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## BUILDING PERFORMANCE EVALUATION, DOMESTIC BUILDINGS AT SCOTLAND'S HOUSING EXPO

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BY ARCHITECTURE AND DESIGN SCOTLAND  
AND THE MACKINTOSH ENVIRONMENTAL  
ARCHITECTURE RESEARCH UNIT

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Summary of Final Report



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## INTRODUCTION

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### PURPOSE

To highlight the outcome of a two-year study on the performance of social housing at Scotland's Housing Expo site.

### BACKGROUND

Scotland's Housing Expo was held in August 2010 in Milton of Leys, Inverness. It was a high profile event developed to showcase innovative sustainable housing with a variety of design ideas and technologies contained on one site. The event was the first of its kind in Scotland and was based upon similar Expo models found in mainland Europe and the Nordic countries.

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 56 individually designed low energy homes.

### THE BUILDING PERFORMANCE EVALUATION (BPE)

The BPE study was undertaken from August 2012 - October 2014 and the final report submitted to the funding body TSB (now Innovate UK) in December 2014 and approved by them in February 2015.

The study focussed on eight dwellings: four of these were social rented homes and four 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.

The study is now complete and the findings are set out in the summary report attached below.

The main findings were that:

- **Well sealed buildings without whole house ventilation units result in unacceptably high CO<sub>2</sub> levels especially overnight when windows are less likely to be opened and in situations where people dry clothing indoors. In addition, air quality was generally poor in terms of high moisture levels.**
- **Trickle vents are not adequate to compensate for inadequate ventilation.**
- **Under-heating was not an issue due to high levels of insulation - but this was counterbalanced by the fact that most of the houses had unnecessarily**

complicated systems with at least two methods of heating in each house.

- The group heating system in the flats was poorly managed and the back-up boiler was inadequate to heat all six flats.

Energy consumption was much higher than the house EPCs suggested, and while this was understandable to us as professionals, it was considered misleading by the occupants.

Lessons learned relate mainly to the impact on performance and usability of the houses due to the lack of follow through on design intent.

All of the participants in the study appreciate the opportunity of living in the development and they were all very pro-active in the monitoring.

All of the participating households have agreed to retain the monitoring equipment for a further year to allow monitoring to continue.

**Lori McElroy**

Head of Sust/Access

*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.*

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# 1 BUILDING PERFORMANCE EVALUATION STUDY (BPE)

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## 1.1 INTRODUCTION AND OVERVIEW

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). 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 of these contain one or more architect 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 Building Performance Evaluation (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.

*The purpose of the Expo was to promote best practice in design with the aim of making sustainable design features commonplace in every home.*

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Key to Figures  
Plot No.

Architect

1	JM Architects
2	NORD Architecture
3	Highland Council
4.1	John Gilbert Architects
4.2	Andrew Black Design Ltd.
4.3	David Blaikies Architects
5	JM Architect
6	AIM Design
7	David Somerville Architects
8	Keppie Design Ltd.
9	Graham Mitchell Architects
11	HLM Architects
12	Trevor Black Architects
14	Richard Murphy Architects
15	Bracewell Stirling
16	Graeme Massie Architects
17	Rural Design Ltd
18	Brennan and Wilson Architects
19	Joseph Thurrott Architects
20	Keppie Design Ltd
21	Graeme Massie Architects
22	Malcolm Fraser Architects Ltd.
23	Oliver Chapman Architects
24	McLean Architects
25	A&J Burridge
26	Studio KAP Architects
27	Malcolm Fraser Architects Ltd.

Figure 1: Site Plan of Scotland's Expo site indicating location of each plot. The monitored plots are 3, 4.2, 4.3, and 8



