the highest consumer in the dwelling under both occupancies and rises, as expected, with a two person household. The kitchen sockets also increase slightly with an increase in occupancy. The power consumed at the electrical plug sockets is similar. However the greatest difference is the decrease in consumption for the cooker and the lighting circuit on change of occupancy. The running costs of dwelling C1 is significantly reduced for two occupants.

In dwelling C2 the sub-circuit metering (Figure 7:26) illustrates a more or less equal consumption for the shower, kitchen sockets and sockets in the dwelling, with the cooker being the lowest consumer. The usage pattern for electrical lighting clearly identifies a dip in consumption during the summer period, however during the winter the lighting consumption is greater than the cooker.

The hot water in these dwellings is heated by electrical immersion, however due to the way in which the cables had been installed it was not possible to connect a meter to allow separate monitoring.

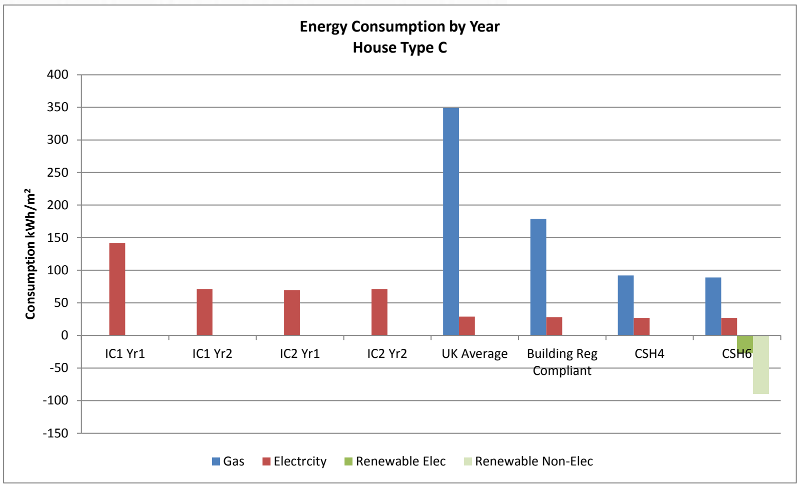


Figure 7:22: Electrical energy consumption of two dwellings in House Type C for two years.

These dwellings are all electric. A large decrease in electrcial consumption in dwelling C1 is noticable between the two years.

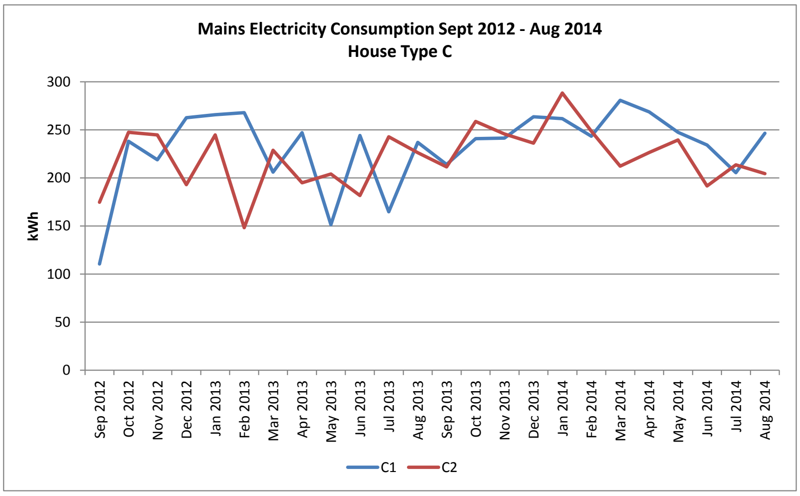


Figure 7:23: Electrical consumption for two monitored dwellings in House Type C.

There appears to be large swings from month to month. Initially consumption in C2 was lower than C2, however arouond August 2013 consumption in both dwellings was similar.

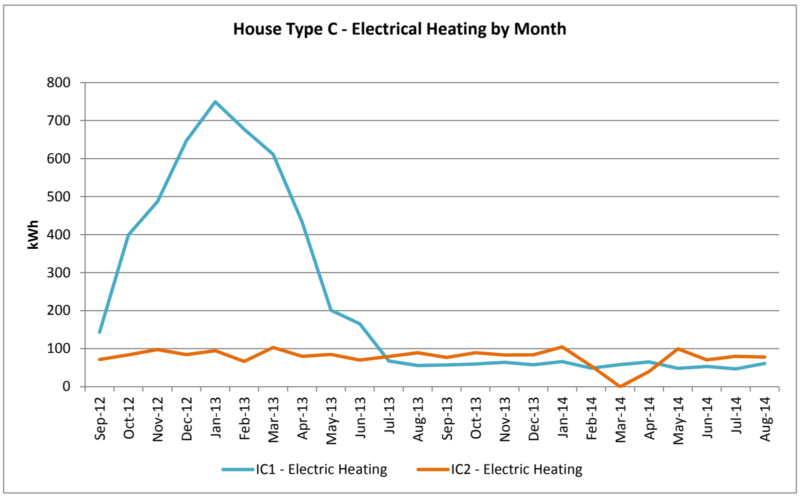


Figure 7:24: Electrical heating energy consumption for two monitored dwellings in House Type C.

The chart illustrates the higher usage pattern in dwelling C1 before and after the change of occupants. Dwelling C2 shows a constant heating load throughout the two year period.

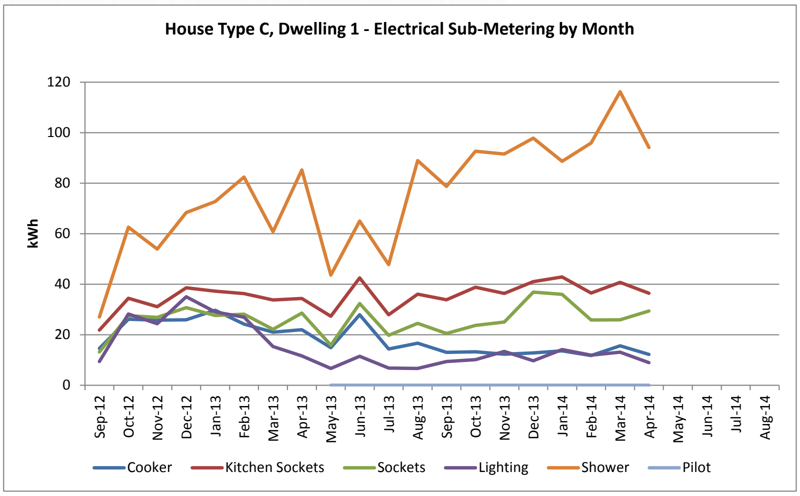


Figure 7:25: Electrical consumption by sub-circuit for two years in dwelling C1.

Electrical heating is not included in this chart. This chart illustrates the electrical shower is the highest electrical consumer in the dwelling. It is of note the increase in shower use after August 2013 when there was an increase in occupant numbers. Kitchen sockets (small power) are the second highest electrical circuit in the dwelling. The remaining circuits have follow a similar pattern with the first occupant and decrease on the new tenancy.

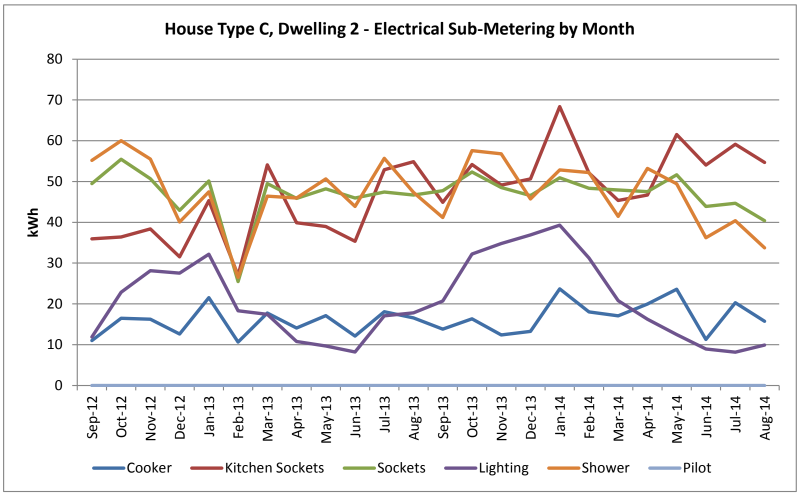


Figure 7:26: Electrical consimption by sub-circuit for two years in dwelling C2.

Electrical heating is not included. In this dwelling the shower, kitchen and equipment plugged into plug sockets are the highest electrical consumers. The cooker uses less energy than the electrical lighting.

DomEARM

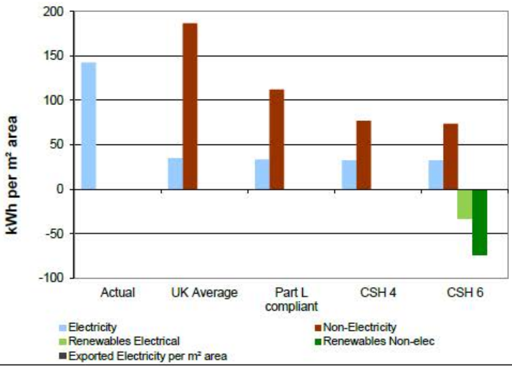
The assessment for both dwellings in this House Type are illustrated in Figure 7:27 and Figure 7:28. These figures have included the Economy 7 meter readings for the electric heating. This illustrates dwelling C1 consumption to be significantly greater than dwelling C2. As indicated above, this is due to more frequent use of electrical heating in this dwelling. In dwelling C1 the overall consumption is lower than UK average benchmark but as the energy is electrical the annual emissions are greater than all of the benchmarks. One could argue that as the electrical grid de-carbonises in the future the emissions associated with this property will also reduce. In contrast, the total electrical consumption (including for electrical heating) dwelling C2 consumption is around 70% greater than the benchmark data. Considering this includes space heating the overall consumption could be considered to be fairly low. The overall dwelling emissions are lower than all benchmark data used for the DomEARM assessment.

Select basis for results: 1

Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kWh per m² area	143	35	34	33	33
% Difference between actual and benchmark		+308%	+321%	+335%	+335%
Non-electricity kWh per m² area	0	187	112	77	74
% Difference between actual and benchmark		-100%	-100%	-100%	-100%
Renewable Electrical kWh per m² area	0	0	0	0	33
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non-Elec kWh per m² area	0	0	0	0	74
% Difference between actual and benchmark		NA	NA	NA	-100%
Exported Electricity per m² area	0	0	0	0	0



***Annual Emissions compared with benchmarks**

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kgCO2 per m² area	74	18	17	17	17
% Difference between actual and benchmark		+308%	+321%	+335%	+335%
Non-electricity kgCO2 per m² area	0	37	22	15	15
% Difference between actual and benchmark		-100%	-100%	-100%	-100%
Renewable Electrical kgCO2 per m² area	0	0	0	0	17
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non Elec kgCO2 per m² area	0	0	0	0	15
% Difference between actual and benchmark		NA	NA	NA	-100%
Balance kgCO2 per m² area	74	55	40	32	0

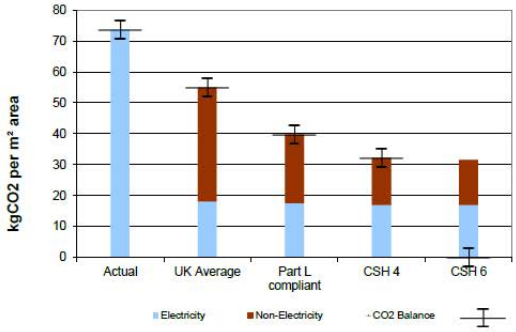


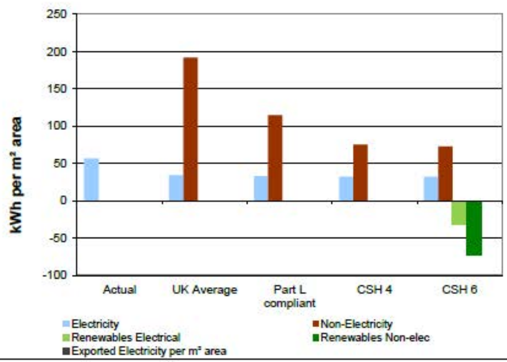
Figure 7:27: DomEARM results output dwelling C1.

Select basis for results: 1

Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kWh per m² area	57	34	33	32	32
% Difference between actual and benchmark		+66%	+72%	+78%	+78%
Non-electricity kWh per m² area	0	192	114	75	73
% Difference between actual and benchmark		-100%	-100%	-100%	-100%
Renewable Electrical kWh per m² area	0	0	0	0	32
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non-Elec kWh per m² area	0	0	0	0	73
% Difference between actual and benchmark		NA	NA	NA	-100%
Exported Electricity per m² area	0	0	0	0	0



***Annual Emissions compared with benchmarks**

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kgCO2 per m² area	29	18	17	17	17
% Difference between actual and benchmark		+66%	+72%	+78%	+78%
Non-electricity kgCO2 per m² area	0	38	23	15	14
% Difference between actual and benchmark		-100%	-100%	-100%	-100%
Renewable Electrical kgCO2 per m² area	0	0	0	0	17
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non Elec kgCO2 per m² area	0	0	0	0	14
% Difference between actual and benchmark		NA	NA	NA	-100%
Balance kgCO2 per m² area	29	56	40	31	0

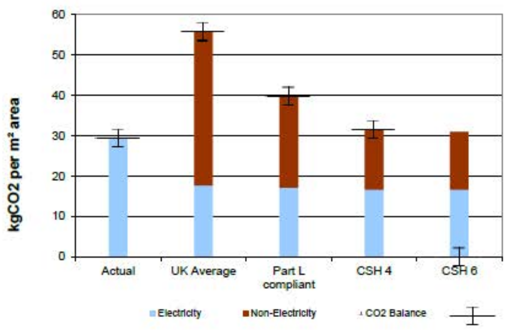


Figure 7:28: DomEARM results output dwelling C2.

House Type D

Figure 7:29 illustrates two years of data for each dwelling and compares to current benchmarks. Thermally, the dwelling compares well with the current Code for Sustainable Homes level 4 and 6 benchmarks. The electrical consumption compares well with the benchmark data. The communal heating is used for space heating and hot water, but as the fuel used has been mains gas instead of biomass, the dwelling CO_2 emissions are much higher than the design intent (as noted in section 2.3 of this report). Figure 7:30 illustrates both sets of occupants as having a clear reduction in consumption in warmer months, however the reduced second year consumption data indicate that the occupants in dwelling D2 are using less heating than the previous year, despite the increase in air permeability measured in year two (Chapter 3). The consumption reduction could be linked to their discovery of the annual communal heating payment was not a one off fixed rate as previously thought and heating use was reduced accordingly or the reduction could be related to the impossibility of the occupants to have all the radiators in the dwelling on at once and therefore only heat the living room.

The electrical consumption of dwelling D1 (Figure 7:31) indicates a large difference in consumption between year one and two, however there were some technical issues with a sub-circuit not being physically connected. While initially the electrical consumption on dwelling D2 was high it settled to be relatively stable until June 2014 which coincided with the birth of the occupants' first child.

Figure 7:32 illustrates D1's electrical consumption by sub-circuit, this chart is difficult to interpret as there had been an initial problem with the quality of data for sockets and upon investigation t-mac deleted a sockets sub-circuit from the monitoring as they considered the loads to be too low. After investigation it was found the low load was a real consumption as one bedside lamp (fitted with low energy light) was plugged into the circuit, the occupants informed us that this was rarely used. Due to the open plan nature of the living space, location of sockets and furniture placement all electrical items within the household were plugged into the kitchen sockets sub-circuit on our visit. This increases the risk for electrical fires within the home from overloaded circuits. However, initially the furniture was arranged differently and was using the living room sockets. While in D2 the sub-metering (Figure 7:33) indicates a clearer hierarchy with kitchen sockets still heavily loaded and few electrical items drawing from the remaining sockets in the dwelling; the lighting load is higher than the remaining sockets.

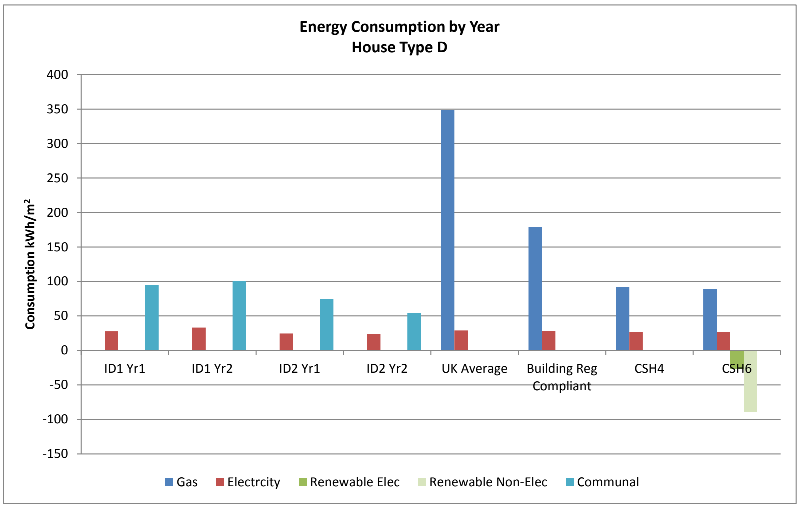


Figure 7:29: Communal and electrical energy consumption for two dwellings in house type D for a two year period.

The chart illustrates the communal heating consumption ito be comparable to dwellings benchmarked under the Code for Sustainable Homes number 4 and6 (English Assessment Method) and electrical consumption in dwelling D1 is slightly higher than the standard benchmarks.

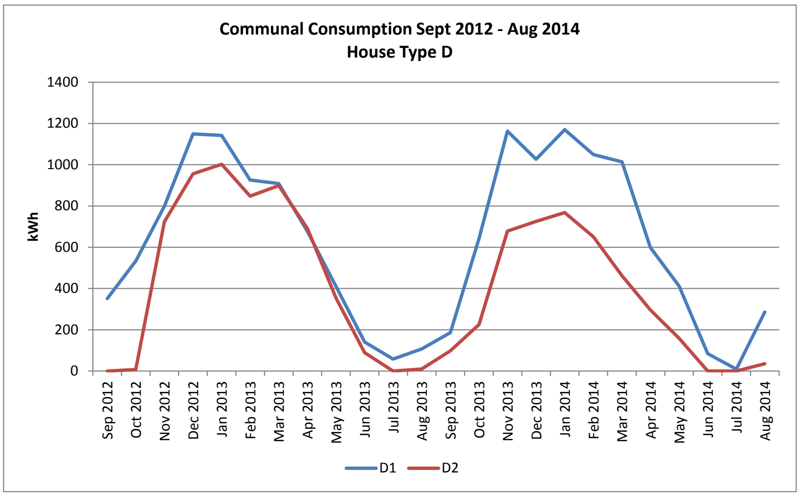


Figure 7:30: Communal consumption for two monitored dwellings in House Type D.

The chart illustrates dwelling D1to continually have a higher consumption than comparision dwelling D2. The difference increases during year two of monitoring.

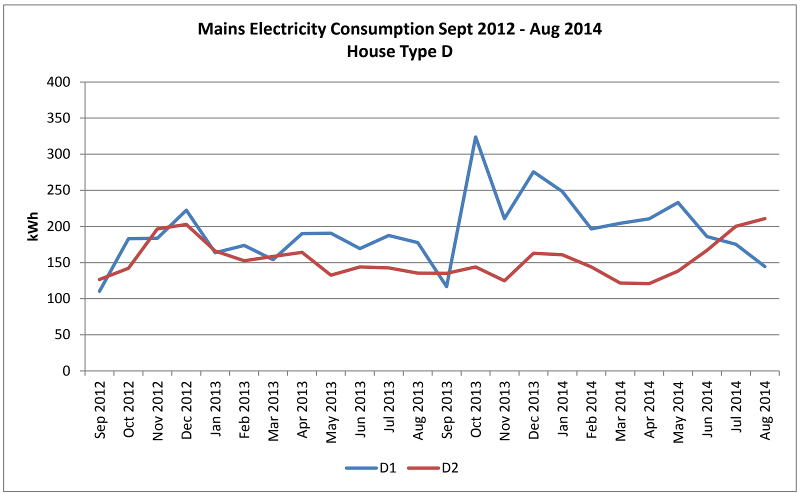


Figure 7:31: Electrical consumption for two monitored dwellings in House Type D.

The chart illustrates a relatively large increase in consumption in dwelling D1, the reason for this increase is unclear. After an initial peak In comparable dwelling D2 the electrical consumption settled to be relatively stable throughout. The consumption has increased since June 2013 which corresponds to the recent birth of the occupants first child.

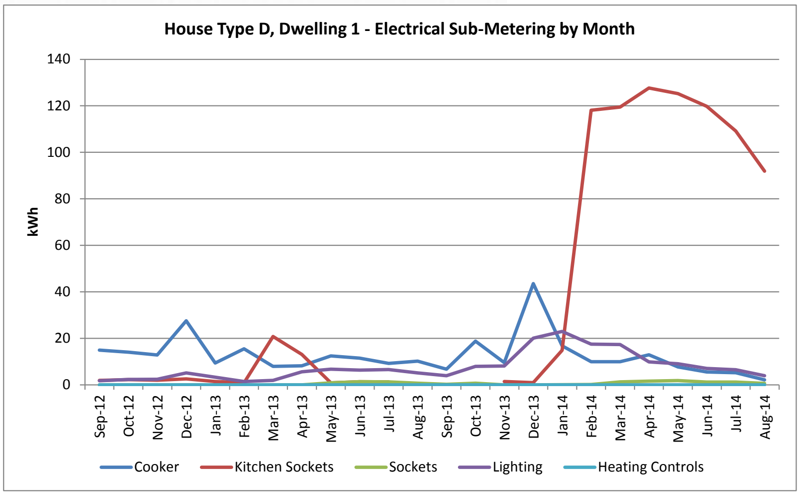


Figure 7:32: Electrical consumption by sub-circuit for two years in dwelling D1.

There were significant issues with the monitoring of socket sub-circuits within this dwelling. Due to the layout of the dwelling it was found that most electrical consuming items were plugged into the kitchen socket circuit. It is of interest that during the winter the lighting loads exceed the electrical consumption of the cooker.

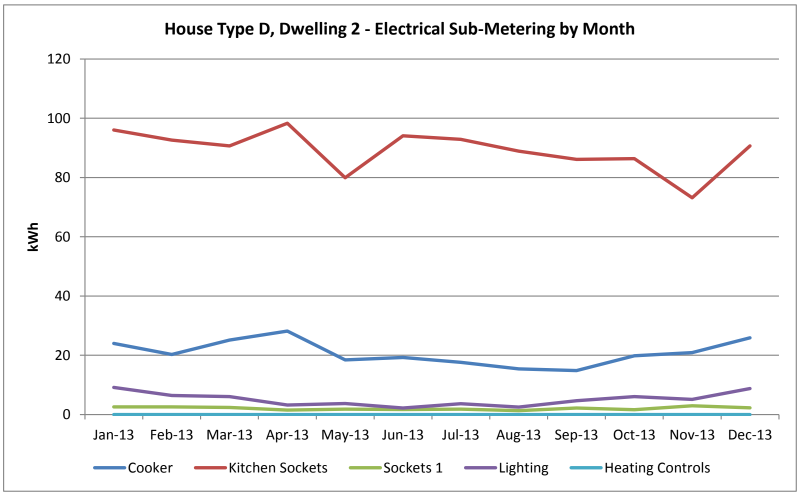


Figure 7:33: Electrical consimption by sub-circuit for two years in dwelling D2.

