Bloom Court

Phase 2 study
In-use and post-occupancy

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

InnovateUK project number	450054
Project author	ECD Architects for Hanover (Scotland) Housing Association Ltd
Report date	2014
[1]InnovateUK Evaluator	N/A

No of dwellings	Location	Type	Constructed
Six	Livingston	One and a half storeys	2010

Area	Construction form	Space heating target	Certification level
Areas not reported	Timber frame	N/A	Scottish *Building Regulations*

Background to evaluation

The homes were designed for low maintenance and long lifespans, with a choice of materials and flexibility for future use being crucial to the concept. Natural Building Technologies was selected as the preferred choice of construction with timber frame, exterior wood fibre solid walls, breathable render and hemp insulation. The dwellings incorporated a natural ventilation strategy in place of MVHR, and the use of natural breathable construction materials.

Design energy assessment	In-use energy assessment	Sub-system breakdown
Yes (SAP)	Yes (DomEARM)	Yes (not reported)

Heating and hot water provision were provided by conventional domestic condensing combi-boiler systems. Energy use assessments were carried out on representative properties: a mid-terrace and end terrace dwellings. Energy use data was run through the DomEARM engine to provide comparisons with the in-built benchmarks. Mid-terrace consumption: Electricity 31.4 kWh/m^2 per annum, gas 79.0 kWh/m^2 per annum. End terrace consumption: Electricity 40.5 kWh/m^2 per annum, gas 88.6 kWh/m^2 per annum. **Note: All detailed energy data, including gross and/or treated floor areas, was reported in an appendix which is missing from the published InnovateUK report.**

Occupant survey type	Survey sample	Structured interview
BUS domestic	11 of 15 (73% response rate)	No

The overall summary of the main issues in the BUS survey indicated that the dwellings scored similar to, or better than, scale midpoints and the benchmarks of comparative dwellings on the BUS database. The scores were variable, but most respondents noted a stable summer and winter temperature. However, the responses suggest that while the houses are prone to overheating in the summer and difficult to keep cool, they perform better in winter. There appeared to be a year-long issue regarding the dryness of the air. This was considered a function of the inherent airtightness of the construction.

Contents

1 Executive Summary

The project comprises six simple 1.5 storey houses, which were designed for low maintenance and long life spans, with a choice of materials and flexibility for future use being crucial to the overall concept. Natural Building Technologies was selected as the preferred choice of construction with timber frame, exterior wood fibre solid walls, breathable render and hemp insulation reinforcing the ethos of sustainability and reduction in high energy manufacture and insulation qualities. The buildings services were intentionally conventional for ease of tenants understanding and use.

1.1 Fabric Testing

1.1.1 Fabric testing of the buildings involved a number of separate investigations.
Air permeability was tested at both the start and end of the project with an average air permeability rate of 3.99 $m^3/h/m^2$ established in the most recent tests. These rates have remained stable over time suggesting that the air tightness strategy and installation was robust. However, the level of airtightness far exceeds that presumed at design stage (a level of $10m^3/h/m^2$ was assumed) which, under current Technical Standards, would suggest that a whole house mechanical ventilation system would be required to provide good IAQ and that the current strategy (using background ventilators) is insufficient.

1.1.2 The general quality of the construction appears to be thermally robust with thermography identifying limited weaknesses around the bay window, rooflight ingoes, 'light tube', toilet cistern, wallhead and eaves conditions. Using in-situ testing kit, the wall construction was found to achieve an in-situ U-value of $0.19W/m^2K$ which compares well to the design value of $0.18W/m^2K$ as this value is derived in much more favourable conditions than those experienced on site.

1.1.3 A co-heating test was undertaken to establish the overall fabric heat loss without occupant behaviour anomalies, although some issues were encountered with failure of testing equipment. Three varied methods were identified for analysis of co-heating data and used to derive different results for this test. Using the LORD method a heat loss coefficient of 64.2 ±4.2W/K and a solar gain factor of 7.6 ±0.5m^2 were identified. The heat loss coefficient compares well (lower) than the SAP prediction of 75.94.

1.2 Walkthrough

1.3.1 It is evident that all the tenants like and are comfortable in their houses. The main comments related to:-

- All tenants generally liked their houses in terms of space standards and energy efficiency. They all liked the location and particularly their neighbours. The ground floor bedroom was particularly appreciated due to their physical needs.