Figure 2: Architects interpretation of dwelling design for each plot

## 1.2 PROJECT TEAM

<p>ARCHITECTURE AND DESIGN SCOTLAND</p>	<p>Lori McElroy Kate Hendry Laura Hainey</p>	<p>Based in the Lighthouse in Glasgow, A&amp;DS acted as the project lead and provided support with contacting residents and survey work. Architecture and Design Scotland (A&amp;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&amp;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.</p>
<p>MACKINTOSH ENVIRONMENTAL RESEARCH UNIT (MEARU)</p>	<p>Tim Sharpe Janice Foster</p>	<p>Based at the Mackintosh School of Architecture in Glasgow MEARU was the academic subcontractor to A&amp;DS. MEARU undertook testing, survey work, and environmental and energy monitoring analysis and report writing.</p>
<p>CAIRN HOUSING ASSOCIATION (CHA)</p>	<p>Simon Campbell</p>	<p>CHA provided initial introductions to project participants living in the socially rented dwellings</p>
<p>ALBYN HOUSING SOCIETY (AHS)</p>	<p>Donald Lockhart</p>	<p>AHS provided initial introductions to project participants living in the owner/ occupier properties.</p>

### 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 Beaully 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 of 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 available that would allow The Highland Council 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 on market and bank confidence, which delayed 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 roles were to raise public awareness of the importance of sustainable design; 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 a traditional form of 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 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 objectives of the Expo included exploring 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 "massive" timber products made in Scotland such as Cross Laminated Timber (CLT) 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. 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:2 illustrates architects' impressions of the 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 average costs for the affordable properties fell within the required limits. However, some of the key design features discussed above were removed during the process; this is elaborated below and discussed further for each of the specific dwellings in section 2.4 of this report.

## 1.4 BUILDING PERFORMANCE EVALUATION (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 was 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 that an apparent lack of understanding of the performance impact of 'value engineering' innovative projects in which the building services and fabric are inextricably linked. 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 thermal mass; in another project, 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. A lack of focus on such issues, could result in risks to fabric, performance and occupant health, but to date this is neither a responsibility assigned to any member of a design or contracting team, nor is it addressed by building standards.

The main project was delivered by 5 main contractors - 4 of which delivered the housing and the other completed the streetscape and infrastructure. Three of the monitored projects were delivered by one of the four contractors and one dwelling type by another. 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 was unsuccessful.

The houses finally selected for monitoring had remained close to the original design intent with 'minimal' design changes, 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 overleaf:

*In Finland, Housing Fairs are generally of a larger scale and while innovative, they showcase fewer house types in greater quantities.... 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.*

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### House Type A: The Shed House

This is a terrace of three 4-bedroom, two storey houses built for Cairn HA. It has a simple and adaptable floor plan, is well daylighted using tried and tested construction systems and highlights that good design need not be radical or expensive. It comprises 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 other building parts also travelled a short distance. As a model for future projects, it was considered important to use an approach that maximised the potential to use the local work force and to design for minimal maintenance.



### House Type B: The Healthy House

This project comprises two units: semi-detached, 3-bedroom, two storey houses for Cairn HA. The design is based around creating an open plan, well daylighted environment with interaction between public areas across both floors. The building is of timber-frame construction with timber cladding externally. By adopting a common sense approach, avoiding the use of high 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.

*There is a need for 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.*



### House Type C: Lios Gorm

This project comprises a fully accessible flat on the ground floor and an identical upper floor flat both with one bedroom for Albyn HS. The approach uses off-site construction and pre-fabricated central service cores, built with Scottish timber. The approach includes 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 (using framed construction with south west facing glazed infill) and minimise heat loss to the north (thick, well insulated walls with carefully located window penetrations).



### House Type D: The Apartments:

This project comprises a three storey block of six 2-bedroom flats constructed for shared ownership with Albyn HS. Structural timber frame with masonry construction on steel frame to the sunspace and communal stair. The Apartments are orientated to maximise solar benefits, both in terms of natural daylighting and passive solar gain, harnessed through the integral 'solar buffer space' by collecting heat during the day, absorbing it in 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 are 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 design of the sunspace was also compromised by lack of high level opening windows and the location of the double glazed windows. The users were not advised how it should be used.

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## 2 ABOUT THE PROJECT

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### 2.1 DEVELOPMENT

The buildings on the Expo site are architect-designed dwellings, mostly of timber frame construction, consisting of flats, terraces, semi-detached and detached dwellings on 27 plots. The design and construction was procured through an architectural competition that aimed to raise the bar for Scottish housing by showcasing innovative sustainable housing to help change attitudes towards housing and place design to 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 was developed with 27 completely different designs, but many of the architects embraced similar design principles, such as taking account of orientation, materials and consideration of occupant well-being.