The chart indicates a distinct consumption heirarchy with the kitchen sockets being the highest consumer. However, as with the neighbouring dwelling most electrical equipment is plugged into the kitchen circuit. The television is indicated by 'sockets 1'.

As noted in Chapter 6 the heating and hot water for house type D is provided by a 30kW communal biomass heating system (wood pellets) with 30kW back-up condensing gas-fired boiler. The heat generated by either boiler is fed in to a 1,000 litre buffer store and fed on-demand to a plate heat exchanger, located in the hall of six properties in the block of flats. A factor (dedicated maintenance company) collects estimated annual heating payments from each property in advance. This is based on the cost of a year's supply of biomass fuel, annual maintenance and a provisional sum for gas back-up, these costs are divided equally between the six properties. The occupants initially viewed this payment as a one-off annual payment irrespective of consumption. However, the cost is linked to actual consumption where annual cost is adjusted at a year end and each household is credited/debited accordingly, if their consumption does not match the estimated charge. The occupants claimed they were originally unaware of this and were surprised to receive a bill for additional heating. Some of the occupants expressed their dissatisfaction in the lack of control over the heating tariffs they are being charged and one of the households is trying to establish whether they can have a gas meter and boiler fitted in their dwelling and the heat exchanger removed. This would allow them to bypass the communal system altogether and feel more comfortable about their heating and hot water tariffs.

The Factor revealed this was the first communal heating system they have been responsible for and based on their experiences would hope that any future communal system;

a) Would have been adequately commissioned to ensure system worked correctly from date of handover.

b) Had clear charging structure in place from the outset and the occupants understood their heating costs are linked to consumption and not the biomass fuel deliveries.
c) That there was an easier way to obtain meter readings from each dwelling, i.e. remote access.
d) The responsibility for maintenance and repair on parts of the system are clearer, i.e. where the Factors responsibility stops and the owners' responsibility begins.
e) The contractor ensures the gas meter is registered before handover to allow the new building owner (Factor or ESCO) to establish who the utility supplier is. Apparently after four years of occupation the gas meter remains unregistered and the Factor has not been charged for the gas used.

There have been reliability issues with the continued operation of the biomass boiler due to a flue gas sensor being missing or faulty. This meant the gas back-up has been in use more frequently than intended, the gas consumption profile (for two years) is illustrated in Figure 7:34. During this time 157,837 kWh of gas has been consumed by the back-up boiler which we estimated to be amount to £5,023. The monthly consumption illustrated in Figure 7:35 highlights the gas consumption of the back-up boiler, the only full months where gas-back up has was not used is July and August 2014. At this time the heat demand would have been met by the biomass boiler.

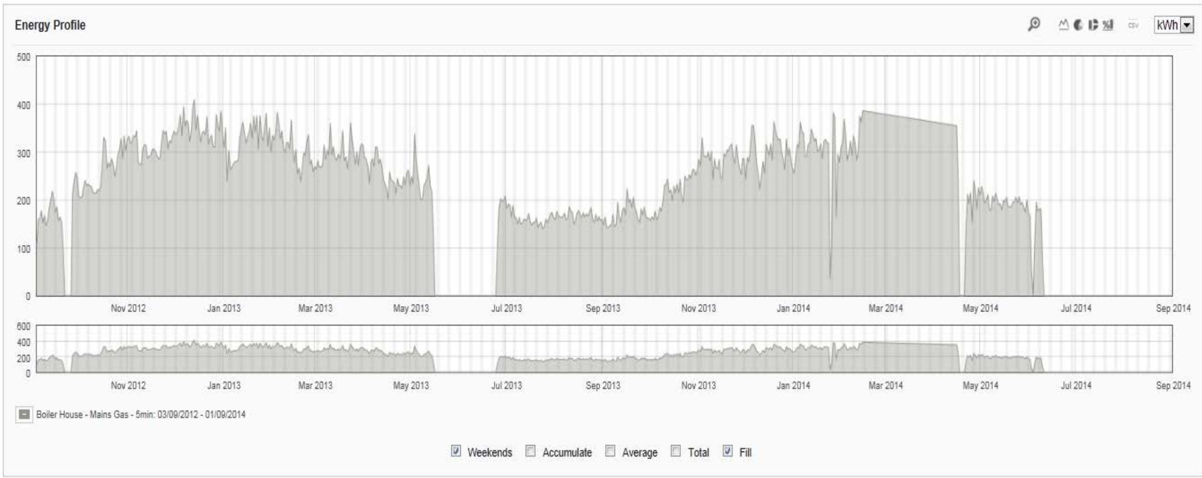


Figure 7:34: Gas boiler operation for two year monitoring period.

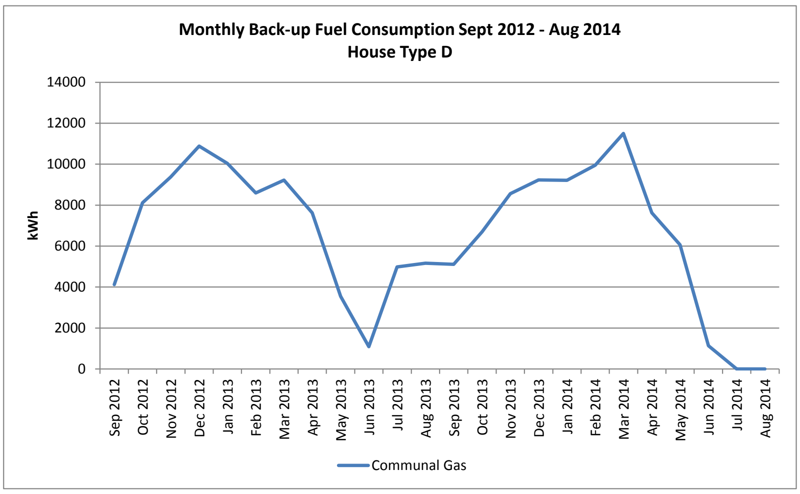


Figure 7:35: Communal back-up gas boiler consumption September 2012 – August 2014.

The chart illustrates constant gas consumption from September 2012 through to mid June 2014 due to a continued fault with the biomass boiler.

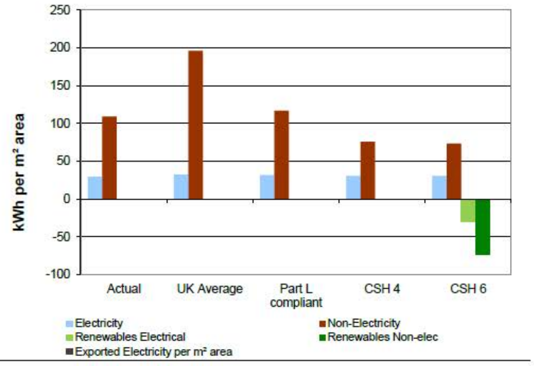
DomEARM

Select basis for results: 1

Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kWh per m² area	30	33	32	30	30
% Difference between actual and benchmark		-9%	-6%	-3%	-3%
Non-electricity kWh per m² area	109	196	117	76	73
% Difference between actual and benchmark		-45%	-7%	+44%	+49%
Renewable Electrical kWh per m² area	0	0	0	0	30
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non-Elec kWh per m² area	0	0	0	0	73
% Difference between actual and benchmark		NA	NA	NA	-100%
Exported Electricity per m² area	0	0	0	0	0



***Annual Emissions compared with benchmarks**

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kgCO2 per m² area	15	17	16	16	16
% Difference between actual and benchmark		-9%	-6%	-3%	-3%
Non-electricity kgCO2 per m² area	22	39	23	15	15
% Difference between actual and benchmark		-45%	-7%	+44%	+49%
Renewable Electrical kgCO2 per m² area	0	0	0	0	16
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non Elec kgCO2 per m² area	0	0	0	0	15
% Difference between actual and benchmark		NA	NA	NA	-100%
Balance kgCO2 per m² area	37	56	39	31	0

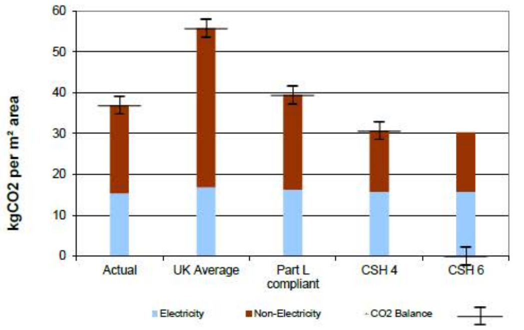


Figure 7:36: DomEARM results output dwelling D1.

The electrical consumption in dwelling D1 (Figure 7:36) indicates an actual consumption slightly lower than the benchmark data, the heating consumption is lower than the UK average and similar to the Part L Compliant predicted dwelling but greater than the Code for Sustainable Homes (CSH) benchmarks. However, the emissions indicate overall emissions to be between Part L and CSH benchmarks. Should the biomass boiler been functional then the emissions relating to space heating and hot water would have been lower.

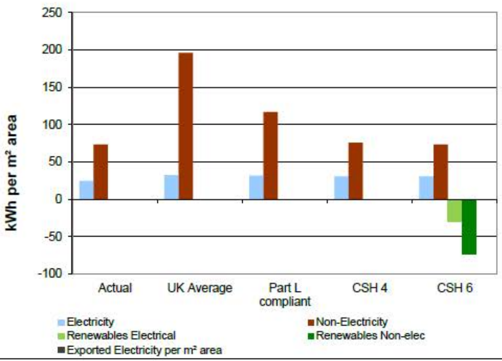
In the comparison dwelling D2 the electrical and heating energy consumption indicated in Figure 7:37 are below all benchmarks. This may be due to the occupants inability to use all radiators in the dwelling for space heating.

Select basis for results: per m² area

Annual energy performance compared with benchmarks

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kWh per m² area	25	33	32	30	30
% Difference between actual and benchmark		-25%	-22%	-19%	-19%
Non-electricity kWh per m² area	73	196	117	76	73
% Difference between actual and benchmark		-63%	-37%	-3%	+0%
Renewable Electrical kWh per m² area	0	0	0	0	30
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non-Elec kWh per m² area	0	0	0	0	73
% Difference between actual and benchmark		NA	NA	NA	-100%
Exported Electricity per m² area	0	0	0	0	0



***Annual Emissions compared with benchmarks**

Note: Benchmark figures include appliance energy use

	Actual	UK Average	Part L compliant	CSH 4	CSH 6
Electricity kgCO2 per m² area	13	17	16	16	16
% Difference between actual and benchmark		-25%	-22%	-19%	-19%
Non-electricity kgCO2 per m² area	15	39	23	15	15
% Difference between actual and benchmark		-63%	-37%	-3%	+0%
Renewable Electrical kgCO2 per m² area	0	0	0	0	16
% Difference between actual and benchmark		NA	NA	NA	-100%
Renewable Non Elec kgCO2 per m² area	0	0	0	0	15
% Difference between actual and benchmark		NA	NA	NA	-100%
Balance kgCO2 per m² area	27	56	39	31	0

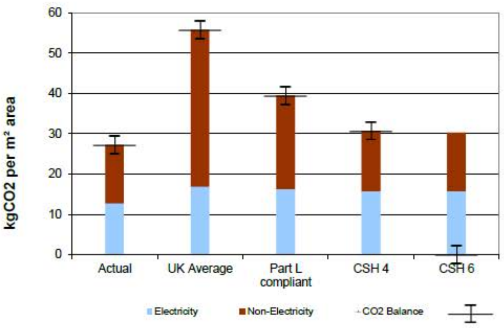


Figure 7:37: DomEARM results output dwelling D2.

7.4 Environmental Monitoring Summary

As part of the project, internal environment conditions were monitored to determine internal comfort conditions in each dwelling and to provide an assessment of indoor air quality. Temperature, relative humidity, carbon dioxide concentrations (CO_2) and window opening patterns were monitored on a five minute grain for a two year period in selected rooms in each dwelling. Initially data collection was erratic for this element of the monitoring which meant data recording was not possible for some dwellings until November 2012. This section of the report reviews the internal conditions for a complete year and compares space temperatures to the design guidance for dwellings in CIBSE (Chartered Institute of Building Services Engineers) Design Guide A. This data was used to provide assessment on whether the monitored rooms were considered comfortable during summer and winter periods.

While there is no recognised upper threshold for internal temperatures in dwellings CIBSE consider a room should not exceed a threshold temperature for more than 1% of annual occupied hours. These threshold temperatures are 26°C and 28°C for bedrooms and living rooms respectively. (Note CIBSE overheating guidance was revised during 2013, the overheating analysis in this document uses previous CIBSE assessment criteria as it was current at the design phase of the dwellings.)

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

This section of the report discusses internal environmental conditions for the period between November 2012 – October 2013, raw data files containing two years data for each dwelling are located in Appendix O. The conditions in each room are reviewed and compared to CIBSE guidance data for comfort. The data is then compared for each pair of dwellings to review the extent differing occupancy has on internal environment conditions. Findings from the first year of monitoring was reported to individual households during planned feedback sessions; the prepared information sheets are included in Appendix P.

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

Table 7:3: Summary of internal conditions for environmental monitoring

House Type A

In this house type three rooms were monitored these were; the living room, west facing bedroom and an east facing bedroom (Figure 7:38 and Figure 7:39). Both dwellings are occupied by large families with broadly similar occupancy patterns i.e. home during the day and night.

Figure 7:38: House Type A –Ground floor plan, indicating location of environmental monitor.

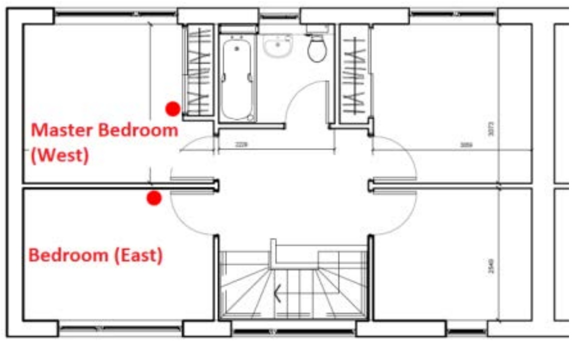


Figure 7:39: House Type A - First floor plan, indicating location of environmental monitors.

Dwelling A1

In dwelling A1 the internal temperature conditions (Figure 7:41), CO_2 concentrations (Figure 7:42) and window opening patterns (Figure 7:43) indicate internal conditions vary considerably with season. Overheating is seen to occur year round (except living room in winter) and is more prevalent during the summer months, followed by autumn. During the summer living room space temperatures peaked at 33.8°C, some 10°C above summer comfort temperatures recommended by CIBSE. The living room temperature tends to exceed 23°C for most of the year with the longest period in the comfort range occurring in the spring. However, in this room, the indoor air quality through each season was below 1000ppm for more than 70% of each season. The windows are frequently opened which assist in dilution of CO_2, however, the separating door between the living room and the remainder of the ground floor is usually open to the hall, stair and kitchen, allowing migration of pollutants through the dwelling.

The air quality in the west facing bedroom is poor throughout the year frequently reaching peaks of 4900ppm for CO_2 concentrations. The fact concentrations were never below 1000ppm indicates the room is under ventilated despite the window being frequently opened. An observation made was there were two adults occupying this room (for the first year of monitoring), with the window open on the 'tilt' mode, however the curtains were frequently closed through the day, restricting air exchange. Readings of 4900ppm are unusually high, however based on studies on the indoor environment in this and other dwellings the readings are considered to be valid. The occupant was known to be frequently smoking within the room and habits formed for lack of curtain opening appear to exacerbate concentrations in the room. CO_2 concentrations for a typcal week have been plotted in Figure 7:44 which indicate poor IAQ through the week but on five consequtive nights CO_2 concentrations exceed 4500ppm. The lack of ventilation and warm temperatures provided conditions that supported condensation and mould growth; these were identified on window frames. There is little in the way of peaks and troughs in temperature in this room with the lowest winter space temperature of 24.6°C and highest 26°C. The window is open for 95% of the heating season and considering the constant high temperatures in the room suggests the heating may be operating constantly which is also affecting the energy efficiency of this dwelling. During the summer the temperature ranged between 23.4°C and 27°C. Although there was a swing of 3.6°C between day and night window opening had little effect in cooling this room adequately. The quality of sleep and health of the occupants in this room may be compromised due to consistently high temperatures, poor indoor air quality and moisture levels high enough to support condensation, mould growth and possibly an increase in dust mite populations.

Conditions in the east bedroom were an improvement over the west facing bedroom, however there is normally one occupant in the room. Temperatures tend to be towards warm to hot with night time temperatures exceeding 24°C (the temperature at which sleep can be affected). Peak space temperature in this room was 27°C (winter), 29.6°C (spring), 30.8°C (summer) and 31.8°C (autumn) indicating occurrence of overheating throughout the year. In winter the high space temperature is indicative that heating set points are too high. In respect to air quality, CO_2 concentrations were poorest in winter despite the windows being constantly open Figure 7:40; this suggests the ventilation path is being obstructed, perhaps by closed curtains and the relatively small aperture of the window. The window sensor was removed from the window during the summer season.

Figure 7:40: East bedroom Dwelling A1 indicating extent of aperture when using 'tilt and turn' mode of operation.

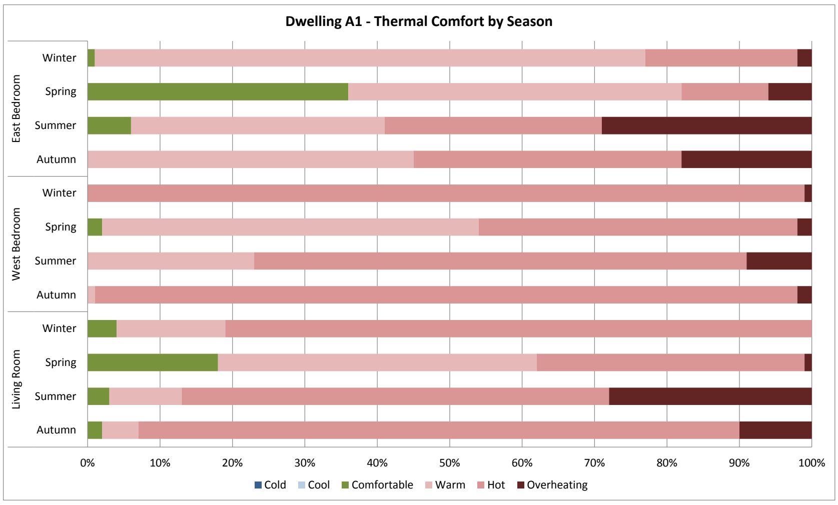


Figure 7:41: Temperature profile by season for dwelling A1.

This figure indicates the dwelling is maintained at a temperature over 23°C for most of the year, with spring having temperature considered to be more inline with comfort conditions. Each room is overheating through the year. Warm temperatures can affect health and sleep patterns.

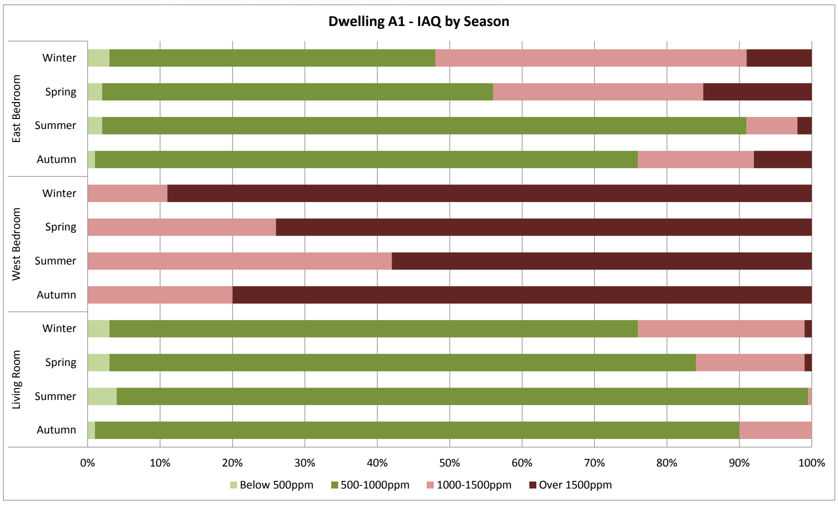


Figure 7:42: CO_2 concentrations by season – Dwelling A1.

The CO_2 concentrations provide an indication of ventilation rates, concentrations shown in pink and red indicate poor and very poor indoor air quality and corresponding low ventilation rates. While CO_2 at these levels are not known to be a threat to health it indicates poor ventilation regimes which allow contaminants such as VOCs, formaldehyde mositure, dust mites etc. to also remain in the property and potentially affect health.

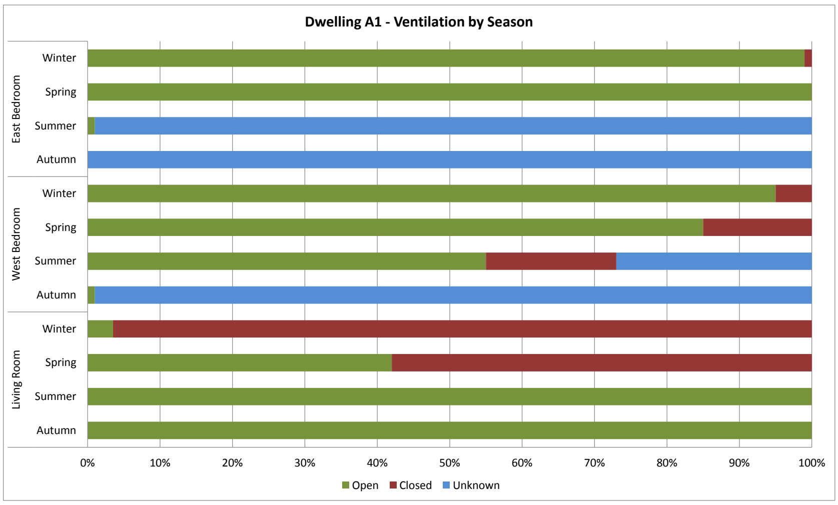


Figure 7:43: Annual window opening expressed as percentage – Dwelling A1.

This indicates the bedroom windows were frequently opened, until the removal of the sensors. However, the living room window opening increased through summer and autumn and was less frequent in winter and spring. The data also suggests the extent of window opening in the bedrooms during the heating season could impact on the gas usage and energy efficiency in the dwelling.

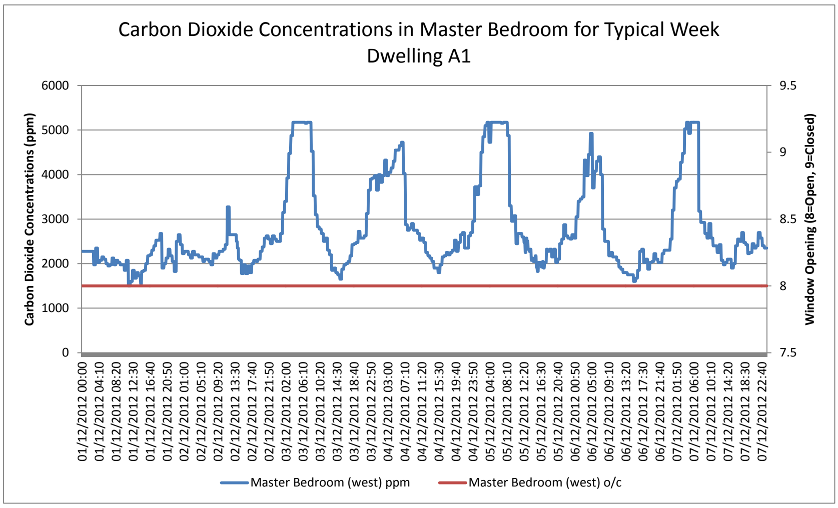


Figure 7:44: CO_2 concentrations in West Bedroom for a week Dec 2012.