- The one major issue with all tenants revolved around the mechanical extract to the ground floor shower room which is reported in section 9 and summarised as follows:- It is evident from the testing undertaken that deficiencies exist with the ventilation strategy used in the bathrooms at Bloom Court; this is characterised by the under-performance of the bathroom mechanical extraction units (50% of fans tested). The correct ventilation to these bathrooms is essential as there is no access to windows for intake of external air. This makes a case for further investigation by the Housing Association throughout the development to assess whether the fan installations should be re-commissioned or replaced to provide good internal air quality for the residents. Alongside similar results from testing in other properties, this provides further evidence that this issue could be endemic within Scottish housing and highlights deficiencies of the Building (Scotland) Regulation themselves.

  The Building (Scotland) Regulations provide recommendations for minimum extract flow rates for intermittent mechanical extraction for kitchen, bathrooms, utility and toilet rooms without shower. Their guidance does not, however, require inspection, testing or commissioning of these extract systems, (unlike Approved Doc F in England), or provide recommendations for fan controls or run-on times for intermittent mechanical systems. Both would seem to be critical requirements in understanding performance if sufficient volumes of moisture are to be removed from internal spaces. Building users need to understand correct operation of the extract fans, for too many occupants override light switch controls with run-on timer. They manually operate the adjacent isolation switch, as fans are reported to be too noisy or perceived expensive to run. It is recommended that a performance specification is provided setting our minimum requirements for extract fans. This should cover items such as extract rate, a delayed start, noise level criteria, low energy, backdraught dampers, control method, timers, duct design, insulation, condensation traps, static pressure etc. Correct specification and control methods could increase the chances the fan is operated correctly to assist in maintaining good indoor air quality.

- Tenants comfort levels and reduced energy bills confirm airtightness and thermal efficiency of construction type.

1.3 BUS

1.3.1 The 4 Red flags relate to:-
- Air in winter: dry/humid
- Air in summer: dry/humid
- Lighting: natural light
- Temperature in summer: hot/cold

1.3.2 Things that the tenants think work well:-
- Ground Floor Bedroom
- Walk in Shower
- Wide Doors
- Control of services

- Economy of energy bills

1.3.3 Things that the tenants think don't work well:-
- Ventilation in the downstairs Shower room.
- Too hot in Summer
- Would like a bath upstairs
- Front path too close to living room window

1.4 Monitoring Methods and findings

1.4.1 An array of t-mac monitoring equipment was installed and linked to the complementary portal to enable remote monitoring. This comprised high level ('fiscal') monitoring of electrical, gas and water consumption for all six properties, along with more detailed information on two of the properties which comprised sub-metering of the electrical sub-circuits and the environmental parameters (temperature, relative humidity and carbon dioxide concentration) of three key spaces within the dwelling.

1.4.2 Gas and Electric consumption varies significantly across the six dwellings and it was shown that this is largely a function of user behaviour. Such variations however call into question the value of SAP predictions when seeking to anticipate actual energy use. Water use is generally comparable across the dwellings and with national norms.

1.4.3 CO_2 concentrations in the dwellings are overly high and this is particularly so during the heating season and in bedrooms.

1.4.4 Internal temperatures are high throughout the year but this is perhaps what could be expected, given the sedentary nature of many residents. This in part explains the higher than expected gas use.

1.4.5 Internal RH is normally good and supports the use and efficacy of the vapour permeable construction. However, in periods without occupation RH can fall too low and potentially dry out and damage internal materials if heating is retained at the same levels.