Following the announcement of the competition winners the successful design teams began working up their sketch design entries. However by the time detailed planning consent was obtained (2008) the banking crisis had begun to affect the construction industry and risked jeopardising the delivery of the programme. A decision was made to postpone the Expo 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 four contractors

with the fifth dealing with the infrastructure and civil engineering aspects of the project.

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 and the required cost of £1000 - £1200 per sqm . The architects were asked to identify their one 'must save' item from their respective designs prompting much debate between the architects and contractors; these are explored later in this report. An abridged project timeline is provided in Figure 3.

A book covering the full project history and further information about each of the plots is available in pdf format from:

[HTTP://WWW.ADS.ORG.UK/SCOTLANDS-HOUSING-EXPO-2010-BOOK/](http://www.ads.org.uk/scotlands-housing-expo-2010-book/)

The book (ISBN: 978-1-905061-28-0) was published by A&DS (Architecture and Design Scotland) for the Scottish Government.

As noted in section 1.4, the BPE project researched two dwellings from each of 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).



**Figure 3: Abridged Expo Project Timeline**

## 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), Bogbain and

Daviot Woods to the south. These contain marked walks as well as cycle routes. The Highlands of Scotland are one of the most popular tourist destinations in the UK. Providing ease of access to 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, which is used to assess and compare the energy and environmental performance of dwellings. Its purpose is to provide comparable assessments of theoretical 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). As such they tend to be accurate in relation to the theoretical performance of dwellings at the design stage, but do not reflect reality.

SAP works by assessing how much energy a dwelling will consume, when delivering a defined level of comfort and service provision. The theoretical 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<sub>2</sub> (the Environmental Impact Rating). Related factors, such as fuel costs and emissions of carbon dioxide (CO<sub>2</sub>) 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 on the BPE study are summarised in Table:2.

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 fact that the unit fuel costs used in the SAP assessment were unrealistically low. It should be noted that 'as built' SAP assessments have not been undertaken and are not required under the Scottish Building Regulations but variations due to occupant lifestyles can be significant. 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 of the main report. Each house type is discussed separately over the next few pages.

*SAP is a theoretical assessment based on standardised assumptions for occupancy and behaviour input by a trained user. This enables a like-for-like comparison of dwelling performance.*

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)	5584	5160	3538	3663	1572	1709	2166	2238
Space Heating Secondary (kWh/year)	572	529	354	364	485	527	0	0
Water Heating (kWh/year)	3484	3484	3246	3246	1899	1899	2809	2809
Electricity pumps and fans (kWh/year)	175	175	175	175	0	0	0	0
Energy for Lighting	734	734	602	602	339	339	509	509
Total CO <sub>2</sub> /year (kg CO <sub>2</sub> /year)	2383	2284	1794	1816	1620	1679	386	388
Dwelling Carbon Emission Rate (kgCO <sub>2</sub> /m <sup>2</sup> )	22	21	23	23	36	36	662	662
Improvement over TER* (%)	<1	0	15	14	11	7	41	41

Table 2: Summary of key SAP calculation predictions for each dwelling assessed in the BPE study. \*Target Emissions Rating

## HOUSE TYPE A

Two four bedroom dwellings situated in a terrace of three, one is 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 the private gardens. The internal floor area is 110m<sup>2</sup> 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 by a gas fired condensing combination boiler serving underfloor heating on the ground floor and radiators upstairs; providing hot water on demand.

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. While the airtightness result was

vastly improved over the design figures, the figure of 10m<sup>3</sup>/(h.m<sup>2</sup>)@50Pa was presumably selected so that an airtightness test was not required on completion of a weather tight envelope.

Despite the improved fabric performance the estimated running costs of £188 per annum for space 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 expressed their annoyance over the unexpected additional expenditure for space heating and hot water. They advised that they partly took up their tenancy based on the low running costs indicated to them by their housing association, thus indicating that 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.

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 were installed. The performance of the fans are discussed in Chapter 6 of the full report, however, the additional energy requirement for one wall mounted fan should not 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:4). The water heating consumption was close to the SAP prediction and the measured lighting consumption was slightly lower than the SAP prediction.