The chart illustrated that although the window is open throughout the week the CO_2 concetrations do not fall below 1500ppm. Occupancy pattern is clearly identified where 5000ppm are exceeded on three occasions and concentrations exceed 4500ppm on two nights during this seven day period.

Dwelling A2

In dwelling A2 the internal temperature conditions (Figure 7:46), CO_2 concentrations (Figure 7:47) and window opening patterns (Figure 7:48) indicate the thermal comfort in the dwelling is normally warm (over 23°C) for most of the year, except in the living room where comfort conditions in line with CIBSE recommendations are maintained during all season for between 15% and 40% of the time, depending on season, despite the windows being closed for much of the year.

The living room thermal comfort conditions (Figure 7:46) indicate that this room was not subject to overheating at any time through the year. However it was noted during springtime the temperature range was between 16.4 - 29°C. Although the cool periods were limited to times during the early hours of morning, this indicates the heating could be off at this time and the living room slowly cooled through the night. Spring temperatures are normally maintained between 21 - 25°C and exceeded 28°C for 0.3% of the season. Interestingly the temperature peaks all occurred between 17:00-18:30hrs on separate days; however this could indicate the effect of solar gains from the setting sun through the west facing glazed doors. The CO_2 concentrations appear to be below 1000ppm for around 70% of the year despite infrequent window opening.

The bedrooms on the first floor are heated by a separate radiator circuit where overall the space temperature is slightly warmer than the ground floor of the dwelling. The east facing bedroom is slightly cooler than the west facing bedroom with a yearly average temperature of 22.5°C (east) and 23.4°C (west). However, the maximum temperatures through the year are 30.4°C in the west bedroom and 28.4°C in the east bedroom. Both bedroom reach temperatures greater than 24°C in all seasons. The indoor air quality is generally good however the monitoring has indicated this household are not frequent window openers during the colder months. In the west facing bedroom the lack of window opening was found to be due to obstruction from a child’s cot placed beneath the window, refer to Figure 7:45.

Figure 7:45: Dwelling A2 West Bedroom detailing obstacles to window opening. The operable section of the window is located on the right hand side, behind the cot.

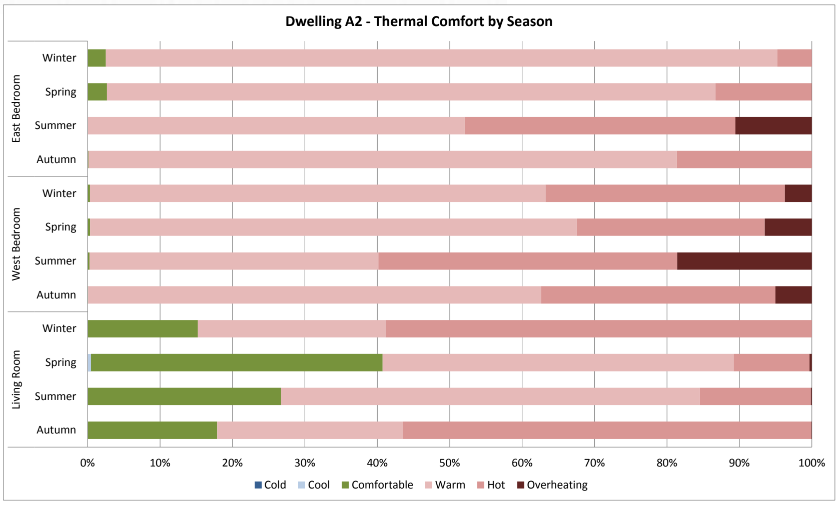


Figure 7:46: Temperature profile by season for dwelling A2.

This chart indicates the bedrooms are maintained at a temperature over 23°C for most of the year, with overheating occuring in the east bedroom during summer. The west facing bedroom indicates overheating during each season. There is a period through the year where the living room temperatures were lower than 23°C, this is more noticable in spring, where there were also a few instances of temperatures between 16-18°C, these were found to be limited to overnight and early morning times.

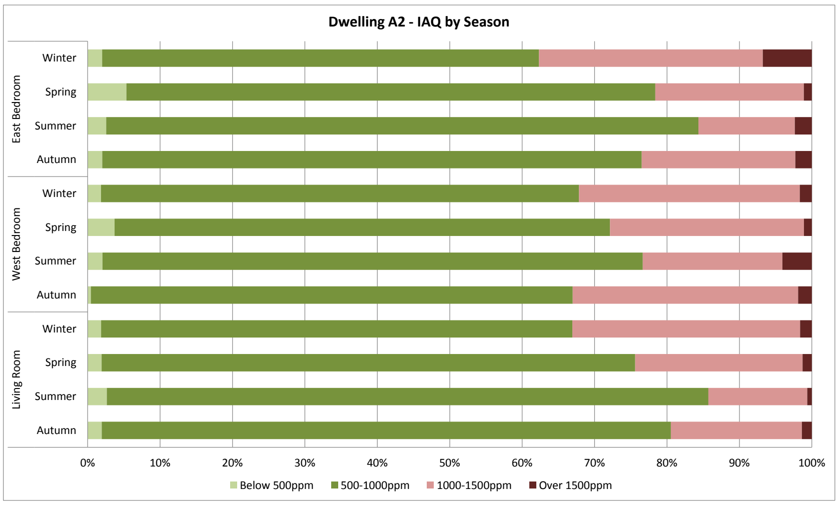


Figure 7:47: CO_2 concentrations by season – Dwelling A2.

The CO_2 concentrations provide an indication of ventilation rates, concentrations shown in green indicate good indoor air quality, the pink and red indicate poor indoor air quality and corresponding low ventilation rates. In this household there are few instances of high CO_2 concentrations.

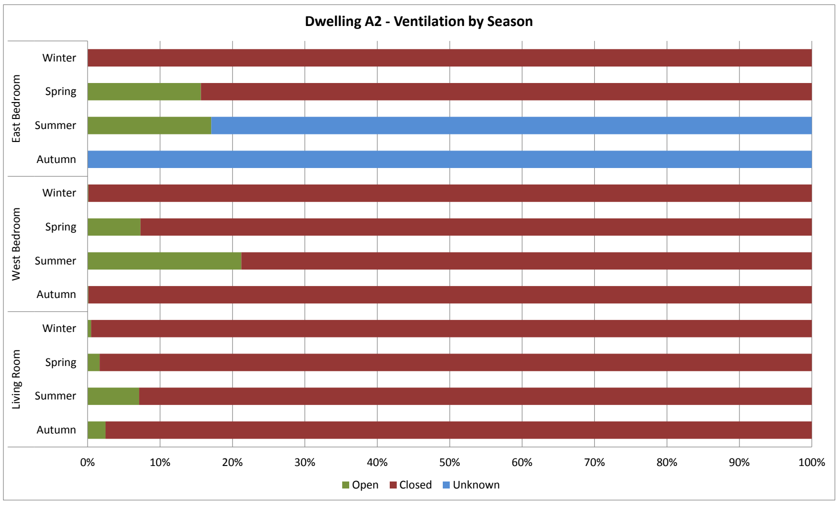


Figure 7:48: Annual window opening expressed as percentage – Dwelling A2.

The chart illustrates the windows are rarely opened during the winter and are opened more frequently during spring and summer. It would have been expected that windows, particularly in the living room would have been opened more frequently.

The sensor in the east bedroom was removed from the window and signal was lost during summer 2013.

House Type B

In this house type three rooms were monitored these were; the living room, a west facing bedroom and the east facing bedroom (Figure 7:49 and Figure 7:50). The residents of these occupy the dwelling at differing times, the occupant in dwelling B1 works from home and is frequently at home, while two occupants in dwelling B2 work varying shift working patterns. In there is one occupant in each of the east bedrooms.

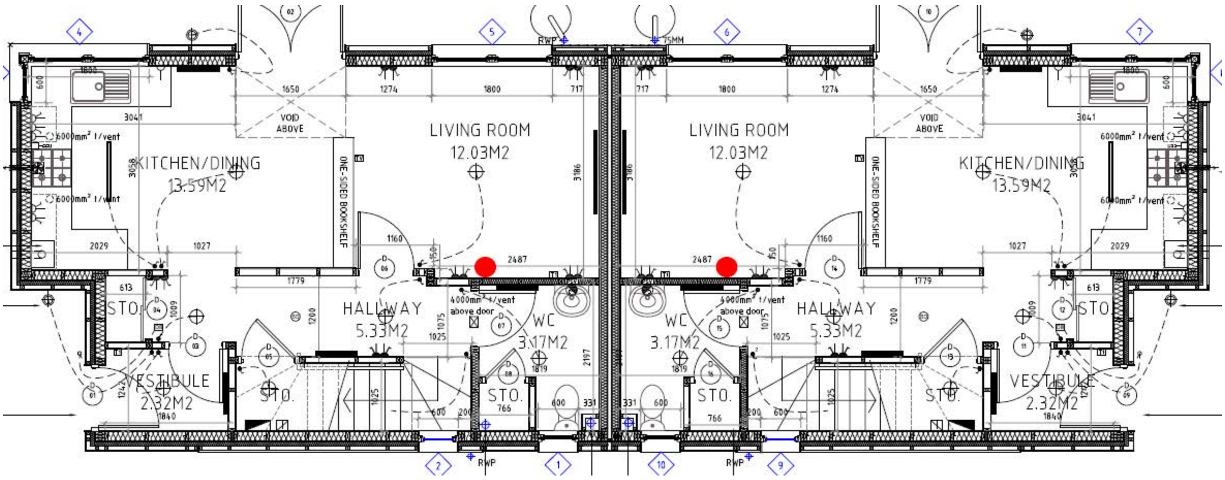


Figure 7:49: Ground Floor Plan Plot 4.2.

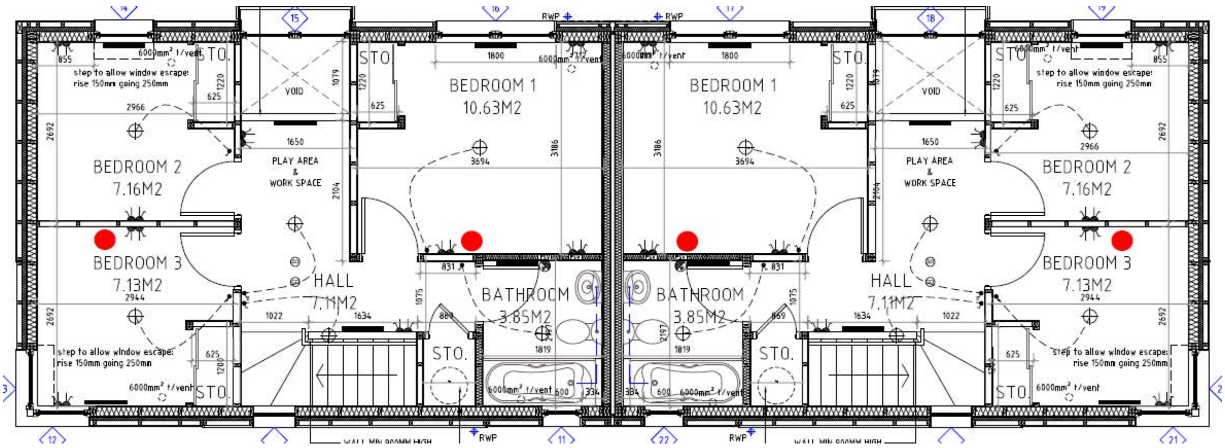


Figure 7:50: First Floor Plan Plot 4.2.

Dwelling B1

In dwelling B1 the internal temperature conditions (Figure 7:51), CO_2 concentrations (Figure 7:52) and window opening patterns (Figure 7:53) indicate internal varying conditions in each season. Severe overheating occurs in both bedrooms year round and the living room maintains relatively comfortable thermal conditions.

The living room temperatures show a relatively comfortable temperature range through the year, however the room is maintained at a warm to hot (between 23°C - 28°C) for the majority of the year. The CO_2 concentrations are mostly below 1000ppm indicating a good indoor air quality even though windows are mostly closed. However the kitchen and circulation space (hall, stairs and upstairs landing) are all connected to the living room. There are opening roof lights over a double height space in the living room and kitchen window both of which were not fitted with contact sensors, their opening status is unknown through the year and these could have been used to assist ventilation.

The comfort range for sleeping is around 17-19°C, the west bedroom consistently exceeded this value through the year, this bedroom was maintained over 24°C for a large percentage of the year and temperatures exceeding 26°C (overheating threshold for bedrooms) were recoded for large percentage of each season. The window opening in summer and autumn assisted in reducing CO_2 concentrations as indicated in the indoor air quality chart during the summer months.

In the east facing bedroom, the thermal comfort is consistently high with severe overheating occurring through the year. The concern here is the extent of overheating during the summer, even with the window constantly open. The research team observed that the windows are normally opened on the 'tilt' mode which clearly does not provide enough ventilation to reduce temperatures, and should be opened wider (if safe to do so) to assist with cooling.

In this dwelling, it was found that the thermostat in the hall was routinely set to 25°C and all TRVs were set to their maximum output.

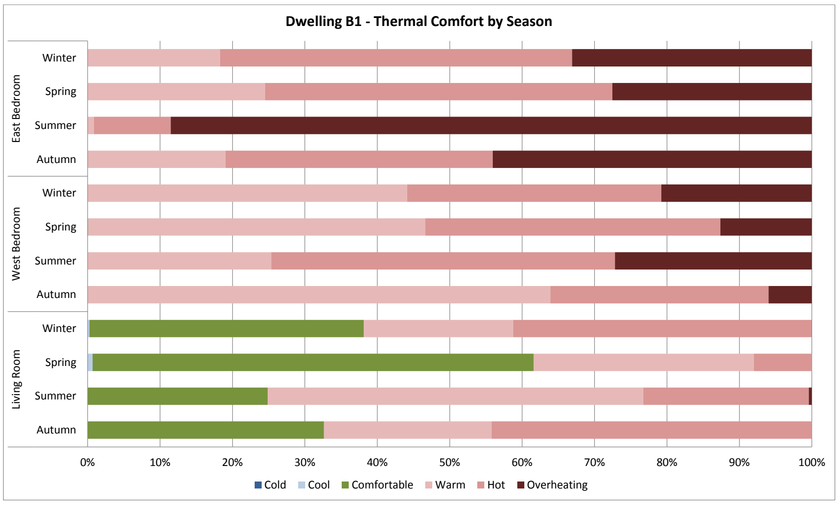


Figure 7:51: Temperature profile by season for dwelling B1.

This chart indicates the bedrooms are maintained at a temperature over 19°C all year with severe overheating in both bedrooms.

The living room temperature is more stable and cooler than the first floor of the dwelling.

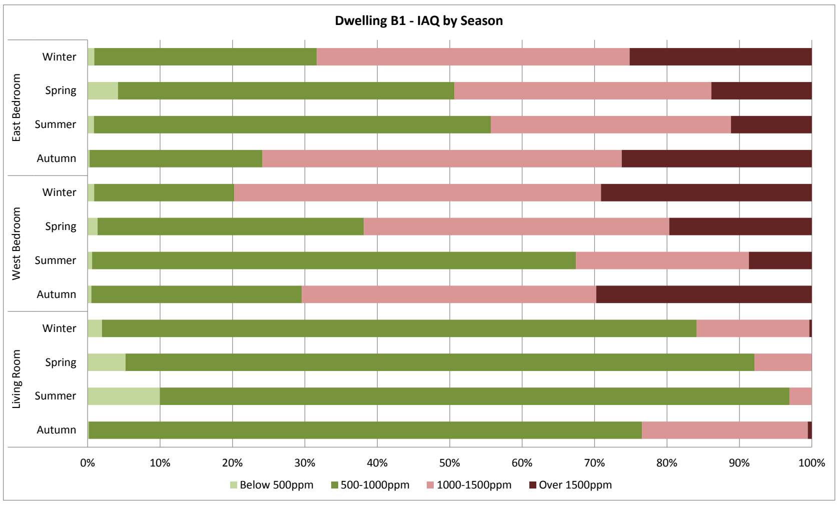


Figure 7:52: CO_2 concentrations by season – Dwelling B1.

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

Generally the living rooms conditions are acceptable, while the ventilation rates in the bedrooms could be improved upon to provide better indoor air quality.

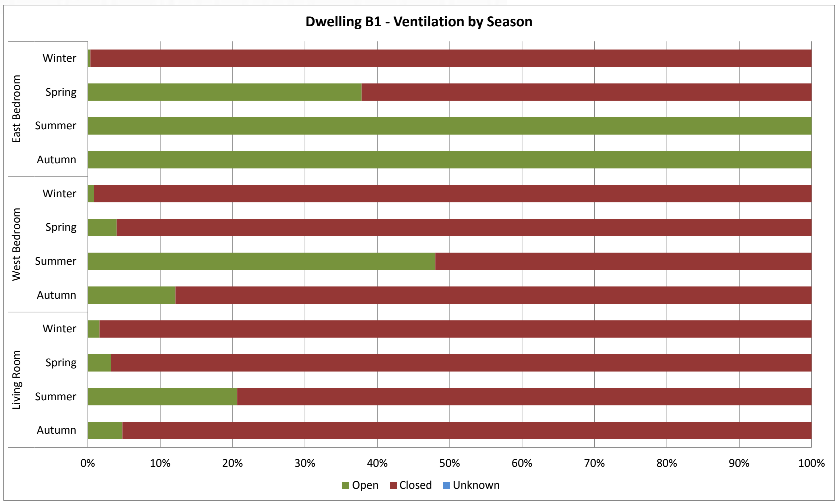


Figure 7:53: Annual window opening expressed as percentage – Dwelling B1.

The chart illustrates the windows are rarely opened in the living room. Bedroom windows are opened more frequently, more often in the east facing bedroom.

Dwelling B2

In dwelling B2 the internal temperature conditions (Figure 7:54), CO_2 concentrations (Figure 7:55) and window opening patterns (Figure 7:56) indicate internal varying conditions in each season in the three monitored rooms. The temperature profile indicates summer overheating in the bedrooms.

Thermal comfort in the living room was generally acceptable however there were periods during the heating season where the space temperature dropped to 16°C. This occurred mainly during early morning, when it was considered that the central heating was programmed to be off. The living room CO_2 concentrations were generally acceptable. The window opening increased with season.

In the west facing bedroom the temperature was mainly between 18-23°C, with acceptable internal air quality and liberal window opening that become more frequent during the summer months. The internal conditions in this room are relatively good considering there are two adult occupants sleeping in this room.

Conditions in the east facing bedroom are concerning, while there are few instances of overheating and temperatures over 24°C the CO_2 concentrations were constantly above 1000ppm with a peak of 4825ppm in summer and 4775ppm for the remainder of the year. The casual window opening pattern was observed until the contact sensor was lost. In conversation with the occupants it transpired that the window was not opened due to a fear of spiders entering the room. The negative effects (poor sleep patterns, waking tired, lack of concentration and potential for dust mite population growth) of high CO_2 concentrations and the 'bad company' were explained to occupants, since this time the occupant reported the window opening has become more frequent, using the 'tilt' mode.

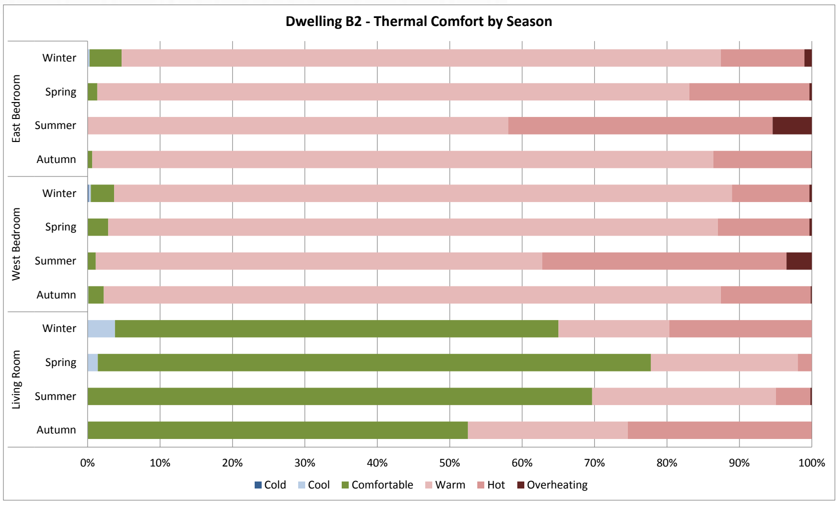


Figure 7:54: Temperature profile by season for dwelling B2.

This chart indicates the living room thermal comfort meets with the comfortable range (18-23°C) for most of the year. The bedrooms were maintained below 24°C for the majority of time, with warmer conditions and overheating during the summer period.

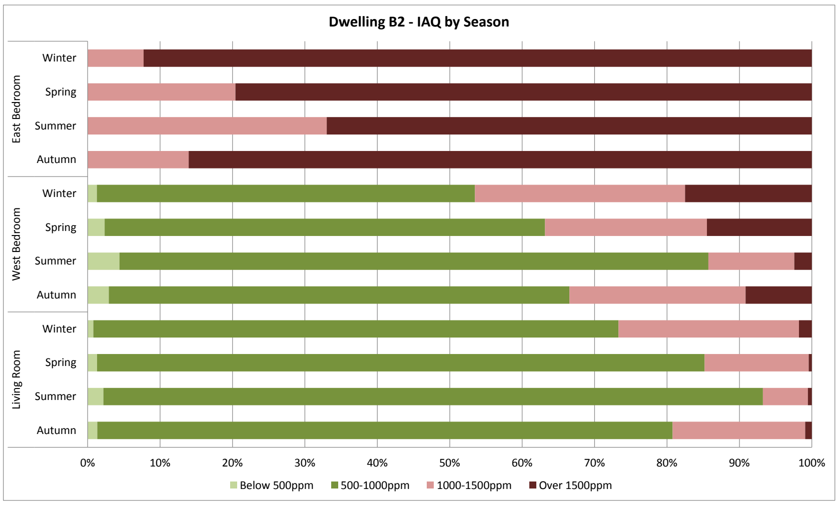


Figure 7:55: CO_2 concentrations by season – Dwelling B2.

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

In this dwelling the living room and west facing bedroom both have acceptable CO_2 concentrations, however the conditions in the east facing bedroom are extremely poor.

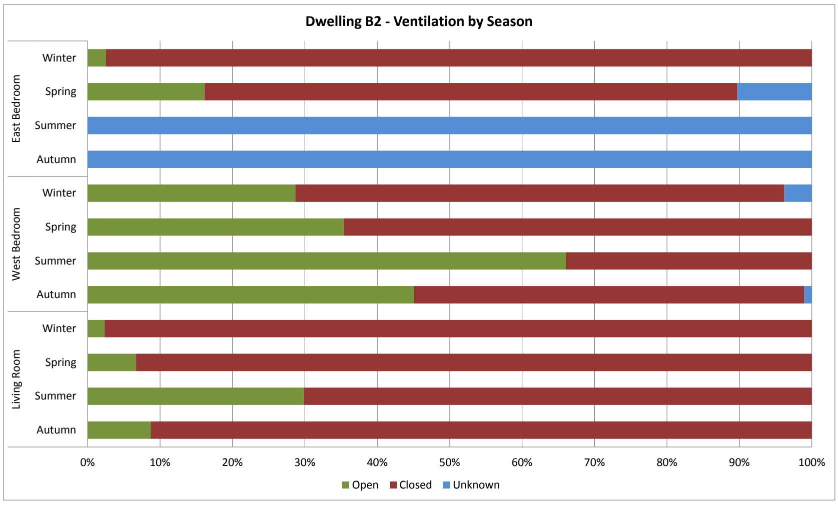


Figure 7:56: Annual window opening expressed as percentage – Dwelling B2.