2 Introduction and Background

2.1 Introduction

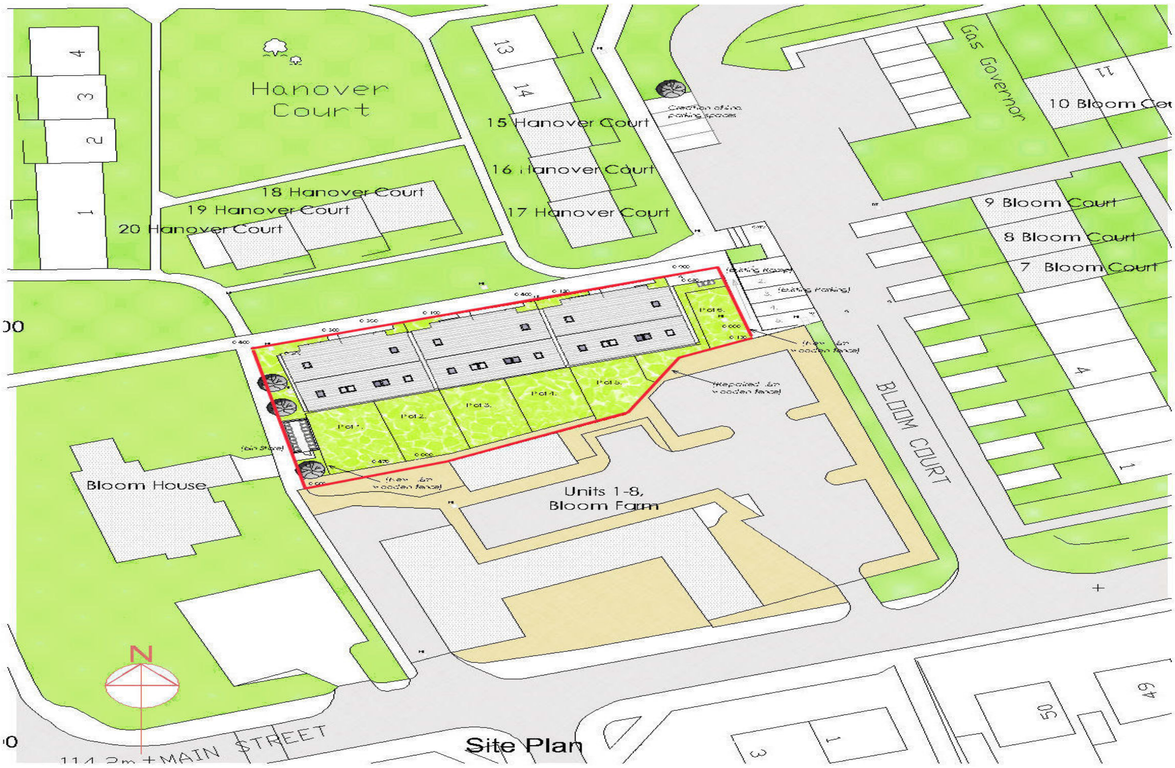
Livingston was the fourth of the Scottish new towns created to help accommodate overspill from Glasgow's densely populated city centre in the years following the Second World War, and by many measures it has been the most successful of them. It lies strategically between Glasgow and Edinburgh, enjoying motorway access to both cities. Bloom Court is located in Livingston village, the original Livingston settlement.

The client, Hanover (Scotland) Housing Association, commissioned a feasibility study on the redevelopment/replacement of Hanover House, within Livingston Village. The existing building, which served as residential accommodation for 20 elderly persons and supporting staff, was considered incompatible with prevailing living practices for the elderly and infirm. The result of the study was to demolish the property and replace it with six no. 3-bedroom houses for elderly and ambulant persons. These were completed for occupation in the Spring of 2010.

Front Elevations to the 6 houses

2.2 The Site

The project is located at Bloom Court, within the historic conservation area of Livingston village. It is adjacent to Hanover Court, a sheltered housing scheme also owned by HSHA. The site occupies some 0.11 hectares, and is surrounded by other Hanover sheltered houses to the north, with small business units in a former steading to the south. Pedestrian access runs along the north and west boundaries. There is no direct vehicular access to any of the houses, but dedicated parking is located to the east side. The development is well served by buses accessed some 75m away on the main route into the town centre.