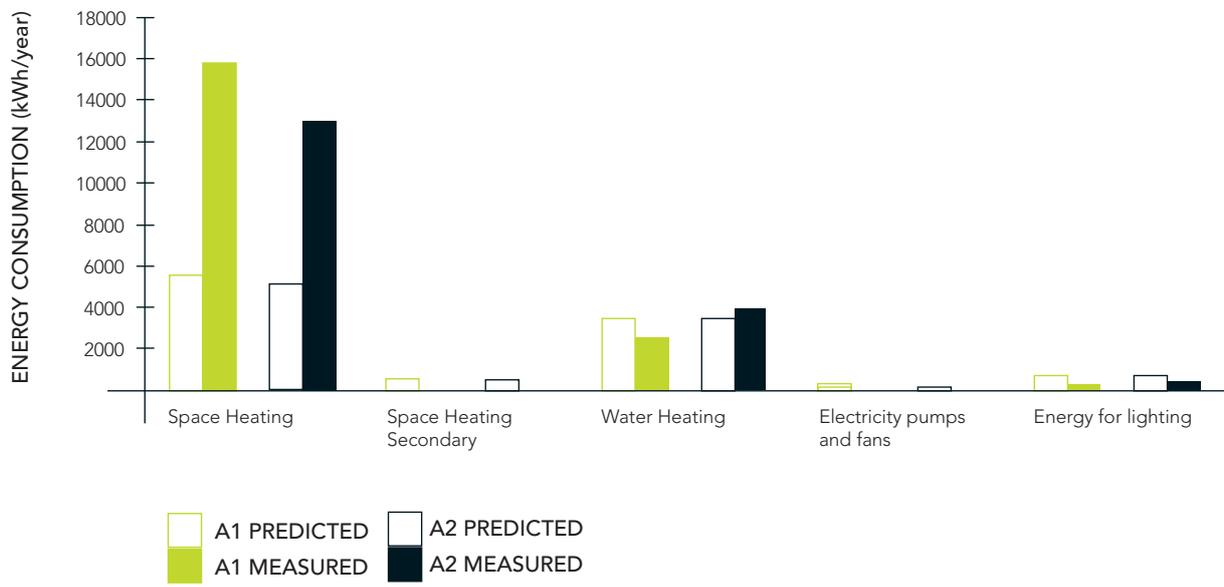


Figure 4: SAP prediction VS measured energy consumption - House Type A



## HOUSE TYPE B

Two, 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<sup>2</sup> 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.

Both dwellings are rated 'B' in terms of energy performance and the emission reductions predicted using SAP were around 15%. The measurements undertaken indicated a slight improvement on wall U-values and airtightness over the standard default figure of 10m<sup>3</sup>/(h.m<sup>2</sup>) @ 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 they both acknowledged that they are still lower than

where they lived before.

A discrepancy with the SAP sheet assumed that these dwellings were fitted with a combination boiler, when in fact 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 standard gas 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 standard boiler would have been included in the original design.

A review of the energy consumption (Figure:8) indicates a smaller performance gap for space heating, compared with House Type A, especially in House B1. The occupiers in this dwelling are often at home during the day and the lower space heating consumption (45%) was 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.

*The running costs were reported to be much higher than the occupants had anticipated, however they both acknowledged that they are still lower than where they lived before.*