The chart illustrates a clear window opening pattern in the living room and west bedroom where occupants' window opening increased as the external weather became warmer. However, the windows in the east bedroom were rarely opened and the contact sensor was removed during the spring.

House Type C

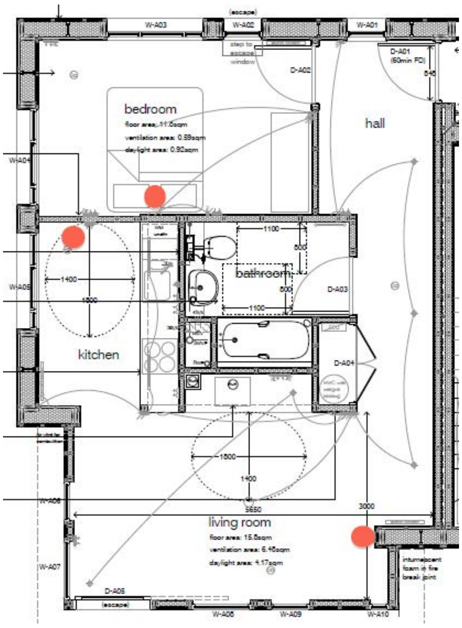


Figure 7:57: Floor Plan and sensor location Plot 9BB and 11BB.

In this house type three rooms were monitored these were; the living room, kitchen (open to living room) and north facing bedroom (Figure 7:57). The residents of these flatted dwellings occupy their respective homes normally during evenings and weekends, while an occupant in dwelling C2 is a shift worker and frequently occupies the dwelling during the day.

Dwelling C1

The temperature profile (Figure 7:58) in this dwelling varies considerably through day and night. Internal space temperatures drop to below 16°C frequently when external temperatures are low and the heating is off. For the period analysed, the occupants heating preference was for use of their electric panel heaters as and when heating was required. This meant during colder periods the occupant woke up to and came home to a cold home. There are health effects of cold indoor environments, these include; condensation and mould growth and an increase in dust mite population on increase of air temperature. Internal space temperatures in the living room and kitchen were broadly similar given they are open to one another, however, some overheating occurred in the autumn in the living room and not in the kitchen. This could be due to solar gains through the large area of south facing glazing. The CO_2 concentrations (Figure 7:59) are relatively poor in the living room, but acceptable in the kitchen, despite lack of window opening (Figure 7:60) in both rooms.

In the bedroom, it appears window opening occurred only during the summer and autumn and remained closed for the cooler seasons of winter and spring, when the internal air quality was also the poorest. The space temperature indicates that although the property is heated using electrical panel heaters located in each room the bedroom is frequently heated more often to temperatures between 19-24°C. This temperature is on the cusp of what is considered to the comfortable temperature range for sleeping, but also increases dust mite populations.

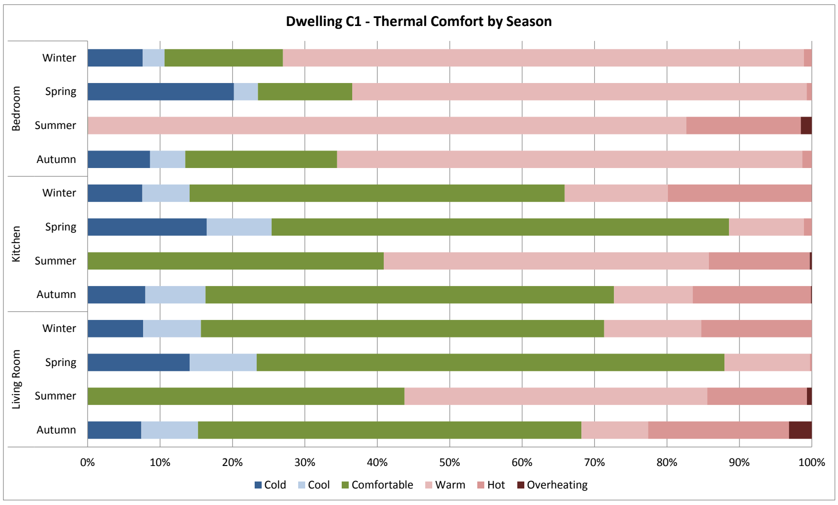


Figure 7:58: Temperature profile by season for dwelling C1.

This chart indicates periods through the year when the internal space temperature drops below 16°C, except during the summer. There are frequent periods in the living room and kitchen where the space temperature aligns with CIBSE temperature recommendations. However the bedroom is a little warm during the winter. Overheating is seen to occur in the bedroom and living room.

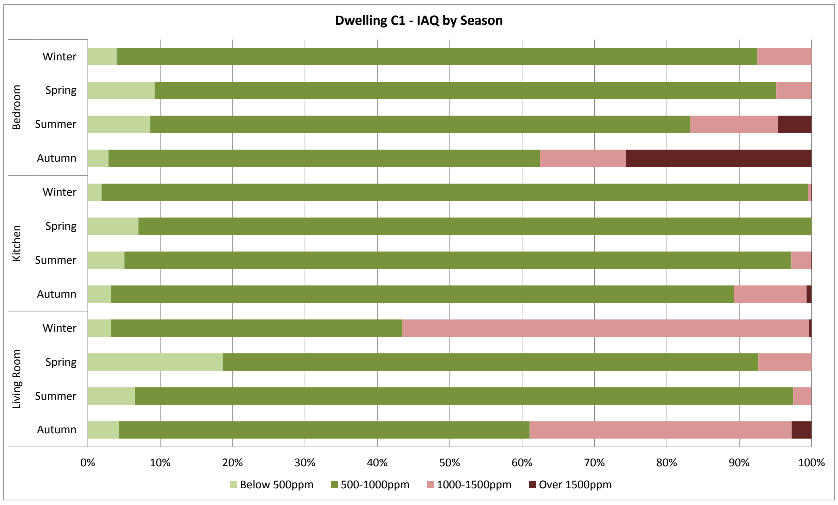


Figure 7:59: CO_2 concentrations by season – Dwelling C1.

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

For the majority of the year the CO_2 concetrations are acceptable, however, there is a period of time where the bedroom air quality in autumn has an extended period of poor air quality peaking at 4550ppm.

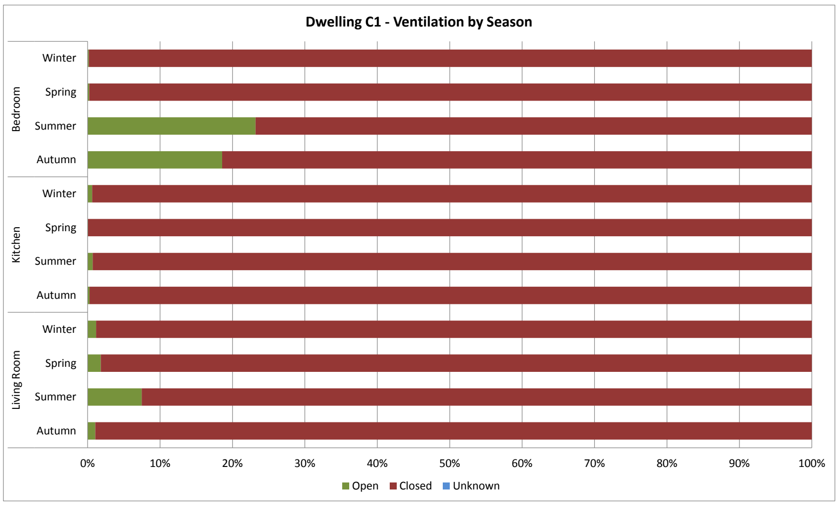


Figure 7:60: Annual window opening expressed as percentage – Dwelling C1.

The chart illustrates the windows are rarely opened during in the dwelling. Bedroom windows are opened more frequently during summer and autumn, living room windows are opened less often, however there is a clear pattern where summer window opening is greater than other seasons.

Dwelling C2

The temperature range (Figure 7:61) in this dwelling varies considerably and there was evidence of overheating during the winter and spring in the living room.

The living room temperatures drop as low as 9.8°C during the winter and rise to 33.4°C. The cold internal temperatures affected the validity of the inset U-value results (discussed in Chapter 3). However, there were instances in winter where the living room temperature reached temperatures in excess of CIBSE comfort bands, in discussion with the occupants it emerged the wood burning stove is used frequently and they are not able to modulate heat output, resulting in localised overheating during the winter. On the whole the living room is maintained at temperatures between 18-23°C and a good indoor air quality for extended periods of the year, despite the windows being closed frequently (Figure 7:63). The furniture placement in the dwelling may have some impact on the window opening routine, as the sofa is positioned in front of the smaller windows.

The thermal comfort range in the kitchen is similar to the living room, cold during winter when heating is off and relatively warm when the heating is on. The summer conditions appear to have been comfortable for over 70% of the year. The indoor air quality (Figure 7:62) is sometimes reaches 1500ppm and borders on poor air quality during each season. This is surprising as the window is permanently open to allow an electrical extension cable to provide power to an external shed.

The bedroom temperatures are mainly warmer than would be expected for sleeping and during the summer is constantly relatively high for sleeping and does reach a peak temperature of 26.4°C. The windows are opened more frequently in the summer however the corner placement, behind the door (and curtain) may restrict air flow in the room. There is opportunity for cross-ventilation in this room as there is a small window on the west wall however, the air path would be across the bed which could be perceived as draughty by sleeping occupants. Although the CO_2 concentrations appear to be relatively good through the year there were times when the concentrations peaked at 2400ppm (spring), 2275 (summer) and 1825 (autumn).

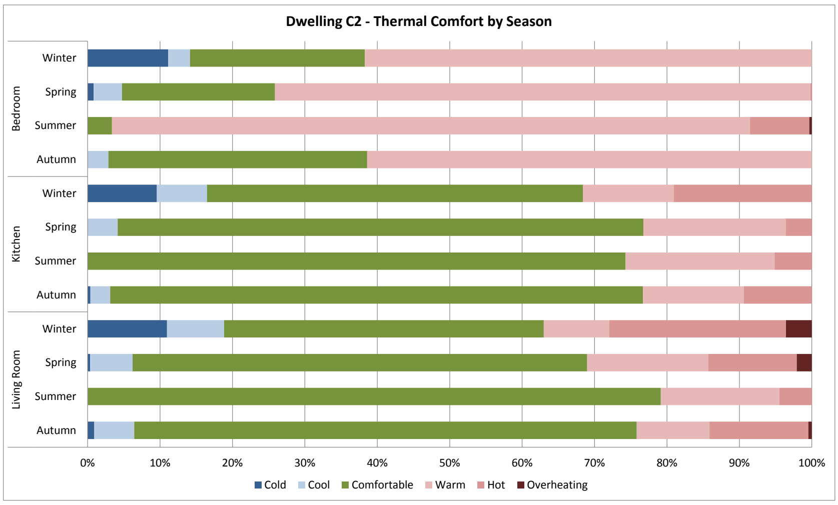


Figure 7:61: Temperature profile by season for dwelling C2.

This chart indicates extended periods where the living room and kitchen are at a comfortable temperature (18-23°C) while the bedroom is mostly heated to similar temperature (19-24°C) however this temperature is considered too warm for comfortable sleeping.

During the winter there are frequent instances when the internal space temperature drops below 16°C.

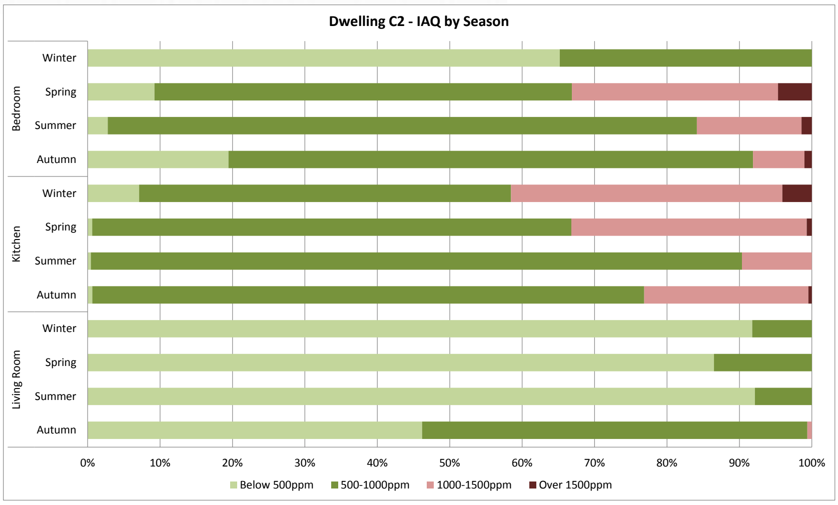


Figure 7:62: CO_2 concentrations by season – Dwelling C2.

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

This dwelling demonstrates a relatively good indoor air quality in the living room, while the CO_2 concentrations are higher in the kitchen and bedroom.

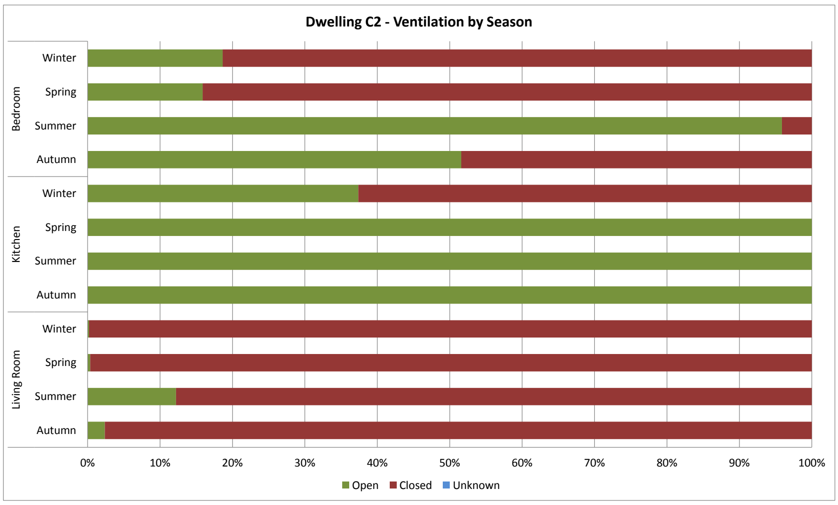


Figure 7:63: Annual window opening expressed as percentage – Dwelling A2.

The chart illustrates bedroom and living room windows are rarely opened during the winter and are opened more requently during spring and summer. The kitchen windows indicate it is perminantly open, through spring, summer and autumn and open around 38% of the time during winter.

However, it would have been expected that windows, particularly in the living room would have been opened more frequently.

House Type D

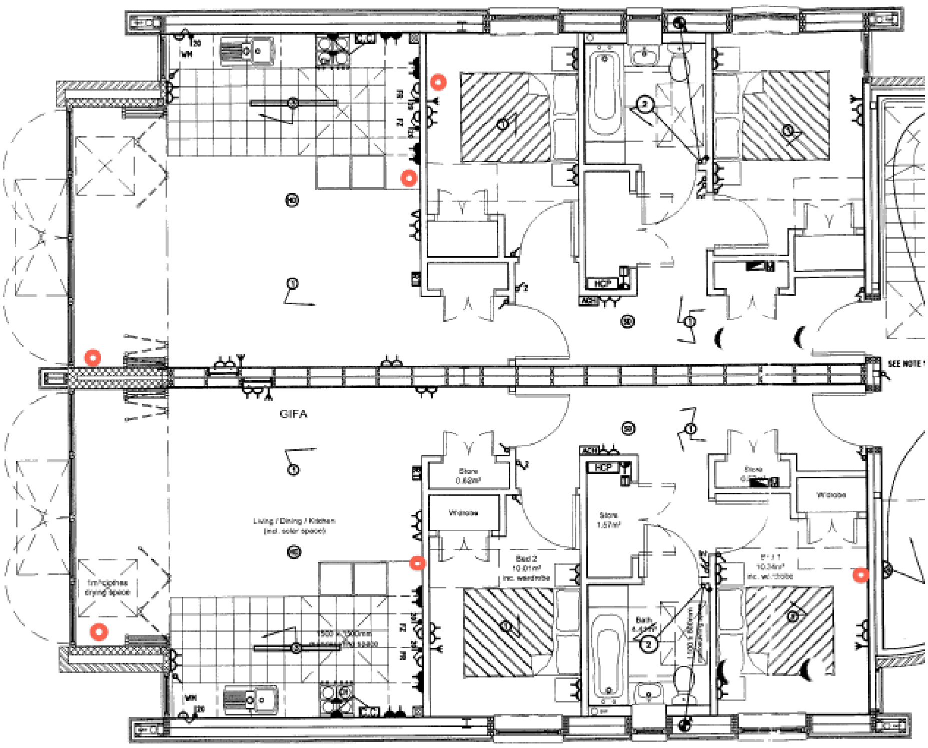


Figure 7:64: Floor Plan and sensor location house type D.

In this house type three rooms were monitored these were; the living room, sunroom (open to living room) and occupied bedroom (Figure 7:64). The residents of these flatted dwellings occupy their respective homes normally during evenings and weekends, while an occupant in dwelling D1 is a shift worker and frequently occupies the dwelling from early afternoon.

Dwelling D1

In this dwelling, the thermal comfort data for the sunroom indicates this to be the most comfortable of the monitored spaces through the year. However, bifold doors separate the living room and sunroom and these are permanently open, in addition to this the occupants have placed furniture (corner sofa) partially in the sunroom to extend their living space. Therefore as these two spaces are essentially one volume the monitoring of these will be discussed together. The temperature range in winter indicates the sunroom to have longer periods of temperatures that are deemed more comfortable than the living room. However during the winter the space heating is utilised to heat the dwelling, as the sunroom temperature was found to be lagging behind the living/kitchen, the sunroom was having a cooling effect on the internal environment, this is graphically illustrated in Figure 7:68 and was identified during thermography (Chapter 3). During summer (Figure 7:69) the opposite is true, where solar heat gains from the sunspace are attributing to overheating in the living room. The final construction of the sunspace with the double glazed façade, being fitted externally (thermal envelope) and the internal single glazed bifold door allow the occupants to use the unheated sunspace in a way that is contrary to the design intent.

In the bedroom, the space temperature is generally below 24°C for most of the year and overheating did not occur refer to Figure 7:65. However, indoor air quality (Figure 7:66) is compromised due to low airchange rates as a result of infrequent window opening (Figure 7:67). When conducting the exit interview (Chapter 5) the occupant had commented the biggest change they have made due to the project was opening the bedroom window at night, and felt the room was less stuffy.

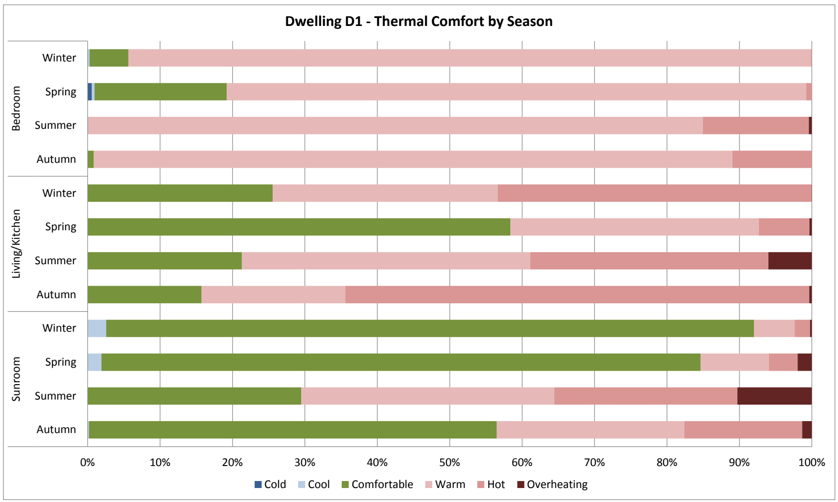


Figure 7:65: Temperature profile by season for dwelling D1.

This chart indicates the bedroom was maintained at a temperature between 19-24°C for most of the year, while both the living room and sunroom show relatively comfortable temperatures during the year and exhibit overheating in summer and spring (sunroom only). All rooms exhibit temperatures in the 'hot' category (23-28° living room and sunroom and 24-26°C bedroom) for long periods.

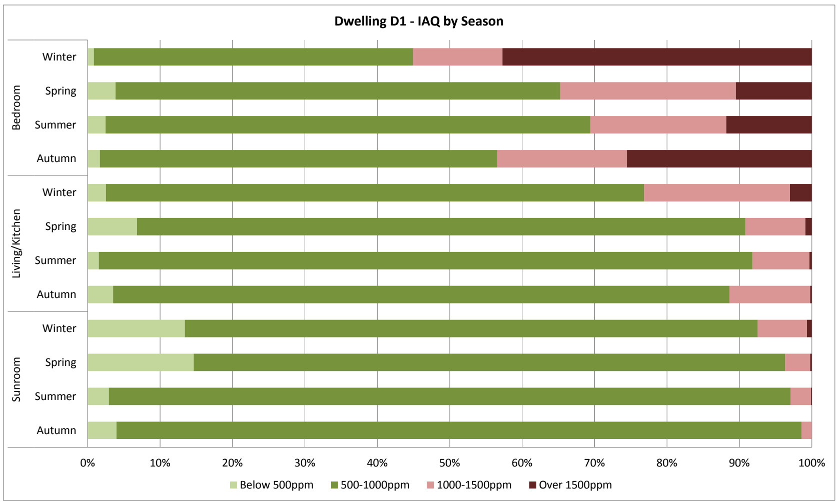


Figure 7:66: CO_2 concentrations by season – Dwelling D1.

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

The CO_2 concentrations in the living room and sumroom are predominatly good through the year, while there are periods when the bedroom CO_2 levels rise considerably providing poor indoor air quality.

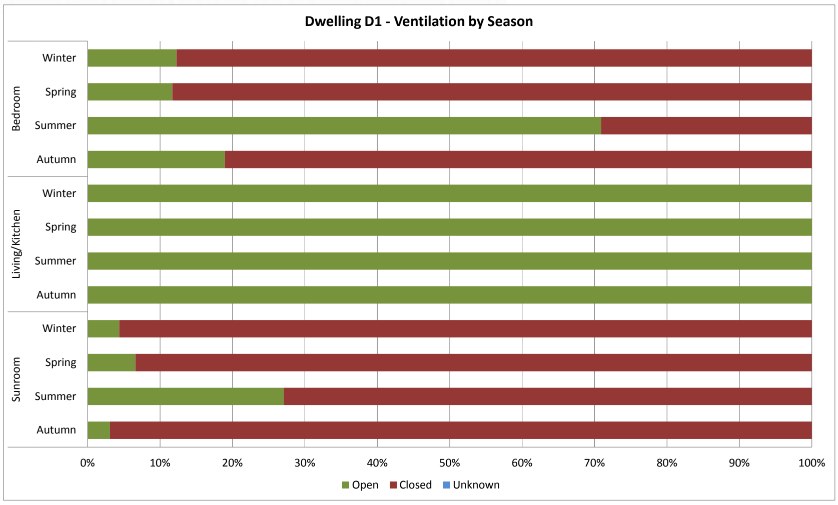


Figure 7:67: Annual window opening expressed as percentage – Dwelling D1.

The chart illustrates windows are opened more frequently during the summer. The bifold doors to the sunroom are constantly open to the living space.

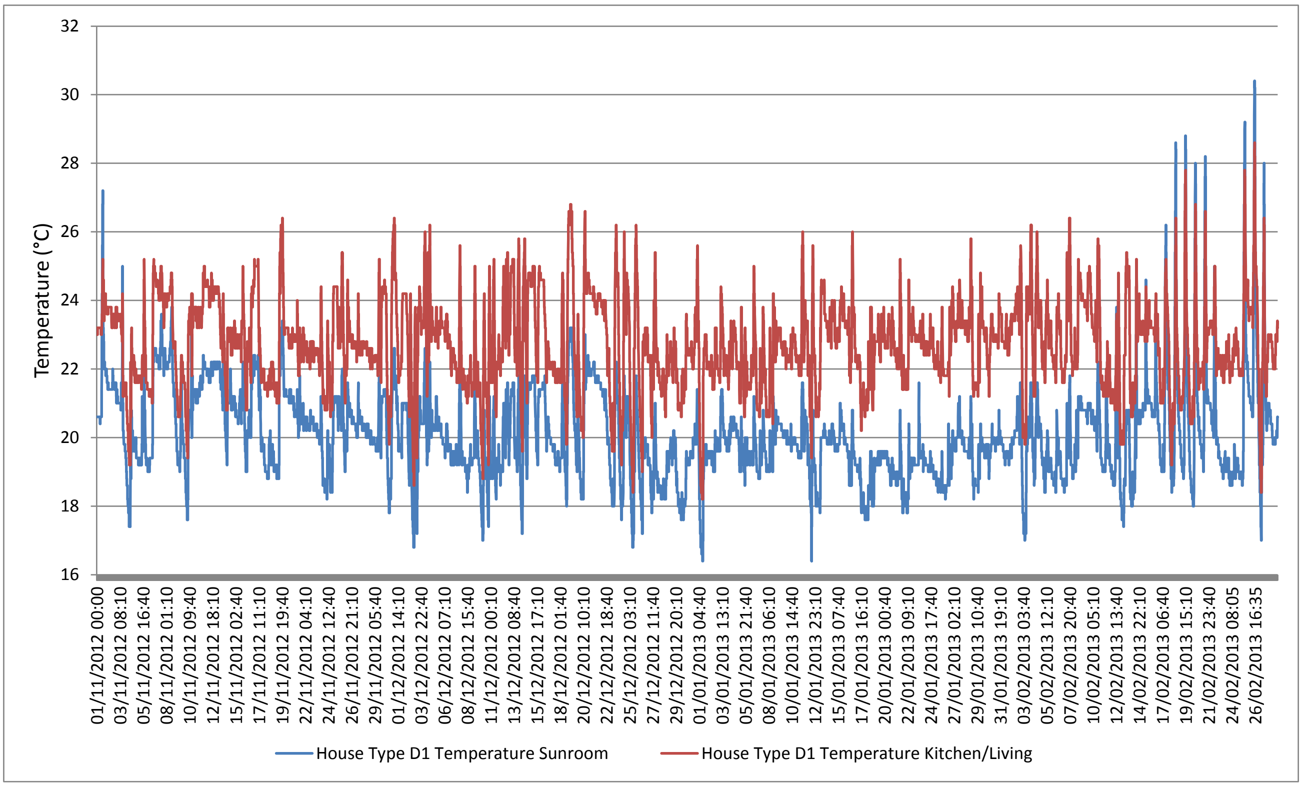


Figure 7:68: Monitored space temperature of Living room and Sunroom winter period (Nov '12 – Feb '13) dwelling D1

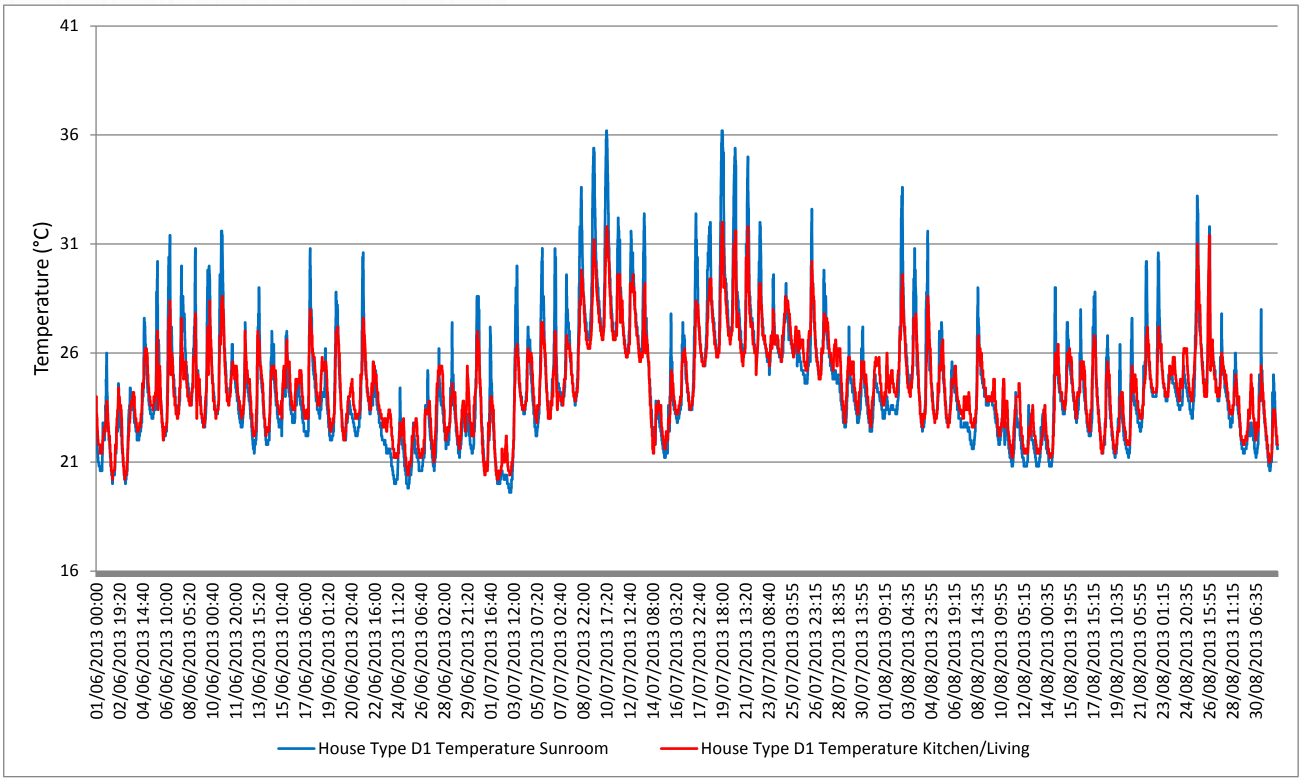


Figure 7:69: Monitored space temperature of Living room and Sunroom summer period (Jun '13 – Aug '13) dwelling D1

Dwelling D2

In this dwelling the occupants have also extended their living space into the sunroom and doors between the living space and sunroom are permanently open to make way for a dining table (Figure 7:70). At the time the data recordings the occupancy pattern was generally evenings and weekends. The heating was programmed to 'off' during the day. As with the neighbouring property living room temperatures are negatively affected by the sunspace, during winter the living room is cooled by the unheated sunspace and during summer the heat gain in the sunspace contributes towards overheating.

In this dwelling, the relatively warm bedroom temperatures (Figure 7:71) were more of a concern for the occupants as they consider the room to be too warm, as a consequence of this the occupants have set the radiator TRV in this room to 'off' but they also consider it fortuitous the bedroom is warm in winter as they would need to decide whether to heat the open plan living area (which is cooled by the sunspace) or the bedrooms, as they are unable to achieve heat output from all the radiators in the dwelling simultaneously. The radiator TRV is set to 'off' and the north facing window is not subjected to solar gain, it therefore appeared unusual for the winter temperatures in this bedroom to exceed the CIBSE recommended winter comfort threshold for sleeping (17-19°C) and be mostly maintained between 19-24°C without heat input from a heating system to the room. (Compared with temperatures as low as 10°C in the north facing bedrooms of House Type C (also lightweight construction), when unheated).

A thermographic survey was undertaken in April 2014, this revealed the bedroom is being heated through heat gains from the fridge/freezer and living room radiator which are both placed beside the wall separating the living/kitchen and bedroom. In summer, the fridge/freezer continues to reject heat to the room and wall, which impacts the bedroom temperature, as it can be seen in Figure 7:71 bedroom temperatures in the summer are mostly over 24°C and overheating (above 26°C) occurs for around 15% of the season. Air quality in the bedroom suggests (Figure 7:72) low air change rates in this room as CO_2 concentrations are frequently high all year round. The occupants open the window at night but also pull a roller blind (for privacy) which is fitted close to the window frame, therefore in summer the ventilation rate doesn't provide enough air changes to maintain good indoor air quality.

Figure 7:70: Dwelling D2 indicating dining table posited between living/kitchen and sunroom.

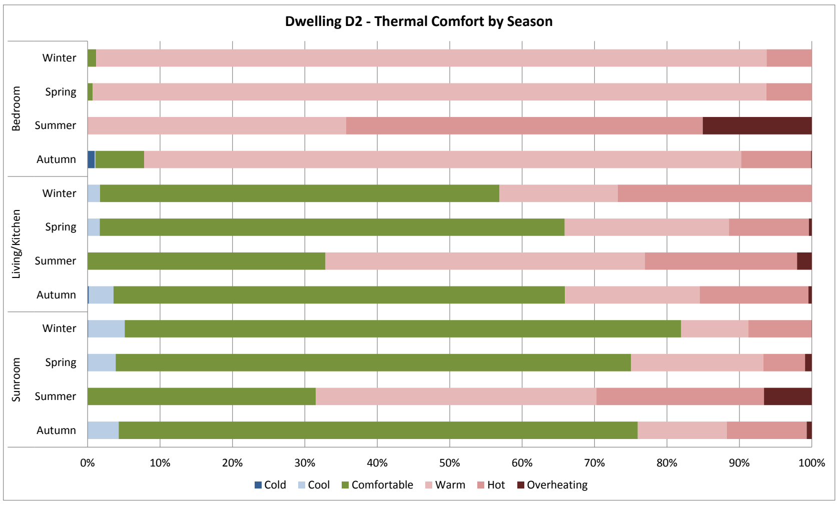


Figure 7:71: Temperature profile by season for dwelling D2.

This chart indicates the bedrooms are maintained at a temperature between 19-24°C for most of the year, except summer where temperatures that exceed 26°C were recorded. There are frequent periods of temperatures lower than 18°C in the living room and sunspace.

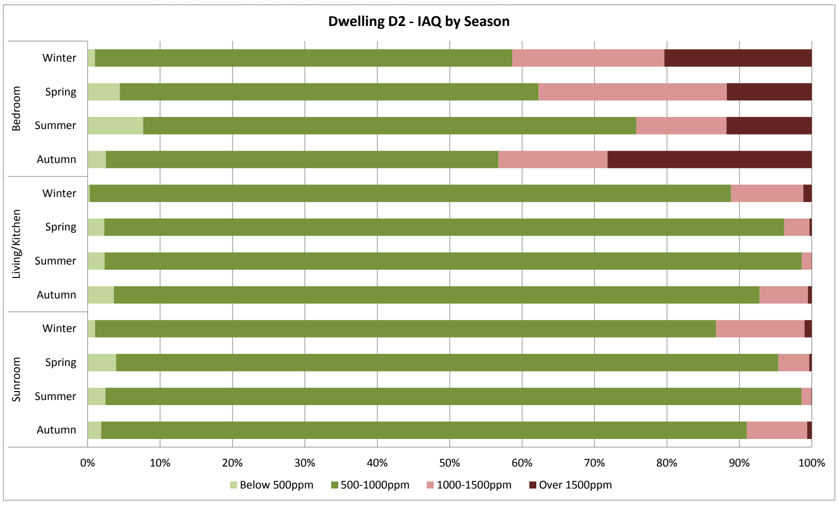


Figure 7:72: CO_2 concentrations by season – Dwelling D2.

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

The CO_2 concentrations in the living room and sunroom indicate good air quality, however, the bedroom concentrations tend to be high.

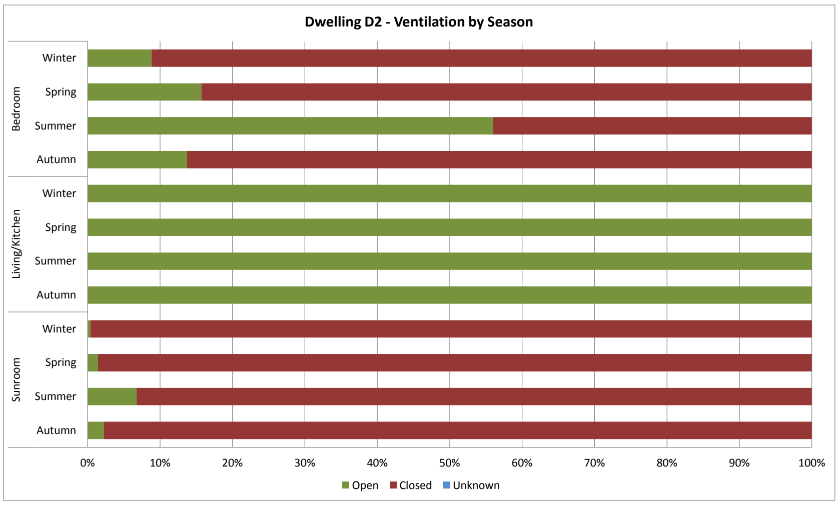


Figure 7:73: Annual window opening expressed as percentage – Dwelling D2.

The chart illustrates the windows are rarely opened in the sunroom and a regular opening pattern is identified through each season in the bedroom.

The internal door separating theliving room from the sunspace is constantly open.

7.5 Water Monitoring Summary

In Scotland new dwellings are not routinely fitted with water meters (nor are they mandated to be fitted) due to water charges being made through the council tax linked to individual properties. Therefore as water consumption is not financially linked to a household, there is no incentive for households to conserve water. There is also a common misconception that as '*it rains a lot*' in Scotland there is plenty of water which again reflects user consumption. However, what is often overlooked is the energy consumed for heating hot water in the dwelling and additionally the significant energy consumption and carbon emissions associated with cleaning, treating and pumping of water and waste water to and from point of use. Figure 7:74 illustrates the two year annual water consumption for each dwelling. There is a distinct link between number of occupants and water consumption.

During occupant feedback sessions in January 2014, detailed information on each households consumption was presented and information on water conservation was provided to them. Only one household, D2, actively engaged with this element of feedback and were genuinely shocked by the quantity of water they had consumed over a year, however the second year of monitoring indicated a minor decrease in water consumed. Water consumption by House Type is discussed below.

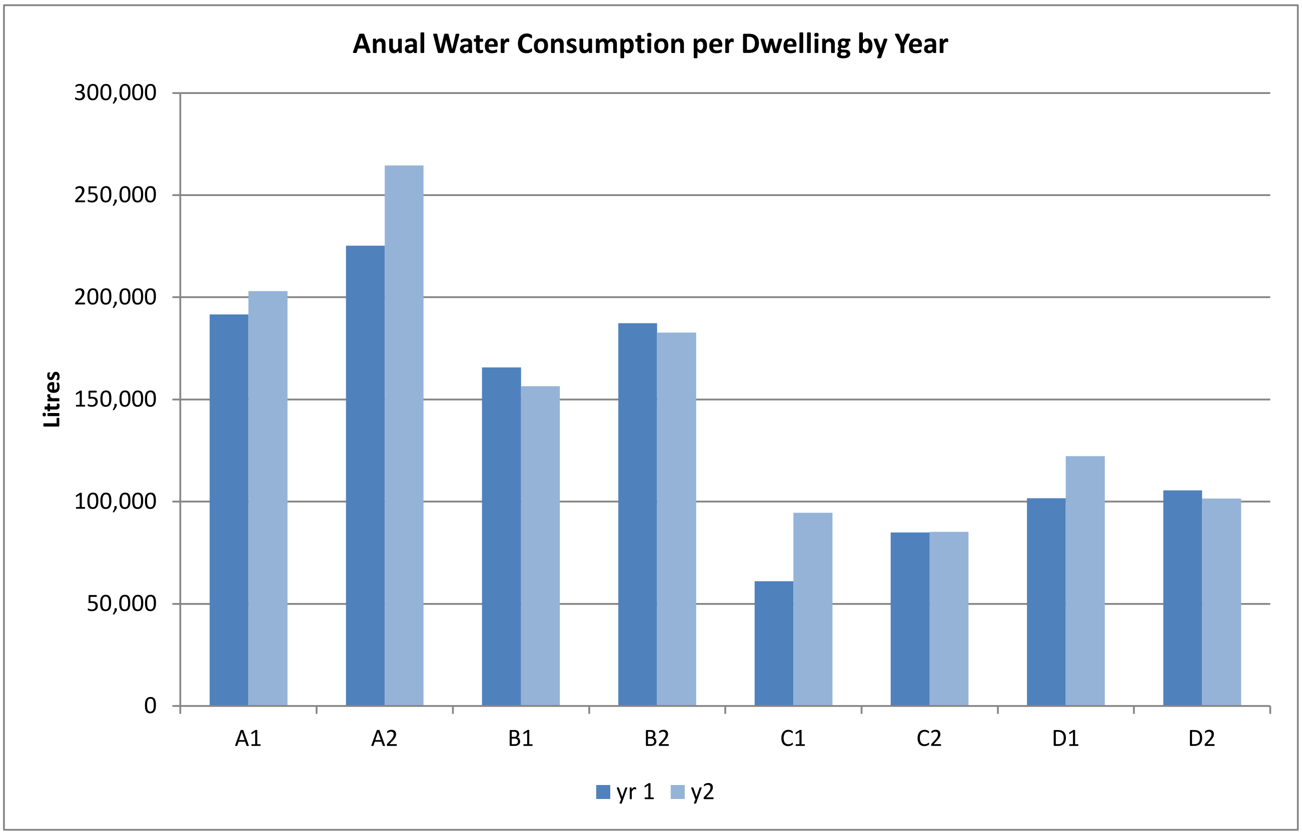


Figure 7:74: Annual water consumption by dwelling for year one and two of the monitoring period.

HOUSE TYPE A

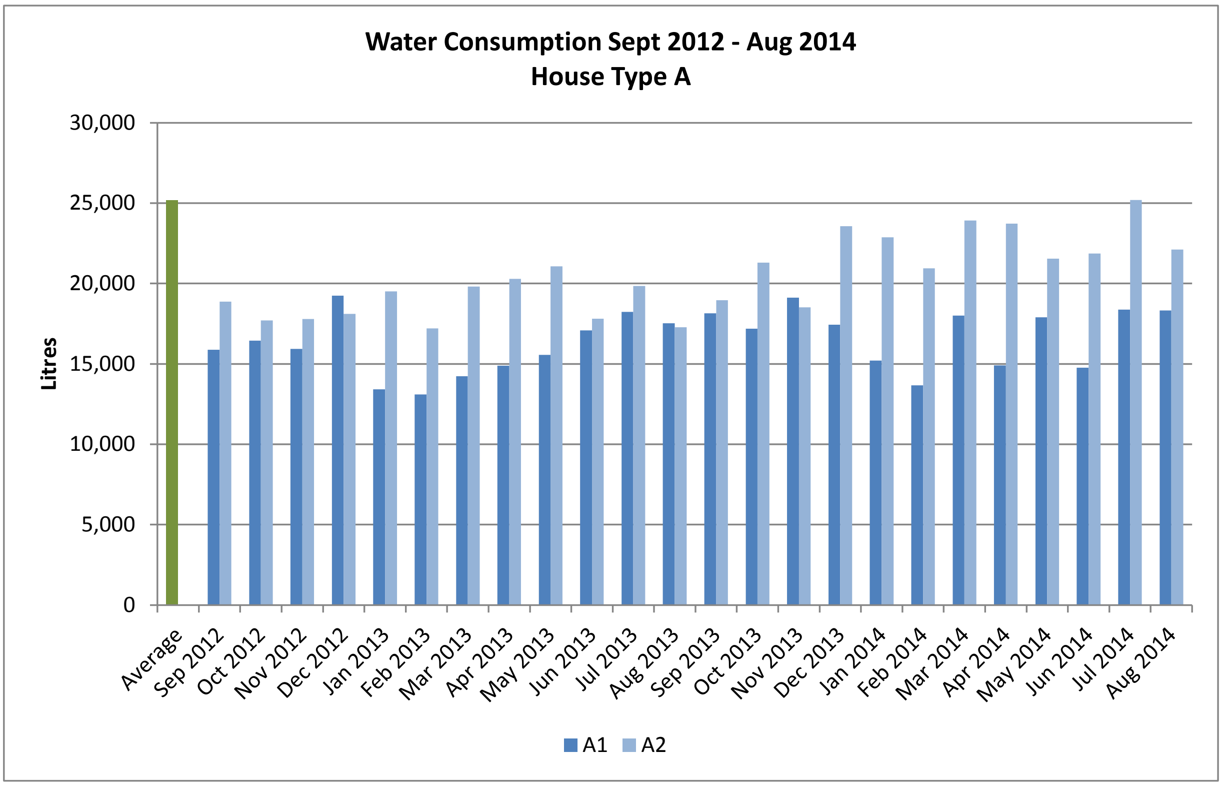


Figure 7:75: Water consumption by dwelling for September 2012 to August 2014 - House Type A.

In House Type A, two year consumption information plotted in Figure 7:75 indicates dwelling A2 to consistently consume more water than dwelling A1. The reason for this is not clear, as occupants numbers in each dwelling are identical and neither of the dwellings have dishwashers. The winter diary data indicates that dwelling A1 has on average three loads of washing per day, while A2 has one load per day. The review of bathing activity for the diary week revealed four of the occupants in dwelling A2 routinely have baths as well as showers. It would appear two bath tubs are drawn per day, indicating bath water is shared between the younger children. However in comparison with standard consumption benchmark data for a six person household (from Energy Saving Trust) consumption in both households is normally below the average (indicated in green in Figure 7:75).