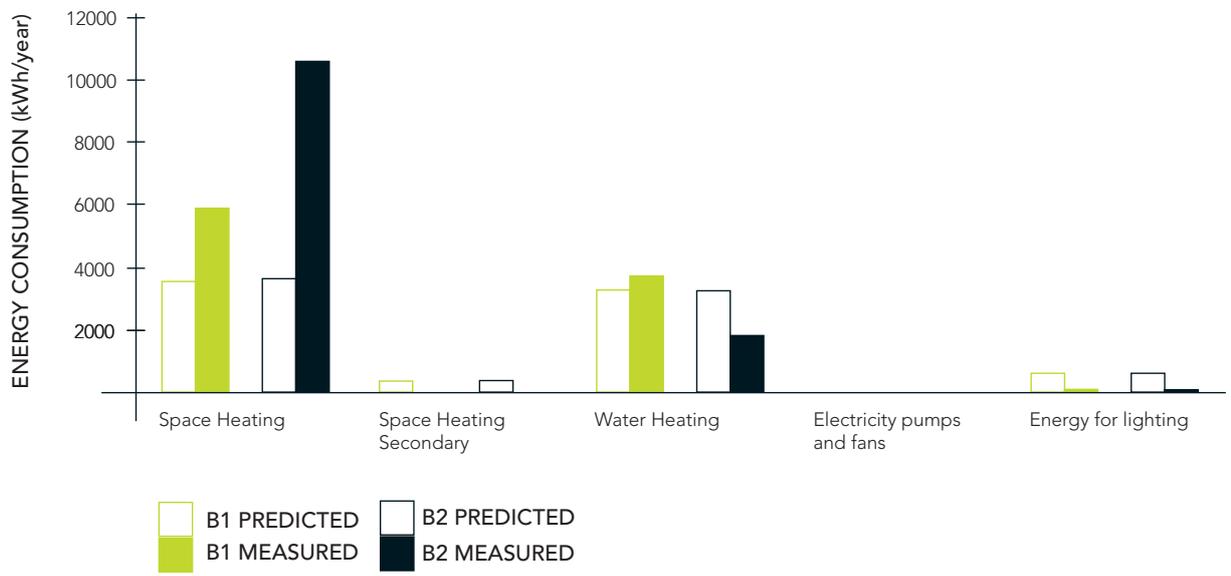


Figure 5: SAP prediction VS measured energy consumption - House Type B



## HOUSE TYPE C

Two 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<sup>2</sup> 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.

The improvement in the DER over the TER was predicted as 11% and 7% for dwellings 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 of the main report). While airtightness test results were better than the standard benchmark (10m<sup>3</sup>/(h.m<sup>2</sup>) @ 50Pa). Discrepancies with the data input in the SAP calculation were not immediately obvious, however the assessment indicated two fans were specified within the dwelling and although there are two grilles (kitchen and bathroom) there is only 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. A low energy system was installed but this does consume some energy, and therefore should have been included in the assessment. It was also found that the specification used in the SAP assessment for the roof element was incorrect. The SAP assessor had simply copied the wall construction layers and altered insulation thickness for the roof.

Figure:6 indicates a large difference in space heating consumption between SAP and the 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. There was no data available for the amount of fuel used in the stove but 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) they were disappointed to find they are paying as much per month as the SAP estimation of £60 a year which is what they were informed the heating costs would be.