HOUSE TYPE B

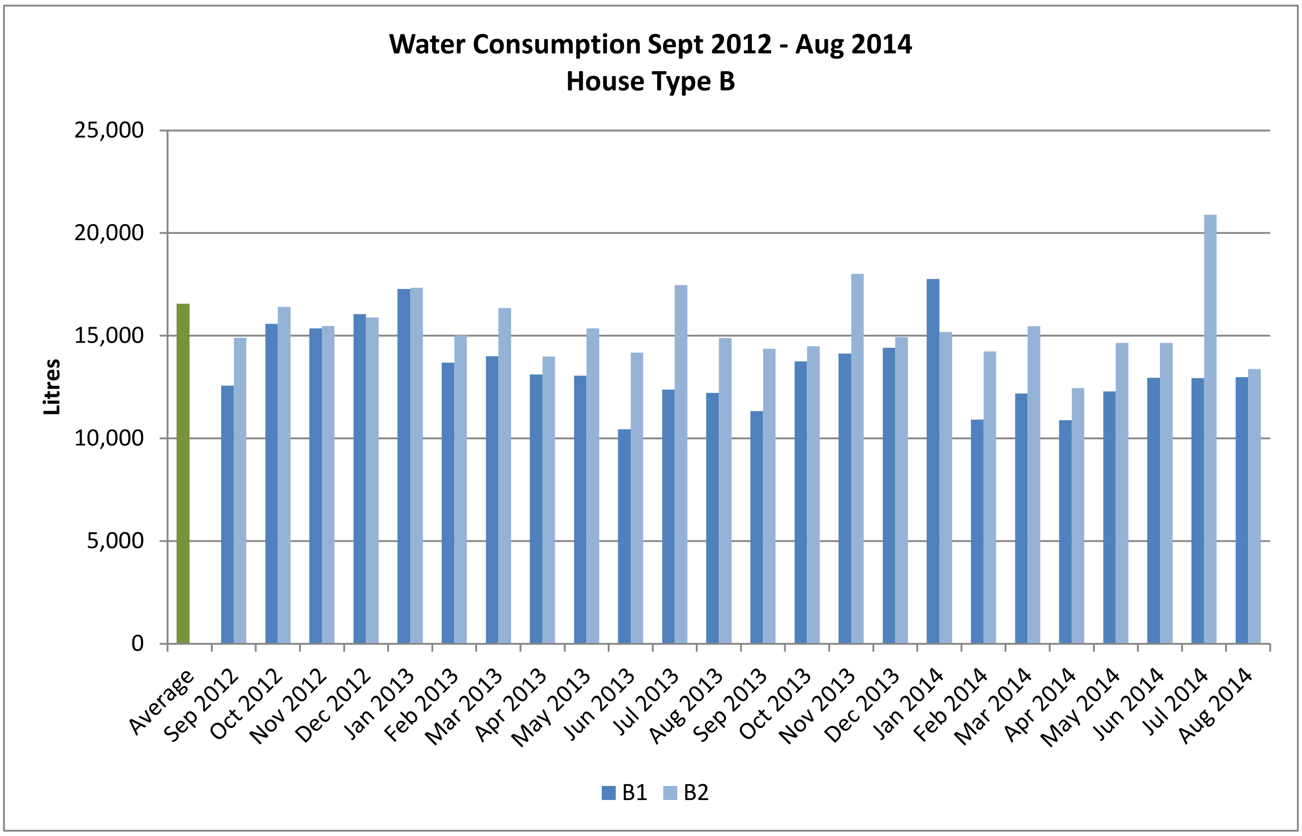


Figure 7:76: Water consumption by dwelling for September 2012 to August 2014 - House Type B.

House Type B has fewer occupants than House Type A and on average consumes less water. Figure 7:76 indicates that the consumption for both dwellings was around or below the benchmark for a four person household (Energy Saving Trust consumption figures). Dwelling B1 typically had lower water consumption than its comparison dwelling.

In dwelling B1 there was a slight reduction in consumption during Feb 2014 and the following months thereafter, this coincided with two of the occupants moving out of the dwelling.

HOUSE TYPE C

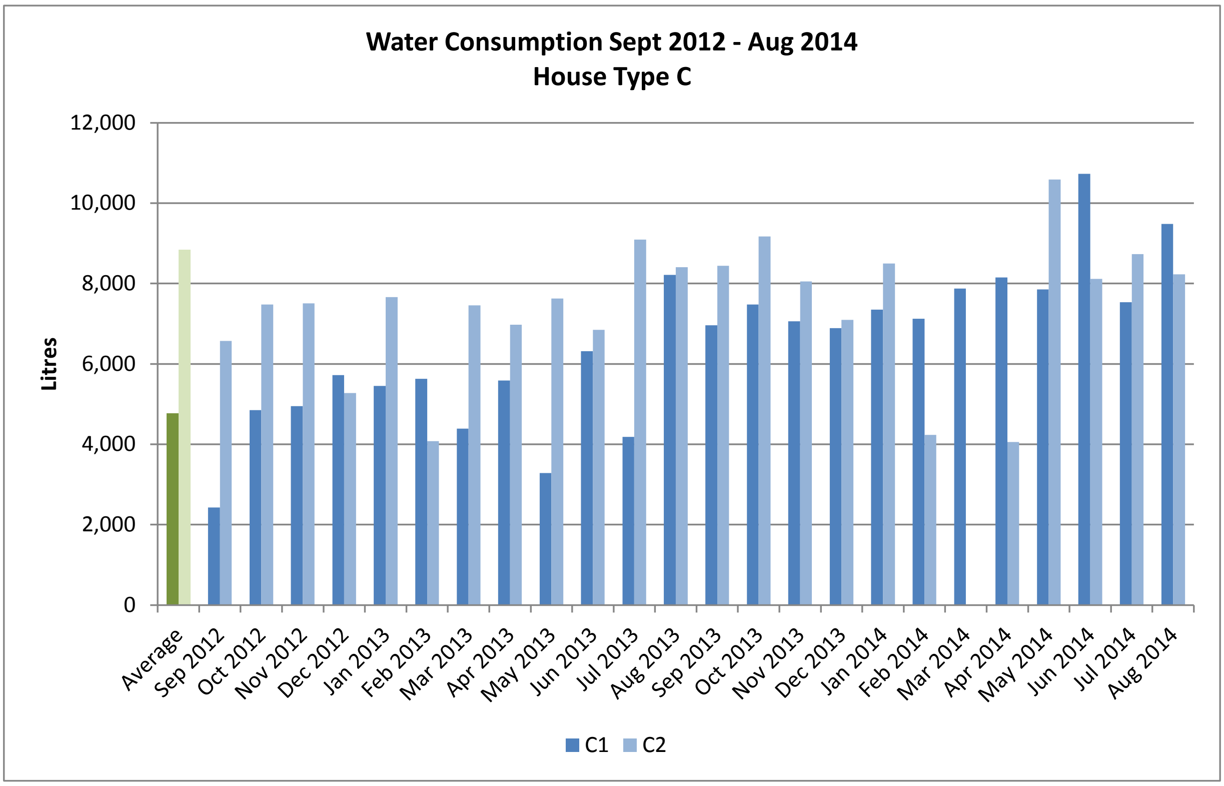


Figure 7:77: Water consumption by dwelling for September 2012 to August 2014 - House Type C.

The data collection for House Type C was problematic throughout the monitoring period with wireless signals frequently being lost. However the plotted data (Figure 7:77) indicates there to be no clear user pattern for water consumed in both dwellings of this house type (as identified in House Type A and B). Consumption comparisons for June 2013 and June 2014 indicate a considerable increase in June of 2014 in both dwellings. This could be directly linked to an increase in external temperature during June 2014.

In dwelling C1 there was initially one occupant until mid-August 2013, the data for before this time, indicates consumption to be slightly above the average for a one person household (dark green column in Figure 7:77). From August 2013, two persons occupied dwelling C1 where consumption was mostly below the two person average benchmark (indicated in light green in Figure 7:77) except for June and August 2014.

Consumption in dwelling C2 mostly falls below the two person average consumption data, except for July and October 2013 and May 2014.

HOUSE TYPE D

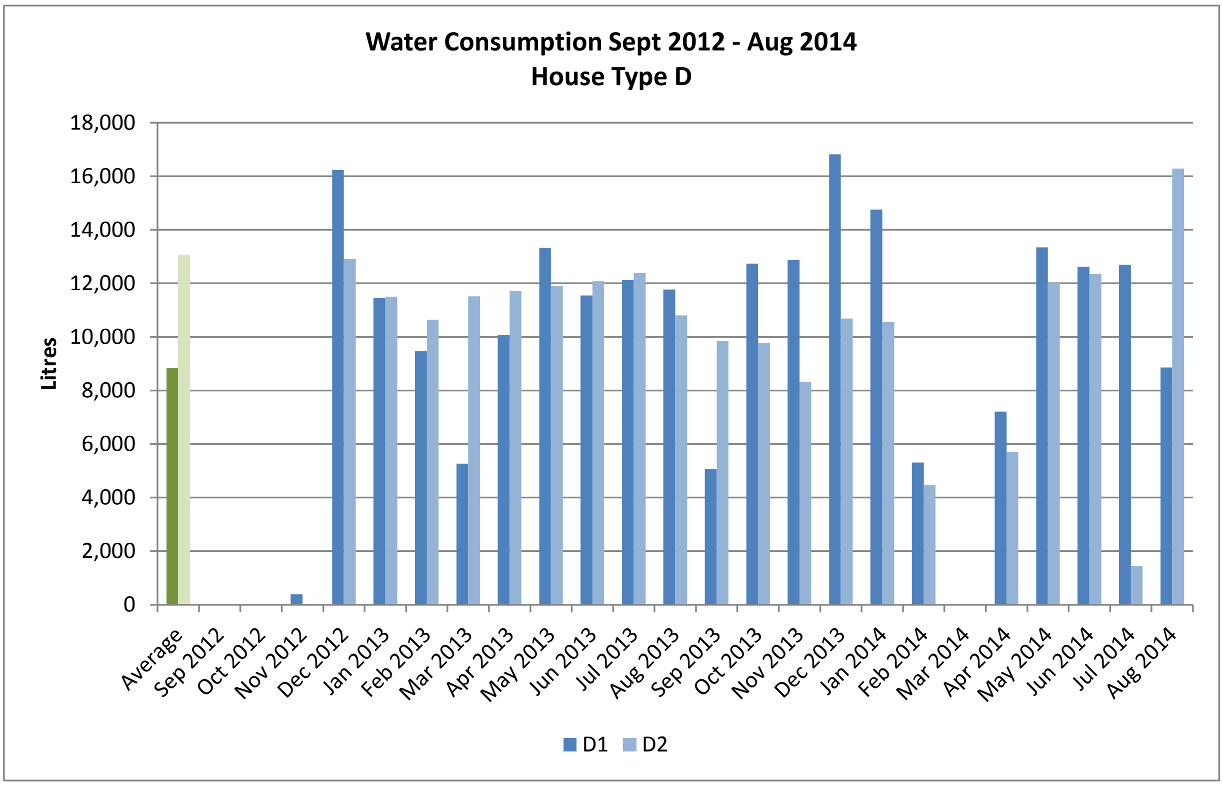


Figure 7:78: Water consumption by dwelling for December 2012 to August 2014 - House Type D.

The data collection for this House Type had frequent transmissions issues. However the data obtained, plotted above indicates dwelling D1 to have been predominately the highest consumer and to be mostly above the two person benchmark data (dark green in Figure 7:78).

In dwelling D2, the consumption was also mostly greater than a two person household, an increase was detected during August 2014 which was linked to the birth of an infant and an increase in daily laundering. The consumption is still around 18% higher than the average benchmark for a three person household (indicated in light green in Figure 7:78).

Both dwellings consumption was more frequently greater than the Energy Saving trust average benchmark figures for two and three person household.

7.6 Conclusions and key findings for this section

Energy

The energy consumption in each dwelling was found to be higher than the consumption indicated by the SAP assessment, and later relayed to the occupants. However, what was not made clear was the SAP assessment and corresponding Energy Performance Certificate produced as a result of the assessment focus only in regulated loads and do not include non-regulated loads (which are the cooker and everything that is plugged in in a dwelling).

The overall consumption for the pairs of dwellings indicated that while overall energy consumption broadly similar, one dwelling in each house type consumed more than the neighbour in an identical house. In the pairs dwelling A1, B1, C1 and D1 all were found to have slightly higher electrical consumption than A2, B2, C2 and D2. The most significant of these was in B1, however this was found to be relating the incorrect use of the electrical immersion for water heating by the occupant. The occupant was grateful of the feedback from the research team and has since switched to using gas for heating the hot water.

Dwelling C1 when under single occupancy had a greater electrical demand than after a change in tenant to two people. This was mainly related to the use of electric heating.

The CO_2 emissions from seven of the dwellings were greater than the SAP predictions, C2 was the exception to this where the data confirmed that due to the frequent use of the wood burning stove the electrical heating use was minimal (the occupants have also removed the electric heating panel in the kitchen to allow fitting of additional units and worktop). A significant increase in CO_2 emissions were identified from House Type A and D (excluding B1 as the emissions were due to electrical water heating), the reason for increase in emissions from House Type A is not immediately clear, but in House Type D the biomass boiler had failed to operate for a significant period through the monitoring period and gas back up was used.

Unregulated loads in each dwelling were found to be high in all dwellings, as noted above, this relates to electrical consumption for cooker and other electrical items plugged in, such as television, fridge/freezer, computer etc. Although there is a drive for conservation of electrical use, it is clear product manufacturers need focus more on reducing consumption of their products. It was noted during the DomEarm study that some households were proud to mention the energy efficiency of the television but were not sure what band their white goods fell into. However, the DomEARM assessment indicated the actual performance of the majority of the dwellings was around the Part L Compliant benchmark, with one dwelling D2, performing well against all benchmarks.

Environment

The internal conditions of each of the dwellings indicated that the living rooms were generally of average air quality and temperature, with overheating during the summer. The living rooms of all of the monitored dwellings are orientated south to west and have large un-shaded glazed areas. Only one of the dwellings (House Type B) was designed with a sun shade (brise soleil) that was removed as part of a value engineering exercise and the architects original intent was for solar gains to be maximised. However the large glazed areas of each dwelling is orientated south-west to west which are difficult to shade from low angle sun.

In House Type B, thermal mass in the floor and a wall were omitted from the living space, this may have provided a buffer during the summer, to help even out temperatures. However, this would only have been effective if the heat stored in the thermal mass was able to discharge at night and it is questionable whether the occupants would have left ground floor windows open to allow this to happen. In House Type D the unheated sunspace in our opinion has failed to operate as the design intended. It was found through the study that in colder weather the sunspace causes cooling of the living environment; essentially the occupants have turned up their thermostats and keep heating on for longer to keep the room at a temperature comfortable for them. While in the summer, the solar gains through the glazing are causing the temperature to rise in the living environment and contributing to overheating. This is due in part to poor orientation of the glazed façade and incorrect installation by the contractor, the omission of high level windows and the habitation of the sunspace.

The temperature in House Type C was seen to drop dramatically to temperatures as low as 10°C during times when the external temperature was low and space heating was off. The stove in dwelling C2 raised the internal space temperature considerably and the occupant had noted lack of control for this. On the whole this House Type maintained comfortable temperatures for the highest portion of the year, but as the dwelling is electrically heated there is concern of comfort conditions if the occupant was unable to afford heating fuel.

Overall, bedrooms performed poorly where they are being heated to temperatures higher than the recommended comfort temperatures for sleeping. However, it is recognised that bedrooms are occupied for purposes other than sleeping and sedentary occupants would feel bedroom design comfort temperatures too low. Therefore the rooms will be heated to temperatures similar to the main living space. Of particular interest was the two east facing bedrooms in House Type B. These are both occupied by single occupants of teenage years who both spend considerable time in their rooms. The occupant in dwelling B1 opens the window frequently, while the occupant in dwelling B2 rarely opens their window. The indoor air quality in B2 is particularly poor, highlighted by concentrations continually over 1000ppm. Similar air quality issues were identified when comparing the west bedrooms in House Type A, where in dwelling A1 CO_2 concentrations were continually high, despite frequent window opening, where the indoor air quality in A2 is better even though the window is opened less often (as access to the window is obstructed by a child's cot). It is believed that the higher CO_2 concentrations in dwelling A1 are due to an additional adult occupant.

Window opening habits were identified for each household, it was seen that in most cases the opening became more frequent with warmer external temperatures and less frequent as temperature dropped.

Water

The conservation of water in the dwellings appears to be a low priority for the occupants of this BPE study. This is mainly due to the way in which households are charged for their water, where a lump sum is included in their council tax, offering little incentive for water conservation. The consumption of the eight dwellings was compared against average benchmark data (based on number of occupants) which illustrated the consumption of the multi occupancy dwellings of House Type A and B to be relatively close to the benchmark data. It was interesting to note the benchmark consumption per household was less accurate for the dual occupancy dwellings (House Type D) and where consumption patterns were more erratic with no discernible pattern. In dwelling C1 it was interesting to notice the rise in consumption following the change of occupants.

It was interesting to note the large energy consumption and CO_2 footprint associated with treating and pumping the water, sewage and waste water was of little interest to the participants as there is no financial incentive for them to be water aware.

8 Other technical issues

This section highlights issues identified that were related to the BPE study and are not captured elsewhere in the report.

8.1 Technical Issues

Lack of specialist equipment – The market for monitoring domestic dwellings wasn't (and still isn't) fully established for monitoring equipment, especially for sub-metering of small electrical loads. There was an issue that arose were despite the specialist supplier undertaking a site survey the smallest CTs (Current Transformers) that were available for sub-metering were 100Amps. Considering the potential largest electrical load in a dwelling is the cooker circuit (32Amp) the CTs were massively oversized. This had an impact of not accurately measuring the current drawn from sub-circuits in the dwelling. There were also technical issues with the environmental monitors not able to measure at the accuracies stipulated by the TSB. Although MEARU have spent significant time in liaising with t-mac (supplier selected for this BPE project) after two years there remain outstanding issues to be resolved in terms of CO_2 monitoring.

Participant access to t-mac data repository - A feature of the t-mac system was to allow each participant to review online their consumption details and indoor environment conditions, this was once of the features that attracted MEARU to the companies monitoring equipment. However, the intention was for the occupants to live in their dwelling in it 'natural' state for one year, undertake feedback sessions and observe whether the occupant had made changes due to the project. In order to set up the online data repository it was essential for each individual household to have a login to access their data. It was found t-mac had set up access to the repository in such a way that it permitted occupants to view data for all dwellings on the site. In discussion with t-mac the data could be made confidential to individual householders but they were not prepared to do this without incurring significant cost. A result of this was the occupants did not receive access to their data which caused frustration to them. One of the participants was so infuriated by lack of data access that they were thinking about withdrawing from the programme. The participant was eventually won over, but the research team needed to purchase and supply a separate energy monitor for this dwelling and produce feedback on one year's data, which was time consuming.

Noise Transfer – during the course of monitoring it emerged that there were issues with noise transfer in flatted dwellings. While using thermography with airtightness testing it was identified there could be a lack of sound insulation between separating floors. The investigation of this was outside the scope of the BPE study and therefore the research team attempted to establish how this could be inspected either as part of the project or to gain funding for this to take place. The BPE doesn't provide any guidance on remedying or probing deeper into defects found as part of the study. The impact noise is causing stress to the occupants and the research team were unable to offer any support, particularly after the households have been willing for their homes to be monitored for two years.

Thermostatic mixing valves – there were reports from two different dwellings where they felt the thermostatic controls on the bath and shower were set too low. The occupant who reported the bath controls described how kettles and saucepans full of water are boiled and carried to the bathroom to top up the hot water temperature.

8.2 BPE Process

While it is understood for reliable data it is necessary to collect data over an extended period the two year monitoring period was lengthy. There were a number of tests that required to be undertaken and some householders became fatigued with the access required to their homes. As they found the project to be more hands on than they had imagined at the start. Occupants who were working found they needed to take holidays from work to allow access during the day. To ease this, the research team attempted to fit in with the timetables of the occupants as much as possible, to minimise disruption to their daily routines. However, on the positive side, the number of times access was required increased familiarity with the researchers and occupants, their homes and routines which broadened the understating of the dwelling and assisted in identifying erroneous data or unusual activity.

The data collection was collected every five minutes for a number of variables, this made examination of the data an onerous task. As a result it was mainly the headline information that was examined from quarter to quarter for the quarterly reporting process. However, it also helped to cement activity and assisted in identification of data errors.

8.3 Indoor Air Quality Testing

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 (IAQ) 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. 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 indoor air quality. The houses at Inverness 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 was undertaken.

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 is apparent that CO_2 levels are higher for longer periods than living rooms. Both the length and intensity of occupation can be more accurately assessed.

The overview survey found that most occupants have their trickle vents closed and very few 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 (also indicated in Chapter 7). 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 these houses fall short of that standard. Calculated air change rates are relatively low in relation to desired rates for good indoor air quality.

8.4 Volatile Organic Compounds Monitoring

Further monitoring of indoor environments using specialist portable equipment for monitoring internal volatile organic compounds (VOC) levels. The equipment monitored internal CO_2 concentrations, temperature, relative humidity, formaldehyde concentrations, carbon monoxide and particulate matter in bedrooms of participating households for short duration of approximately 72 hours. Apparatus was set up as shown in Figure 8:1 in four of the households, however two full data sets were achieved. The following discusses the formaldehyde and particulate matter measurements of the dwellings. As formaldehyde concentrations are known to increase with a rise in temperature and relative humidity, the formaldehyde concentrations are plotted against temperature, relative humidity and CO_2 concentrations.

Figure 8:1: Portable VOC monitoring apparatus in dwelling B1.

Formaldehyde

In dwellings formaldehyde is emitted from a range of combustion processes including smoking, heating, cooking or candle burning. Other sources include building materials and consumer products. These include furniture containing formaldehyde-based resins and glues, paints, wallpapers, varnishes, detergent, carpet cleaners, cosmetics, textiles and electronic equipment. The principal formaldehyde exposure route is through inhalation with the most common effects to the eyes and nasal and upper airways. Formaldehyde is a recognised asthma trigger and is classified as carcinogenic to humans by IARC (International Agency for Research on Cancer).

The World Health Organisation (WHO) guidelines for concentration limits in the indoor environment are for a 30 minute average concentration of 0.1mg/m^3 (100µg/m^3). None of the monitored bedrooms were found to exceed the WHO exposure guidelines, however the peaks occurred during bedroom occupation (detectable through a rise in CO_2 concentrations) and where found to be close to the threshold limit, Table 8:1. The highest measured concentration was 0.09mg/m^3 in dwelling B1 and mean values for the three bedrooms over a 72 hour monitoring period ranged between 0.046 – 0.068mg/m^3, dwelling A2 had the highest average values. Although the monitoring is unable to indicate the source of formaldehyde emissions it is more likely the concentrations derive from consumer items, electrical appliances, cleaning products, candles or cosmetics brought into the home. All occupants are non-smokers and an assumption for off-gasing from the buildings materials is negligible due to the four year occupation period.

Dwelling	Min (mg/m^3)	Max (mg/m^3)	Mean (mg/m^3)
A2	0.038	0.088	0.068
B1	0.026	0.090	0.052
C1	0.029	0.055	0.046

Table 8:1: Minimum, maximum and mean formaldehyde concentrations (mg/m^3) in master bedrooms of participating dwellings.

Figure 8:2 illustrates the monitored conditions in the master bedroom in dwelling B1, between 8th – 11th June 2014. The bedroom window was open during the day and the first night of the IAQ monitoring, on the second night the bedroom window was closed (indicated by grey shading). During the first night with windows open the CO_2 concentrations remained below 1000ppm. The formaldehyde concentrations also increased but lagged behind the rise in CO_2. On the second night of monitoring the occupant closed the window at 22.35hrs for a 25 hour period, the CO_2 concentrations increased rapidly peaking at 3086ppm. The formaldehyde concentrations increased after the window was closed and the peak lagged behind the CO_2, as before. However when the bedroom was vacated the chart illustrates a quick drop off in CO_2 levels however background levels of formaldehyde remained around 60 µg/m^3 (0.06mg/m^3) until the window was opened. Prior to the window being opened there was a rapid rise in formaldehyde concentrations.