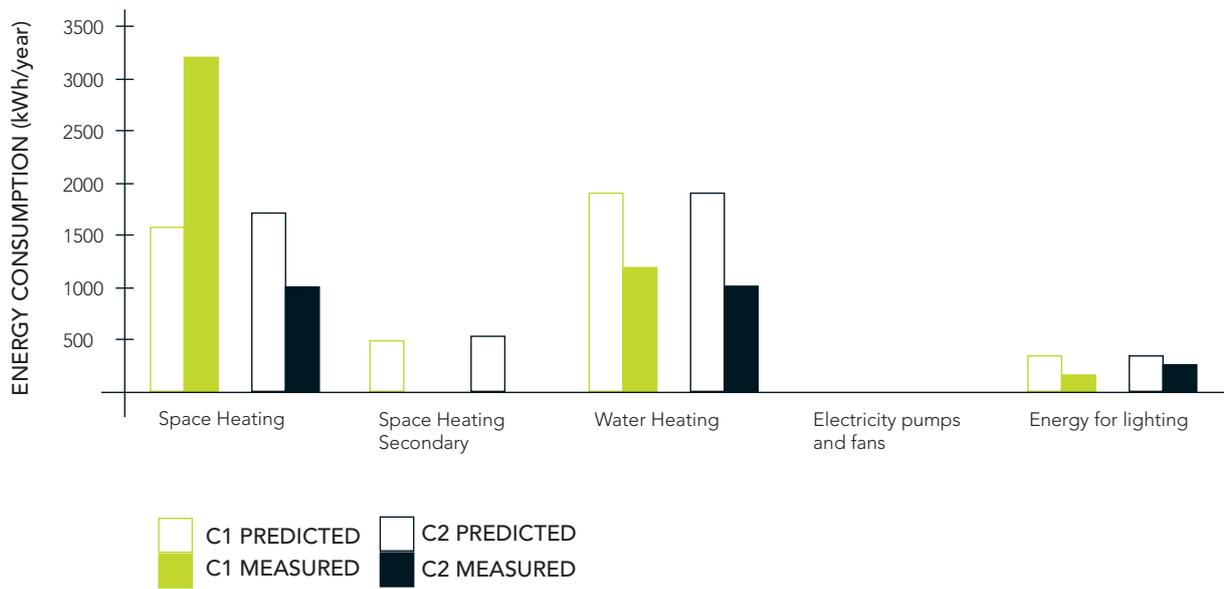


Figure 6: SAP prediction VS measured energy consumption - House Type C



## HOUSE TYPE D

Two, 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 orientated north. Both flats have a floor area of approximately 76m<sup>2</sup> 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, with cellulose insulation, 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 are provided by a communal biomass (wood pellet) boiler located within the curtilage of the plot. Heat is controlled via a room thermostat with radiators fitted with TRVs. Domestic hot water is stored in a hot water cylinder.

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<sub>2</sub> emissions due to the communal biomass boiler for space heating and hot water generation (Table:3). Monitoring has led to the discovery that the biomass boiler has been subject to an on-going operational fault and as a result has rarely operated. The fault was repaired in July 2014, almost four years after installation. This has meant space heating and hot water has been provided almost entirely by the back-up condensing gas-fired boiler. The EPC (energy performance certificate) is based on the biomass fuel for carbon dioxide emissions and therefore the rating

of '97 - A' is not realistic, as the building has been predominantly operating on gas for the first four years of occupation. Using SAP predictions and CO<sub>2</sub> factors (2005 SAP) for gas, the total CO<sub>2</sub> per year for House Type D increases significantly as indicated in Table3 the rating for this dwelling operating becomes '87 - B'. 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 did not contain a heat exchange option. For assessment of solar gains, the SAP calculation highlights the "likelihood of high internal temperatures during summer weather: HIGH!" this was confirmed by the environmental monitoring. As with House Type C there was no account for pumps and fans made. 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 an annual fee for heating and hot water, based on consumption and boiler running costs including wood pellet fuel. Costs have been significantly higher than the occupants' expectations and there is tension between occupants and the factor over the amount of money being charged for heating and hot water. They feel that the biomass system is more expensive than gas.

The comparison of regulated loads (Figure:7) 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.

DWELLING	A1	A2	B1	B2	C1	C2	D1	D2
Total CO <sub>2</sub> /year (kg CO <sub>2</sub> /year)	2383.94	2283.39	1794.00	1816.00	1620.12	1679.05	1180.00	1194.00
Dwelling Carbon Emission Rate (kgCO <sub>2</sub> /m <sup>2</sup> )	21.75	20.83	19.94	20.19	31.96	33.12	15.53	15.71

Table 3: Adapted excerpt of SAP CO<sub>2</sub> calculation predictions for each dwelling assessed in the BPE study. House Type D amended.

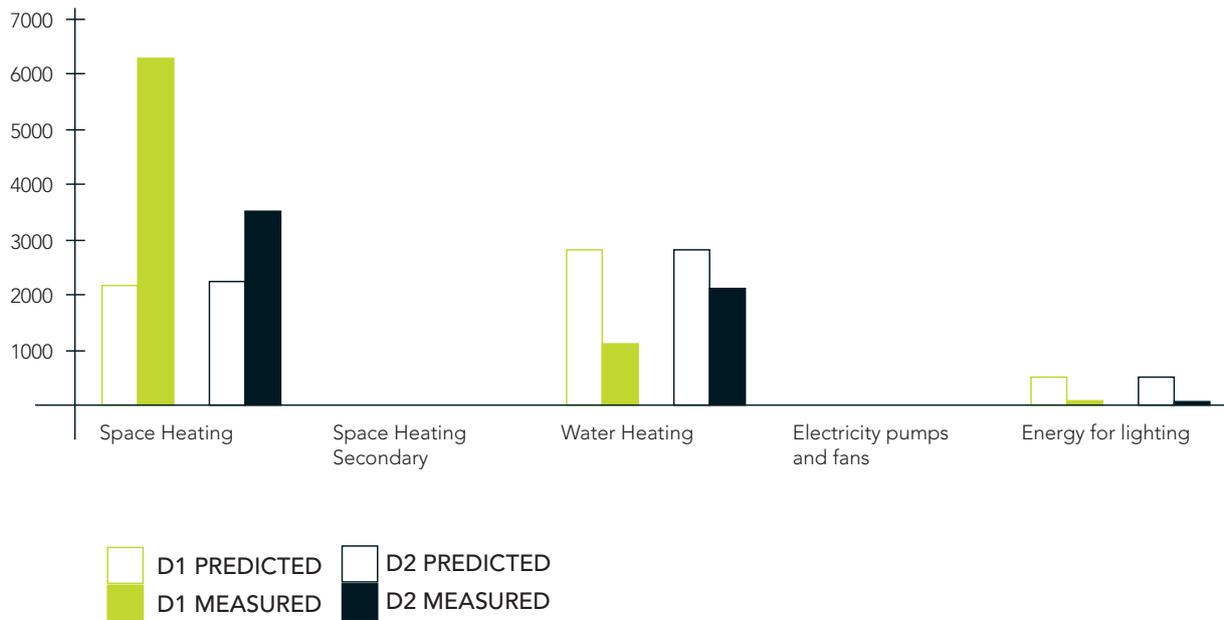


Figure 7: SAP prediction VS measured energy consumption - House Type D



## 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 in that the contractors had largely delivered each of the plots. However a late change in the form of contract from traditional to 'design and build' 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 that 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 were watered down to reduce capital costs (due to the economic downturn) with designs simplified to enable them to be constructed within the available 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 met with delays owing to severe winter conditions with record amounts of snowfall and long lead times particularly for windows, which were predominately ordered from one manufacturer. The site foreman informed the research team of the necessity for long working hours, with 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 timescales and lack of familiarity with methods may have had on each house type.



## HOUSE TYPE A

**Design Intent:** From the architect's 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 also 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 a 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 reported that 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, however due to the form of contract the identification/reporting of such issues was outwith the architect's 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 goodwill amongst 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, keeping 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 (£1000 - £1200/ sqm).
- Removal of healthy materials and breathing wall construction. These were considered to be too expensive based on the client's previous experience of 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 with 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, resulting in cluttered entrance hallways, which doubled as bike and pram stores.

**Delivered Dwellings:** The overall design remained largely intact after the value engineering process, albeit that 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 of the main report). The air permeability testing revealed infiltration levels were lower than the design target; to the extent that this 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 detail in Chapter 3 of the main report.
- 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 of the main report).
- 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 of the main report).

- When interviewed, the occupants confirmed that 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 with regard to ventilation tie 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 cooking 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 than downstairs and condensation has been observed on windows and frames. Window opening frequency is discussed in Chapter 7 of the full report.



*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*

## HOUSE TYPE B

**Design Intent:** For this house type, the design intent was to adopt a 'fabric first' approach that included the architect's specification of products/materials that 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 if there was a lack of familiarity with the proposed materials. What was clear, through the interviews, was that 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 were 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<sup>2</sup> 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, and is reviewed in Chapter 7 of the main report.
- 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 result in 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 that they were not precious over the omission of these elements, but questioned whether or not 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. This omission, especially when coupled with the loss of external woodfibre could increase the risk of overheating internally (as identified during the environmental monitoring, refer to Chapter 7 of the main report).
- '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 over 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 in 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 and space standards in livingrooms, kitchen and bedrooms and space standards the tenants are happy with living in these houses and the client believes that they represent 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 had been retained. There was also thermal bridging at roof trusses where an external layer of woodfibre insulation had not been specified. While reviewing the architect's drawings a discrepancy was identified with 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 with wood fibre insulation. This discrepancy was not picked up during the construction phase. The air permeability testing (refer to Chapter 3 of the main report) 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  $6\text{m}^3/(\text{h}\cdot\text{m}^2)\text{@}50\text{Pa}$  for a dwelling designed to operate 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 resulting 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 further 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.