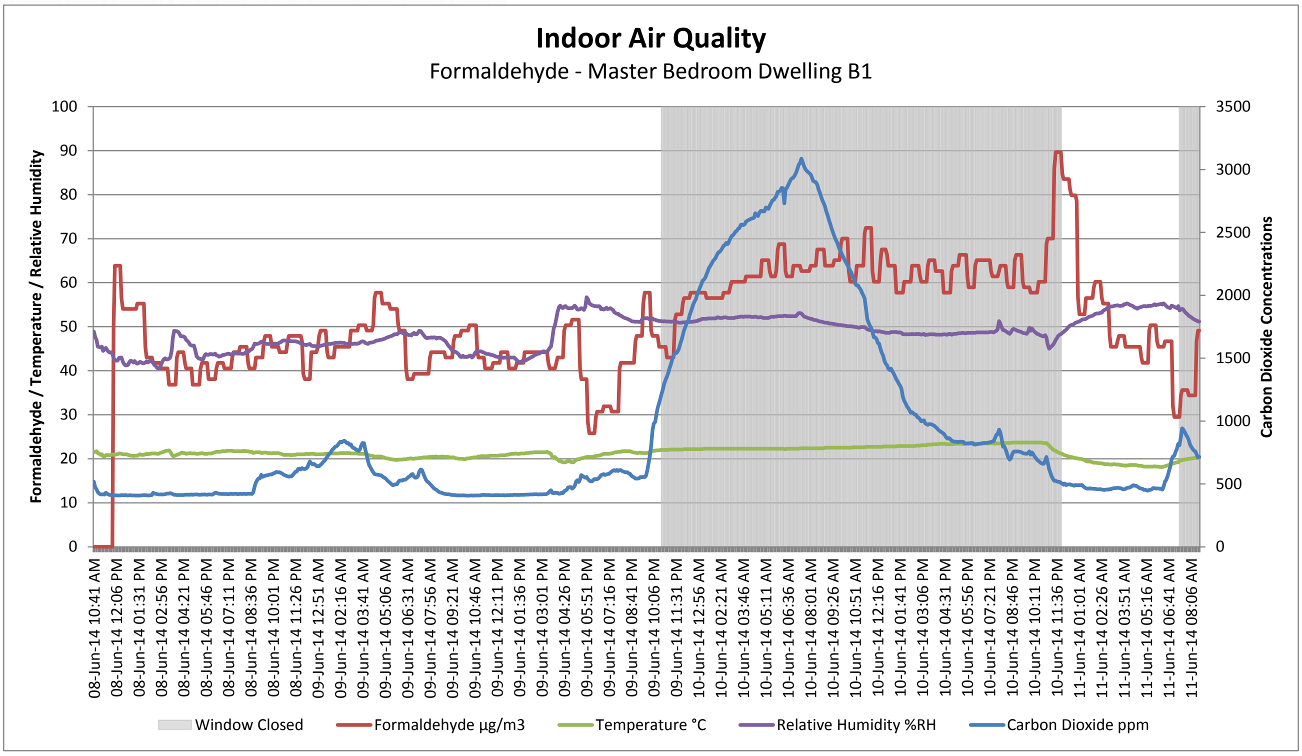


Figure 8:2: Measured indoor air quality in master bedroom in dwelling B1.

In dwelling A2, as with dwelling B1, formaldehyde levels increased as CO_2 concentrations increased, however the data indicated the bedroom window was open for the duration of the IAQ monitoring (Figure 8:3). The CO_2 concentrations were mostly over 1000ppm indicating that the natural ventilation air flow was insufficient to dilute the CO_2 and formaldehyde concentrations. However, the formaldehyde levels are seen to drop off when the room is unoccupied.

This pattern observed supports the 'bad company' theory discussed in the previous section of this chapter. However, what was not evident was measured data to support the link between a rise in formaldehyde concentrations and an increase in temperature and relative humidity. A larger sample set would need to be obtained to test this theory.

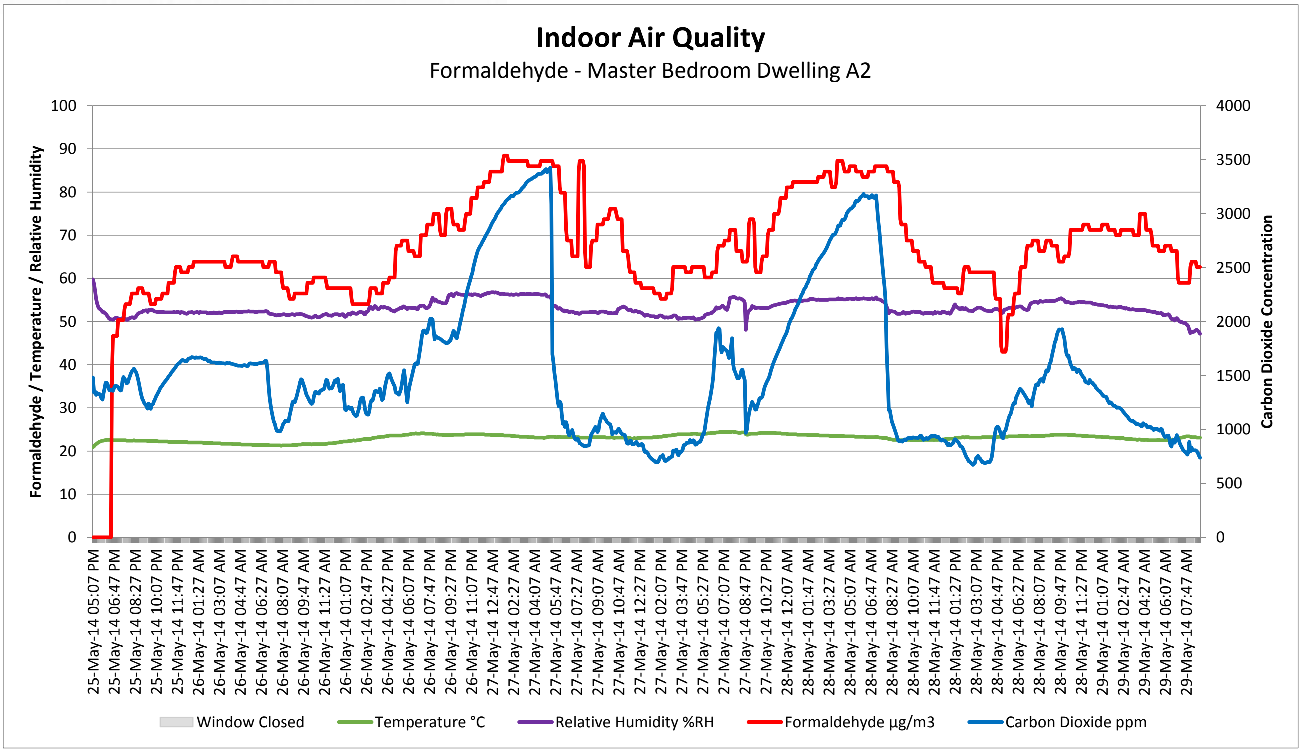


Figure 8:3: Measured indoor air quality in master bedroom in dwelling A2.

Particulate Matter

Particulate matter is a term used to describe airborne particles present in outdoor and indoor air. It is known that the particulates affect human health and the WHO report these to affect health of more people than any other pollutant. The most damaging particles as those with a diameter of 10 microns or less ($\leq PM_{10}$) as they are able to lodge deep inside lungs causing asthmatic symptoms, bronchitis, coughing and decreased lung function. Prolonged exposure contributes to risk of lung cancer and cardiovascular and respiratory diseases. PM_{10} is created from smoke, dirt, dust, farming, roads, mould spores and pollen. When airborne they typically travel distances of up to 30 miles from point of production. However, smaller particles $PM_{2.5}$ are toxic organic compounds and heavy metals generated from vehicles, burning of plants and smelting processes. These particles are lightweight and when suspended in air can travel hundreds of miles. As they are smaller they can be breathed deeper into the lungs and because of this $PM_{2.5}$ has a greater negative health impact. The WHO have identified that damage to health occurs at low particulate pollution levels where the 2005 guideline values were set as:

- $PM_{2.5}$ 10 µg/m^3 annual mean or 25 µg/m^3 24-hour mean
- PM_{10} 20 µg/m^3 annual mean or 50 µg/m^3 24-hour mean

Using the portable handheld equipment, illustrated in Figure 8:1, internal particulate matter was monitored and recorded in master bedrooms to determine the air quality in the internal environment of dwellings situated in a semi-rural location. The monitoring duration was 72 hours in three dwellings (A1, A2 and B1) and 24 hours in dwelling C1. The monitoring for dwelling A1 failed; therefore the findings from the three remaining dwellings are discussed here.

Dwelling	Min $PM_{2.5}$ (µg/m^3)	Max $PM_{2.5}$ (µg/m^3)	Mean 24 Hour $PM_{2.5}$ (µg/m^3)	Min PM_{10} (µg/m^3)	Max PM_{10} (µg/m^3)	Mean 24 Hour PM_{10} (µg/m^3)
A2	8.32	60.13	28.83	17.06	131.25	60.39
B1	2.15	115.98	18.23	6.60	608.70	79.38
C1	6.10	19.76	10.75	11.92	147.84	41.24

Table 8:2: Minimum, maximum and mean particulate matter concentrations (µg/m^3) in master bedrooms of participating dwellings.

Using the WHO mean values, stated above, Table 8:2 indicates dwelling A2 exceeds the daily mean value for $PM_{2.5}$ by 15% and dwelling A2 and B1 exceed the PM_{10} guidance by 20% and 58% respectively. The peak valued indicate dwelling A2 and B1 to exceed the mean value for PM2.5 and the peak PM10 values are much greater than the daily mean in all three dwellings. The peaks in dwelling in B1 were significantly high in comparison to the other two bedrooms. The concern is whether the bedrooms are occupied at the time of peak concentration (due to impact on health) and also to establish whether there is a relationship between an increase in particulate matter increased when a window was opened.

Figure 8:4 - Figure 8:6 plot recorded $PM_{2.5}$ and PM_{10} against CO_2 and window opening for each of the bedrooms. There appears to be a correlation between higher particulate concentrations, particularly PM_{10} in the bedroom with closed windows, as noted in dwelling B1. This suggests this bedrooms is more polluted with windows closed and particulates orginating in the outdoor environment had a minor impact on concentrations. It should be borne in mind that PM_{10} orginate from smoke, dirt, dust, farming, roads, mould spores and pollen, although the dwellings are located in a semi-rural location the busy A9 trunk road is approximately 300m from the site and dust from nearby farming activities, as well as pollen could have an impact on indoor particulate matter concentrations. When using CO_2 as an occupancy indicator, there was no clear evidence to determine whether bedroom occupancy increased particulate matter. The graphs illustrate particulate matter to lag, lead and be equal to CO_2 production.

This monitoring work was undertaken on a small sample group, where the measured data indicates that for this location window opening assists in dilution of particulate matter, but more work would need to be undertaken to determine this. Additionally there is no clear correlation whether occupancy causes particulate matter to increase due to the differing occurrences of peak particulate matter.

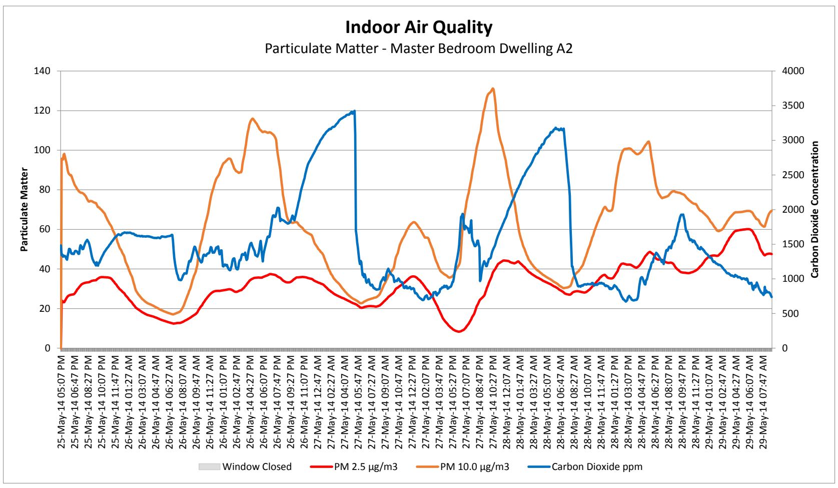


Figure 8:4: Measured indoor particulate matter and carbon dioxide concentrations in master bedroom in dwelling A2.

The plot indicates the window was constantly open during the monitoring period. This room is occupied by a young child and a parent. It appears that particulates begin to increase with one occupant present and peaks prior to full occupancy. CO_2 peaks are seen to lag behind the particulate peaks. PM_{10} concentrations are greater than $PM_{2.5}$.

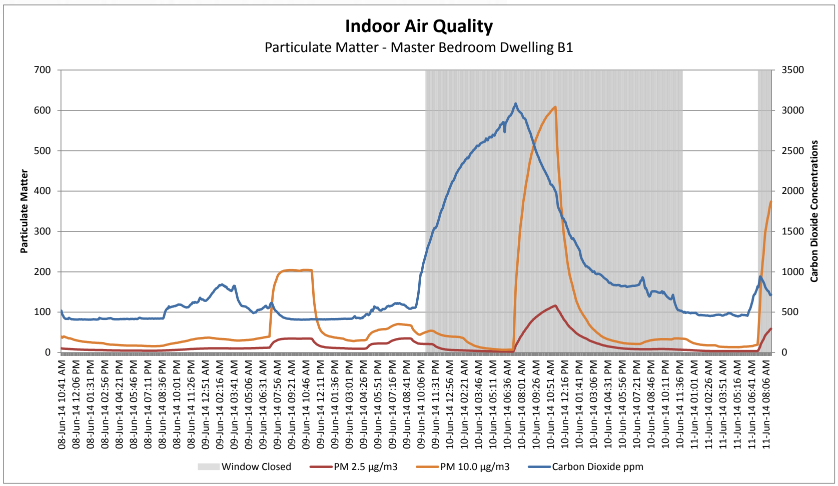


Figure 8:5: Measured indoor particulate matter and carbon dioxide concentrations in master bedroom in dwelling B1.

This room was initially monitored with the window open and then closed as indicated. The plot illustrates the particulate matter lags behind CO_2 concentrations, however the concentrations rise rapidly when the window was closed. PM_{10} concentrations are greater than $PM_{2.5}$.

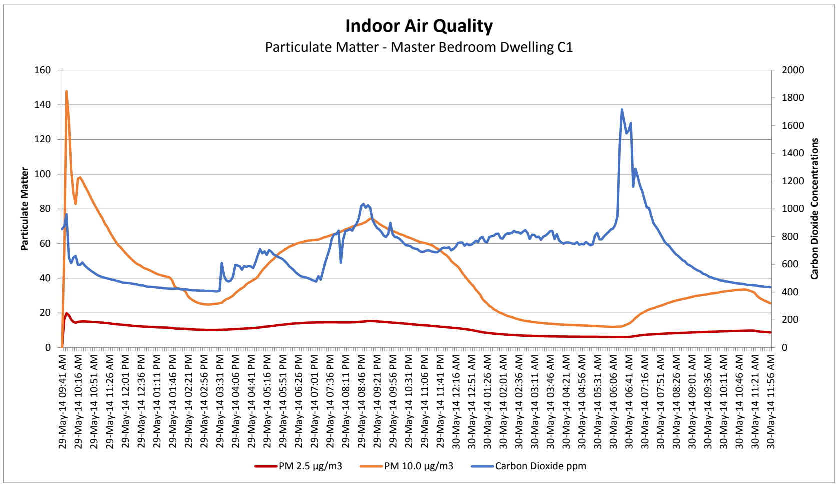


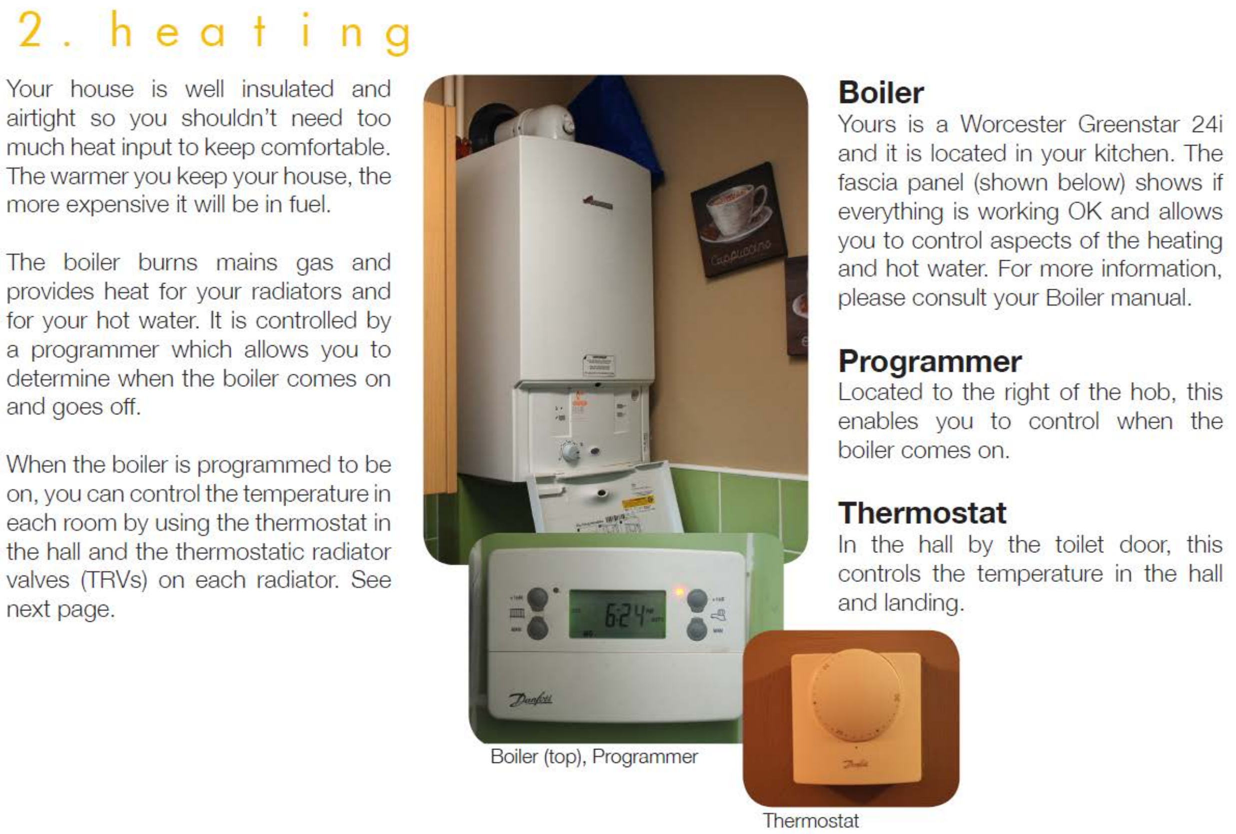
Figure 8:6: Measured indoor particulate matter and carbon dioxide concentrations in master bedroom in dwelling C1.

Window sensor data was not available during the monitoring period. The $PM_{2.5}$ concentrations remained relatively constant through the monitoring while a steady increase in PM_{10} was noted with the first rise in CO_2 (indicating room occupancy) however when CO_2 levels peaked at 1600ppm, PM_{10} did not rise as much as expected.

8.5 Quick Start Guides

Individual Quick Start Guides were developed and handed to the occupants during the annual feedback sessions that took place in January 2014. The guides were produced using photographs of the equipment in the actual house, rather than generic images this was to increase engagement with them and to simplify information provided to the occupants by the respective Housing Associations. The content relates to the operation of systems in the house as well as including details of the building fabric. A page relating to heating in House Type B's guide is presented in Figure 8:7, complete guides for all eight dwellings are located in Appendix Q.

The concurrent handover of the guides and feedback allowed a discussion to develop with the occupants and for them to feel comfortable about raising questions about their home, building services. The guide and feedback was also designed to engage occupants into more efficient energy use and greater comfort levels in their homes.



2. heating

Your house is well insulated and airtight so you shouldn't need too much heat input to keep comfortable. The warmer you keep your house, the more expensive it will be in fuel.

The boiler burns mains gas and provides heat for your radiators and for your hot water. It is controlled by a programmer which allows you to determine when the boiler comes on and goes off.

When the boiler is programmed to be on, you can control the temperature in each room by using the thermostat in the hall and the thermostatic radiator valves (TRVs) on each radiator. See next page.

Boiler
Yours is a Worcester Greenstar 24i and it is located in your kitchen. The fascia panel (shown below) shows if everything is working OK and allows you to control aspects of the heating and hot water. For more information, please consult your Boiler manual.

Programmer
Located to the right of the hob, this enables you to control when the boiler comes on.

Thermostat
In the hall by the toilet door, this controls the temperature in the hall and landing.

Boiler (top), Programmer

Thermostat

Figure 8:7: Sample page of occupant guide for House Type B.

On handover of the guides, it was found none of the occupants indicated any issues for control of their heating system, timers etc. and commented that they felt comfortable using the controls due to the length of time they had lived there. All had commented their preference for a smaller guide rather than the large folders containing technical manuals handed to them on moving in (Figure 8:8). However, since the distribution of the Quick Start Guides one occupant mentioned during the exit interviews (Chapter 5) that he had seen a similar guide in a friend's house (located in a development elsewhere in Inverness) which he felt was more informative than what MEARU had provided. Three occupants commented they have changed their behaviour as a result of the guides and feedback session, in so far as their windows are opened more often. However, high temperatures and CO_2 concentrations are still evident in the dwellings and habits formed do not appear to have changed significantly. This could be due to the timing of the delivery of the guides as the occupants has lived in their homes for three years and had fathomed the operation of the systems by this time.

There was an example in one household (A1) where the occupants were adamant the setting of the programmer for underfloor heating was easy, however the day and time on the programmer clock were found to be set 12 hours ahead of the actual time, as illustrated in Figure 8:9.

Figure 8:8: Example of ‘user manual’ provided to occupants from Housing Association.

Figure 8:9: Underfloor heating programmer with date and time incorrectly set Dwelling A1.

8.6 Energy Comparison

Through the two year monitoring period the research team were undertaking BPE on dwellings in six separate sites that all were subjects of other TSB projects. These dwellings are located in various locations in Scotland, are of differing construction types and occupied by a wide demographic. The energy consumption for each of these have been plotted (Figure 8:10) to illustrate how well the energy consumption of the eight dwellings forming this study compare with other dwellings in Scotland that were designed and constructed in the same period. Five of these are Passivhaus construction.

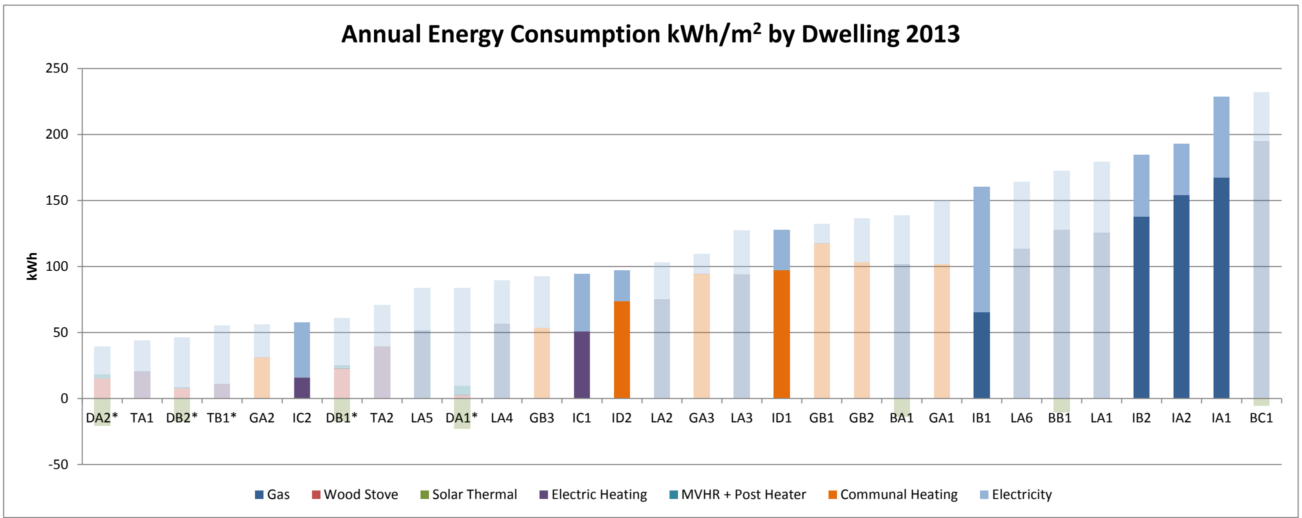


Figure 8:10: Comparison of annual energy consumption of dwellings of six TSB BPE projects. Note those with * are Passivhaus dwellings.