*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.*

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## 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 reported to be an expensive solution but the contractor was positive that it 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 roofing 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 contract the architect had no authority to instruct their rectification.

The architect believes that offsite construction is key to the 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 the 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 rises within boxing at the periphery of the living room in the flat above, it was believed that this change resulted in the ensuing sound transfer issues between the two properties.

**Delivered Dwellings:** The overall floor plan remained true to the architect's initial concept except for the removal of the 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 as 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 removed and rolled up in the dwelling for more than a year. The research team observed additional 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 of the main report).
- 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 of the main report) and internal temperature swings in winter are large where internal temperatures are low enough for condensation to occur.



*The method of construction was to promote the manufacture and capability of off-site prefabricated panels made locally.*

*The architect believes that offsite construction is key to the future development of the Scottish building industry and integral to sustainable procurement.*

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## 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 that this project was the smoothest they were involved with. This could be due to the relationship with the architect who was 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 contractor 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 did affect the build quality.

**Design Changes:** From the outset of the competition the architect was novated to the contractor under the 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 sunspaces as part of the main living room.
- Omission of high level opening casement windows in the sunspace, meant that the space could not effectively allow warm air out of the building during warmer 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, but this was not thought through in performance terms.
- Building orientation (as far as we can gather) appears to have altered and now the solar buffer spaces are not positioned to optimise solar gain, being orientated to 53° west of south. This increases the risk of overheating.
- The 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 insulation defects were highlighted. These affect the external wall and the separating ceiling/floors. The thermography identified thermal bridges in the 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 of the main report for results). Defects with insulation between the separating ceiling/floor may be exacerbating the sound transfer issues that 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 of the main report). 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.



*The contractor advised the sunspace was changed to deliver a project cost saving, before the project started on site, but this was not thought through in performance terms.*

## 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, a primary school 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 significant impact on the original architectural design concepts. These were simplified by contractors to 'de-risk' and to speed up construction by removing 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 (a summary of design changes and likely impact can be found in Appendix D of the main report). 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, but the space would not function without them.

*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 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.



*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.*

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## 3 KEY MESSAGES FOR THE CLIENT, OWNER AND OCCUPIER

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### 3.1 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 the decision that the only part of the site with 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, occupants 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 a 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. 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.

### 3.2 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<sup>2</sup>. 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 overleaf:

*...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.*

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## 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 -

- 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.
- 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.

*Dont experiment on  
occupants:*

*Heating systems and  
controls should be kept  
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Even systems that appear  
straightforward to designers  
can be complicated for  
users, as noted in each of the  
homes monitored.*

## 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 little 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.**

*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.*

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**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 used off-site construction and pre-fabricated central service cores (removed at change of form of contract), built with Scottish timber and utilising offsite 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 occupant 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, despite this, the owners love these compact, easy to heat (part electric/part wood stove) homes – again we would recommend a degree of caution around delivering new ideas through a contract such as this where overall control is transferred to a third party.**

*The owners love these compact easy to heat homes.*

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#### HOUSE TYPE D: THE APARTMENTS: (3 STOREY BLOCK 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 circulation and the sun space. Both sets of occupants in the monitoring programme have overcome this by extending the living room 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 individual 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 to

confirm or otherwise. The research team was concerned that 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 hopes 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 that at times the heat to the six dwellings was provided by a 35kW gas boiler, this could perhaps be a little undersized.** However the distribution pipework and control valves were not accessible to the team and therefore not tested or observed, this could add to the heat distribution problem.

**Designers should think through design features as if they were going to live in the house themselves – 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 becoming 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.**

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## 4 WIDER LESSONS

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### 4.1 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.

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### **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 make efforts 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 and 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.

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## 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 daylighted 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.

*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.*

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## 4.2 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.



Scotland's Housing Expo was held in August 2010 in Milton of Leys, Inverness. It was a high profile event developed to showcase innovative sustainable housing with a variety of design ideas and technologies contained on one site. 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 26 individually designed low energy homes.

The BPE study was undertaken from August 2012 - October 2014 and the final report submitted to the funding body TSB (now Innovate UK) in December 2014 and approved by them in February 2015.

The study examines 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.

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