In terms of overall energy consumption in kWh/m^2, the chart illustrates dwelling IC2 to have performed well during 2013 with a consumption lower than two of the five Passivhaus dwellings. In comparison the larger homes in House Type A and B have performed poorly (in terms of this floor area benchmark) indicating they use more gas for space heating and hot water.

8.7 Conclusions and key findings for this section

The main design issues discussed here that was not covered by the mandatory elements of this project was for noise transfer issues. It became apparent through the BUS (refer to Chapter 5) that there are a number of noise issues. Reports were made of noise transfer between properties, within open plan dwellings and from building services. A future BPE study could include a study on noise transfer issues as the occurrence of noise transfer had caused participants significant stress.

The design intent of these dwellings was to use low or zero VOC emitting materials and paints and were termed ‘healthy’ by the architects. During the value engineering exercise the ‘healthy’ building materials were omitted and replaced with more mainstream building materials. A study to be included in future BPE projects could include monitoring and measurement of VOCs, formaldehyde and particulate matter, ideally prior to occupation and post occupation. The results of this could be compared to ventilation rates to determine optimum ventilation rates to provide a healthy indoor environment.

The Quick Start Guides distributed to the occupants appear not have made much of an impact to energy consumption and internal comfort conditions. This is partly due the late distribution of these being some three years after occupancy when occupant habits had already been formed.

9 Key messages for the client, owner and occupier

9.1 Introduction

As stated above, before commencing the study the key concerns in terms of building performance were the potential adverse impact of the change in delivery model from standard contract to design and build, the associated impact of value-engineering, the decision to move away from a site wide energy plant, and finally the decision that the only part of the site served by a centralised heating system would be the 6 flats on Plot 8 (House Type D).

Although the BPE study focuses mainly on building performance, the occupants' response to living in a place designed to Designing Streets standards and where the houses were architect designed was also of interest to us in terms of examining the 'value' that people place on the quality of design in terms of how the project was received by the new residents.

The objective of the Expo to explore the potential to make better use of local products in construction in Scotland, and the use of Scottish timber, in particular has spawned a number of initiatives exploring the development of mass timber products from Scottish timber and a number of other innovations in the development of new high quality construction materials and systems from Scottish grown materials, although not new window systems as yet.

During the BUS survey we interviewed residents about their impressions of the design of the place and the individual house designs as well as obtaining their impressions of the performance of the dwellings. It is difficult to draw definitive conclusions from this as most stated that they had moved there because it was 'different' and that they had no desire to live in a 'standard developer house'. Many had visited the Expo in 2010 so had even visited the houses they now lived in before deciding to move to the Expo development - including many of those living in the Housing Association properties. The Housing Associations had allocated the rented properties to carefully selected 'non-vulnerable' tenants so the situation on site is to an extent a-typical albeit that the occupants are all 'ordinary people'. Key highlights for occupants on site are the sense of space internally and externally, an appreciation of the good quality of daylight and 'airiness' afforded by a mix of double height and fully glazed facades, the benefits of more shared family space and fewer rooms which many had not considered before but now appreciated as beneficial (especially in this age of children locking themselves away in their rooms with computers), they also appreciated the fact that the site is a safe place for children to play. In the main they liked the performance of the houses although there were issues such as noise transfer, condensation due to the removal of a ventilation system in one of the house types, lack of ability to control heating (many houses were 'stuffy' and few people found their houses draughty). Some specifics are outlined below with regard to the monitored houses. The biggest complaint was the cost of heating and although in most (but not all) cases occupants thought the houses were cheaper to heat than their previous homes, they were much more expensive than anticipated. In some cases this was due to issues with the design of heating systems and/or control systems, incorrectly sized air source heat pumps in some of the private (un-monitored) houses in others it was due to an expectation that actual bills would be close to the SAP figures which they had been supplied with.

Our concern around dropping two of the house types from the study remains. We were able only to gather anecdotal information on these. In one (where the ventilation system had been removed during the value engineering exercise) these were severe condensation issues and the house seems to be overly airtight. Occupants of these semi-detached properties also experienced sound transfer issues between the two properties. In the other two where the Trombe-Michel wall had been changed to timber frame we were not able to gain access, but occupants returned the BUS surveys and no significant issues were reported.

We would reiterate that with energy systems and fabric becoming intrinsically linked there is an argument for new funding programmes to begin to explore the apparent lack of understanding of the impact of 'value engineering' on ultimate building performance, and the potential damage to fabric, performance and occupant health. We would also stress the fact that heating systems and controls should be kept as simple as possible and that over-complicated 'eco-bling' should be avoided. Even systems that appear straightforward to designers can be complicated for users, as noted in each of the homes monitored.

We also recommend that consideration be given to the development of handbooks for occupants of innovative/low energy homes, rather than being handed operation and maintenance (O&M) manuals that are considered 'too technical' by the building users.

9.2 Conclusions and key findings for this section

The eight houses that formed the focus of the BPE study were delivered on time and on SG guideline budgets of £1000 - £1200 per m^2. Overall lessons include:

- Don't experiment on people – they are the ones who pay the bills at the end of the day – so if you are going to try something new – try it out in a controlled way first.
- People only ask for help once or twice and then get fed up and find ways around the problems they experience so sometimes problems persist without anyone being called in to assist.
- Provide simple user guides and advice and support for all new home occupants.

Specific anecdotes and lessons for each of the monitored dwellings are given below:

House Type A: The Shed House (terrace of 3 No. 4-bed 2 storey houses) for Cairn HA.

Occupants of both of these houses were more than satisfied with the quantity and quality of the accommodation that had been provided for these two large families. Neither used the upstairs bathroom much and preferred to use the downstairs shower room. This could be worth noting for two reasons -

1. The upstairs bathroom in both cases was pristine hardly used whereas both families had problems with condensation due to poor ventilation and (arguably) over-use of the downstairs shower room. The study confirmed that the shower room fan was inadequate and although replacement more powerful alternatives were supplied, these were reported to be unacceptably noisy and the method of control became an issue.

2. It is worth considering supplying a choice of two showers rather than a bath for large families to help with load sharing.

The heating system was complicated to use - with underfloor heating and radiators supplied separately from a gas fired combi system via a single control panel which both occupants had difficulty in understanding. Both families had experienced higher than expected running costs for different reasons. In one house the family enjoys the outdoors and often has external doors open to the garden - not just in summer, and the other family is often up and about during the late evening/early morning which extends the heating season/period in both cases. The key lesson was that heating systems should not be over-complicated, it might seem like a good idea to have underfloor heating downstairs and radiators upstairs but controlling these separately was found to be complicated and can result in tenants having higher bills than if a simpler approach is used.

Storage was felt to be an issue in these houses and it was interesting to find out that a garden store had been removed during value engineering. The impact of this was that the entrance hall, under stair cupboard and shower room all doubled as outdoor clothing, toy, bike and pram stores and this made it difficult to access monitoring equipment and meters housed in the under stair cupboard.

The rear gardens become saturated after wet weather and due to a lack of drainage remain waterlogged for extended periods. It appears that garden landscaping and drainage was compromised by the 'value engineering' process.

House Type B: The Healthy House (2 units: semi detached 2 storey houses, 3 bedroom) for Cairn HA.

Both occupants of these houses with open plan living/dining kitchens loved their homes. They described them as well daylit and family friendly with reasonably low running costs (although higher than expected). A feature of the house was the ability to interact between public areas across both floors, however some of the occupants (parents) found this could be problematic with teenage children (e.g. music) and others (younger family members) found it a little intrusive. The houses are well constructed and warm but in both cases it was felt that the kitchens were too small for a family and although storage was generally found to be good in the house, the kitchen has very llittle storage space.

Generally energy use was thought to be reasonable, but one of the occupants had been advised to use the electric hot water immersion booster rather than relying on the gas heated hot water coil. This resulted in a higher than necessary electricity consumption in this house. Although after a feedback session with the occupants, the user has altered the method of water heating.

The original concept focused on material choices to provide a healthy living environment; including breathing walls and natural clay paints, and natural stains/paints within a formaldehyde free construction. Due to budget restrictions these were omitted from the final construction, however the overall form and concept has been retained and occupants commented on how fresh and airy the house felt.

Overall it should be considered that noise transfer can be an issue in open plan homes, in this house type noise transfer was exacerbated because of the compact nature of this three bed home.

Tenants need to be fully advised with regard to operating heating and hot water systems, as in this case where one user ran the electric immerser to save money and the effect was the opposite.

House Type C: Lios Gorm (3 bed, 2 storey house; 1 bed upper floor flat; and 1 bed ground floor flat) for Albyn HS.

Very few changes were made to this project and the architect remained involved throughout. The design approach uses off-site construction and pre-fabricated central service cores (removed at change of form of contract), built with Scottish timber and utilising modern methods of construction to minimise waste and maximise quality. The houses were designed to maximise solar gain from the south and to minimise heat loss to the north.

The occupants of these houses responded well to the design features that the architect built into this project. The homes are easy to heat, but heating cost experiences were different in the ground and upper floor flats. In the ground floor flat the occupants changed half way through the monitoring programme. The original occupant used the primary source of heating - which is by electric panel heaters - and found the cost was higher than might have been expected for a compact well insulated one bedroom flat. The upstairs occupant almost exclusively used the secondary heating source - a woodburning stove - and had minimal heating costs as they had access to a cheap supply of wood fuel. The new occupants of the ground floor flat use the woodburning stove most of the time as they have a free source of wood fuel.

This flat had two key issues - overheating of the living room - which is small, highly glazed and faces south and noise transfer (structural and airborne) between the living spaces in particular. Issues with the floor construction were eventually addressed, however the main source of the problem was diagnosed as being due to a last minute change in the location and treatment of the wood stove flue from the downstairs flat - which exits through the upper flat. Both issues have now been resolved.

Overall, this development incorporated a central bathroom pod and the building is entirely built of timber. It was in part tried and tested and in part 'experimental' which combined with the lack of site supervision (due to the design and build nature of the delivery) resulted in ongoing sound transfer issues between the flats for almost two years.

However, despte this, the owners love these compact easy to heat (part electric/part wood stove) homes – again a note of caution around delivering new ideas through a contract such as this where overall control is transferred to a third party.

House Type D: The Apartments: (3 storey black of 6 no. 2-bedroom flats). Shared ownership with Albyn HS.

These flats are the only dwellings on the site with a shared biomass heating system. The Apartments are orientated to maximise solar benefits, achieved predominantly through the integral ‘solar buffer space’ in the main living area. The objective was that this would collect solar energy during the day, releasing the warmth into the living area at night. However, the apartments were originally designed as one bedroom flats and then re-configured to provide two bedrooms. Although we did not have access to the original plans, there was an impression that this had compromised the proportions of the living room and kitchen as while the kitchen area seemed generous, the living space is small and further compromised by the location of the access corridor and the sun space. Both sets of occupants in the monitoring programme have overcome this by extending the living space into the sun space. Initially, in one flat, the occupant was convinced that the sunspace should be open during the day and closed at night - contrary to the architect's philosophy - and attempts to retreat into a smaller space at night - despite this compromising the use of the space.

Both sets of occupants noted impact noise transfer issues from the upper floors, this has caused some tension between indiviual flat owners in the block. During the thermography undertaken during the second airtightness testing it appeared there may be a lack of sound insulation in the separating ceiling. However, due to warm external temperatures the required temperature difference between inside and outside was not achieved and therefore it was unable to be confirmed; further investigations and sound impact testing are required. The research team were concerend this type of testing was outside the scope of BPE funding and due to anxiety and ill-health that can be caused by noise transfer, the research team hope to secure funding from another means to investigate the noise issues experienced by the residents.

Finally, issues with the heating system capacity in winter were reported, in that it was impossible to get heat from all radiators in the middle of the heating season. Despite all of this - the occupants in both cases love their homes and were keen and active participants in the study.

Overall, if installing an innovative system designers should make sure they are correctly sized – making allowances for how people live and not just based on theory – the wood pellet system here does not deliver enough heat in really cold weather. It was noted the heat to the six dwellings has been provided by a 35kW gas boiler, this could perhaps be a little undersized. However the distribution pipework and control valves on the Factor side were not accessible and therefore not tested or observed, this could add to heat distribution problem.

Designers should think through design features as if they were going to live in the house – the living room in these flats is too small if the sunspace is not opened up. There was also no advice provided on how to use the sunspace.

Adequate ventilation and air quality are an issue in well sealed homes – this is a growing problem and must be addressed – particularly in terms of value engineering and seeing things in the round.

10 Wider Lessons

10.1 Achieving Objectives

Survival of the fittest?

Scotland's first Housing Expo aspired to be a catalyst for the country's building industry, by creating an exemplar community which would act as an inspiration for future housing design and development.

Key objectives were to:

- showcase creative design solutions to encourage an improvement in design standards in public and private sector housing;
- create a sustainable living environment with a focus on the use of local materials and low energy houses;
- encourage technological and construction innovation;
- encourage a step change within sectors of the building industry including component suppliers and self-builders;
- capture public imagination and raise expectations in house design.
- promote a distinctive local vernacular;
- promote the creativity and quality of lifestyle in the Highlands to residents and visitors;
- exploit regional development opportunities including trade links and local manufacturing potential;
- encourage innovation in interior and product design;
- enable future Expos to act as a catalyst in assisting in the regeneration of smaller communities.

The extent to which these were achieved is discussed below.

Value Engineering

Early involvement from the contractors focused mainly on construction advice and cost control, but as the projects developed many if not all of the projects had to be value engineered in conjunction with the contractors to ensure that they could be built more cost effectively. This made the project process more challenging for all involved. The experience was more constructive for some than for others, a lot depended on the amount of time that each practice could set aside for dialogue during an unprecedented economic downturn.

The outcome extended beyond the common understanding of 'success' or 'failure'. While positive engagement and an acceptance of the cost constraints worked to the advantage of some projects, for others, solutions that met the needs of both designer and contractor were more difficult to achieve. It was not a matter of resistance or submission to the process, the most successful projects in some cases were achieved through intense collaboration, but others were simply easier to resolve. Similarly, for others, solutions seemed forever beyond reach, despite engagement between teams. Every project was different.

The project architects were asked to highlight the signature element of their building, with a view to establishing what was and what was not negotiable. This resulted in material changes in some projects and for the majority, the removal of features such as solar thermal and rainwater harvesting tanks, for financial reasons. These could all have been considered supplementary to a building that is inherently sustainable due to its energy efficiency and material use, and many of the architects reported subsequently that the removal of these systems had little or no impact on performance. However, the expected future changes to Building Standards will strongly encourage the inclusion of renewables at some level or other. This raises a potential dilemma for the future and the need to decide our priorities for investment: in fabric and passive measures or in renewables. In addition, the study indicated that systems considered by the designers to be straightforward were not always seen that way by users. The inclusion of additional renewable systems in housing where occupants have not requested or bought into such solutions should be approached with care.

At the end of the day the challenge remains constant: to push the boundaries of housing design and low energy sustainable strategies, to raise the bar for housing in the UK and in the longer term to encourage a step change in the industry.

Innovation has to be followed through or not done at all

In this case, to the credit of those who designed the houses and those who delivered the Expo, there was a clear desire to ensure that the architectural appearances of the designs remained true to the competition winning entries as far as possible. But appearances can be deceiving in some cases, and beauty is (sometimes) only skin deep.

A number of the winning designs adopted innovative construction systems, some of which were critical to the performance of the dwelling. Decisions to change the construction system should take full account of the consequences to environmental performance.

In attempting to address the challenges of climate change, the low carbon economy and the associated demands of increasingly stringent Building Standards, we have to begin to understand that buildings are evolving, the fabric is becoming part of, and in some instances is replacing, conventional energy systems. Generally, there was concern expressed at some of the workmanship, particularly the fixing of insulation and air-tightness. This study suggests that concerns over poor air tightness was largely unfounded and that we are becoming so good at making our buildings air tight that air quality is beginning to suffer.

The issue of non-negotiables in buildings where the fabric is a determinant of performance is not new, or confined to the Expo project. But it is essential, as we move forward with new ideas to address climate change mitigation and diminishing fossil fuel reserves, that all members of the design and construction industry re-skill in order to appreciate the potential impacts of what seem on the face of it to be logical decisions.

The devil is in the detail

After novation to the 5 contractors, some of the architects reported that value engineering commenced immediately. Even those who felt that they had costs tied down were advised that in the interests of time and the tight delivery schedule, some of the construction innovations would have to be simplified. There was no suggestion that the house layouts should be changed, and while the contractors argued that the impact would be minimal as the volumes and spaces created would not be affected by materials changes, for some of the designs, materials were an integral part of the design offered.

In summary, lack of direct control over delivery, due to the design and build process, meant that the innovative construction approach was in the hands of the contractor, rather than the designers.

Setting targets / Monitoring and Post Occupancy Evaluation

If the evaluation of all of the houses had been possible, then more comparisons could have been made and the delivered houses measured against a variety of targets. However, there were insufficient resources available and so that opportunity was lost. The architects were supportive of Monitoring and Post Occupancy Evaluation indeed many felt that this was as critical in terms of achieving Government targets on climate change mitigation and reduction in carbon emissions.

There are those who would argue that beyond aesthetics, the first Scottish Housing Expo achieved very little. One of the most important things that it did accomplish was that people started talking about architecture, design and place.

In part due to the omission of the proposed site-wide district heating plant, many of the dwellings had not costed-in a conventional system and then elected to go for the cheapest option - a condensing gas combi-boiler – but across the site 12 no. have air source heat pumps, 4 no. have woodburning stoves due to minimal heating requirements, 4 no. solar thermal heating and the 6 apartments have their own biomass (wood chip) group heating system.

Green Jobs

As discussed above, the Expo also began to explore opportunities for manufacturing products from home grown resources. So far, there have been two strong ideas emerging, and success could lead to more projects coming to fruition. Two examples are outlined below.

Cross-laminated timber – the future for home grown timber?

Prior to the economic downturn, in association with the Forestry Commission Scotland and the Centre for Timber Engineering at Napier University, a local Highland timber product manufacturer had expressed an interest in setting up a plant to develop cross-laminated timber panels from Scottish grown timber. Fast growing Sitka spruce is ideally suited for this purpose as it has inadequate structural strength to be used in construction on its own, but if cross-laminated in layers, its strength is greatly enhanced. The Expo tested cross-laminated and other massive timber systems and although the desire to bring a Scottish grown to the market, was one of the victims of this, interest has not waned, and further investigative work is underway as a result of the showcasing at the Expo of this construction approach.

Mac-Passive House?

One team succeeded in producing and delivering a Scottish Passive House, which had no conventional heating system and a design that will reportedly achieve energy savings in the region of 80%. In achieving this, the designers managed to hold on to increased insulation, design for high levels of air-tightness, the mechanical ventilation system, the high spec external windows and doors and even the tiled floor finish specified to attenuate solar gains on the ground floor. This team was able to convince the developer that all of these elements worked in harmony as part of the whole house concept and to remove a single element or to reduce its specification would have meant the whole idea of a heating system free house could not be realised. These units were delivered for a similar budget to the others across the site. The occupants of one of these houses agreed to take part in the BUS survey and reported living in an airy, beautifully daylit house with minimal heating costs and that the house was (for them - a couple with three small children) comfortable all year round.

New model required

The experiences of the architects and contractors on Scotland's first Housing Expo varied greatly, and the solution of a design and build approach was adjusted to by some better than others. In some ways it simplified things for the Highland Housing Alliance who delivered the project, but it also provided added complications and disharmony in some quarters, all of which had to be managed. Most architects involved still think that it was worth doing, despite the problems, but the majority would like to see a different delivery model within realistic timescales in the event of a future Expo.

While it was felt that the Finnish model was not suited to our construction and health and safety models, one project was delivered in a manner very close to that of the Finnish Fairs. The Secret Garden on Plot 17 was the only project delivered by an independent architect/ developer team. Interestingly, this project was completed first, well in advance of all of the other plots, to an extremely high standard of finish, and attracted more sponsorship in the form of furniture, fixtures and fittings and flooring and paint finishes than any other house on the site. This may be because of the commitment of the architect and contractor (who was sub-contracted to one of the 5 main developers), who were both able to focus solely on this project, or it may be that the sponsors were quick to grasp the potential marketing benefits of the Expo. It would be interesting to know how much of the success of this project was due to working with their own contractor to demonstrate that the solution to costs does not have to be provided by scale.

Should it be done again?

Overwhelmingly the conclusion from post-Expo focus group meetings with the architects and others who visited the site in August 2010, was that there should be more Expos – in order not only to raise the bar again, but also to put into practice what was learned on delivering the first one. The Expo provided an opportunity to do what we needed to do: to demonstrate what can be done within costs. Most of the architects would participate again, but there was a clear call for the need for a framework agreement between architects and much more encouragement and opportunity for them to work together. They all felt that the timescale for this one had been far too tight to resolve the design of the houses properly, and too tight to reach the standard of finish that they had aspired to.

At a time of economic difficulty, it gave so many practices much needed work, and particularly gave an opportunity to young architects and some of the smaller practices .

There was a strong sense that the problems arising from procurement can be tackled for future events. One architect observed that it was noticeable that the projects where the developer was building the house that they had been involved with from the outset, went relatively well because a two-way relationship of trust had already been established.

Comparison with Finland

Visitors from the Finnish Housing Co-op were impressed by the scale of our activities in Scotland. In Finland there are typically fewer 'one-offs' and more terraces of identical homes. They also use the Housing Fairs to showcase new ideas from their private housing developers, i.e. their top of the range offerings - which the public flock to see - as well as a smaller number of one off innovations that are more typical of what was delivered in Inverness. The houses in Finland's Fairs are not routinely monitored for performance as the raison d'être for their Fairs is different from ours.

10.2 Conclusions and key findings for this section

The designs for these houses incorporated new ideas in terms of fabric and systems as well as place making and infrastructure design. It loosely followed a model used in Finland to achieve a similar aim. While the project reflected a genuine desire across the board to raise the bar for the future of where and how we live in Scotland it could be that on reflection it tried to do too much

We would reiterate that with energy systems and building design and fabric becoming intrinsically linked, there is an argument for new funding programmes to begin to explore the apparent lack of understanding of the impact of 'value engineering' on ultimate building performance, and the potential damage to fabric, performance and occupant health. We would also stress the fact that heating systems and controls should be kept as simple as possible and that over-complicated 'eco-bling' should be avoided. Even systems that appear straightforward to designers can be complicated for users.

We also recommend that consideration be given to the development of handbooks for occupants of innovative/ low energy homes.

However, despite the fact that the occupants of all of these homes had issues with one or other aspects of their homes, it is interesting to note, that contrary to what we are often told by housing developers, the people in these houses reported that they liked living somewhere 'different'. Previous studies undertaken by Sust. have uncovered evidence of a 'forgiveness factor' associated with living in or using a building that is designed with people in mind - in that people are willing to put up with a building's foibles when they love it and the anecdotal evidence suggests that this is borne out by this project.