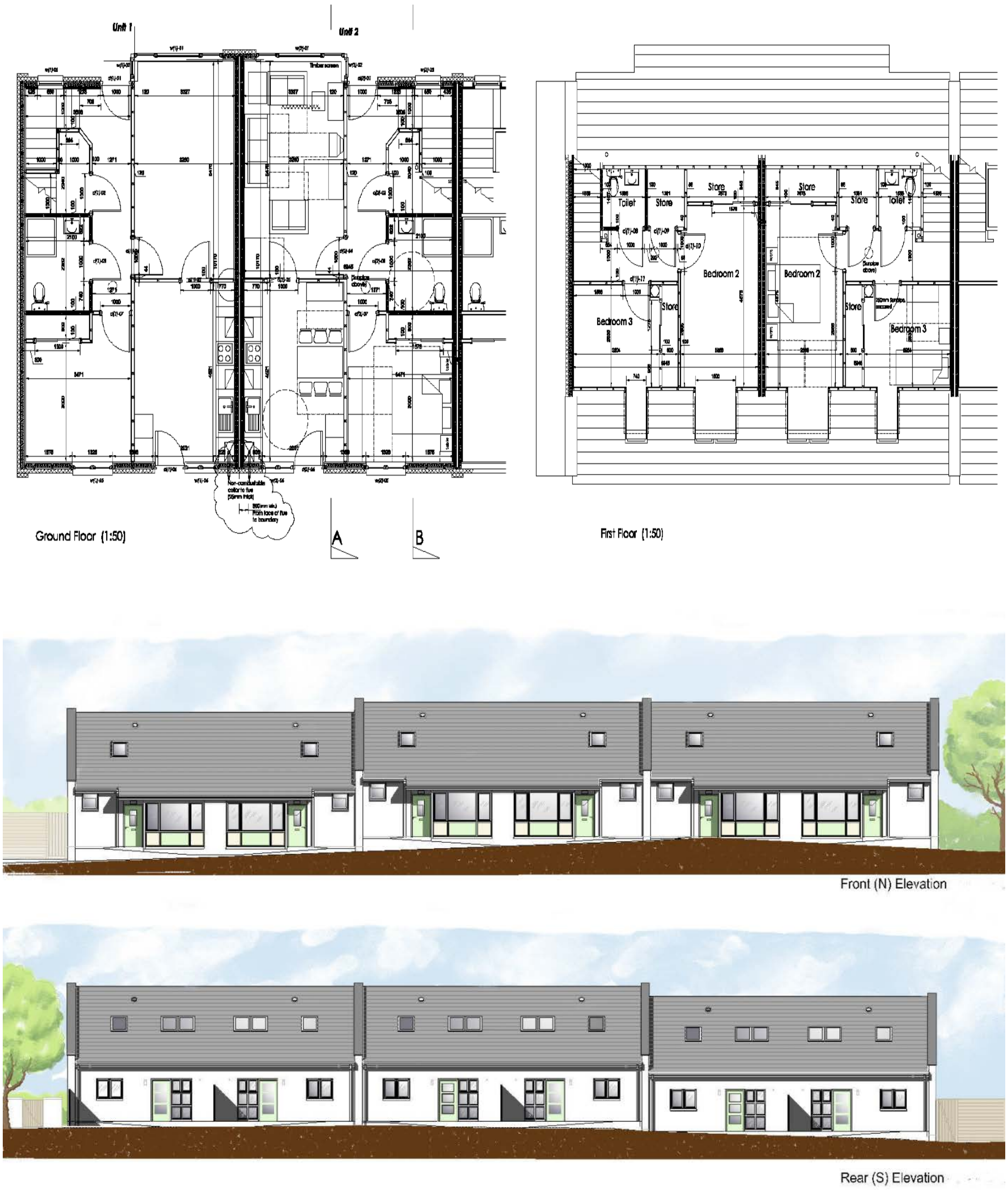
Site Plan

2.3 The Houses

The new proposal consisted of 6 no. 1.5 storey houses designed for flexibility of operation. Most facilities would be self-contained at ground floor level, with living, kitchen, shower and a double bedroom located on this level. Two bedrooms and a second toilet were located within the roof area, allowing accommodation for family members, carers, etc. The buildings were to be barrier free, in accordance with the prevailing HSHA and DDA principles.

The scheme was designed as a terrace, with a low profile and finish sympathetic with the neighbouring sheltered housing. The buildings were to have a ‘traditional’ character, with tile and render finishes.

The client was keen to explore a low energy, sustainable proposal, and to be low CO_2, with lightweight materials of low embodied energy in their manufacture and erection.



Plans and Elevations

2.4 Objectives of the Study

1. In Scotland there is a serious shortfall in housing suited to people who are less able than the majority. Changing demographics and approaches to social care provision will likely see increasing demand for dwellings that allow persons to live as independently as possible. It would therefore be valuable to review in detail the qualitative and quantitative performance of a project designed in accordance with current best practice for addressing comfort, convenience, safety and security needs of elderly and ambulant disabled occupants.
2. The materials and method of construction used for these dwellings, NBT Diffutherm, were a departure from more traditional options normally used by HSHA and the construction contractor, and indeed are novel for the UK construction sector as a whole. The proposed study will allow HSHA and the project team to extract the maximum knowledge from this

project in order to transfer this to future projects. The study will help HSHA understand if sustainable development and occupant wellbeing aspirations were met in full alignment with value constraints, e.g. construction cost and ongoing operation and maintenance requirements.
3. The dwellings incorporate a range of design features, the study of which would inform the ongoing industry debate on appropriate solutions for delivering comfortable and manageable energy efficient dwellings. For example, the decision to adopt a natural ventilation strategy in place of MVHR, a decision supported by the use of natural,breathable materials due to the expected lack of 'off-gassing' and low internal air pollutant levels.
4. This project would augment POE work already undertaken on behalf of HSHA by the Glasgow School of Art's MEARU, thereby informing broader research activities including a comparative evaluation of HSHA assets. Further to this, the scope of the proposed project goes beyond that of previous work, thereby offering valuable new insights and experience that can be taken forward in future work.
Specific questions we would hope to find answers to include: Do the dwellings provide a healthy and comfortable environment that can be easily managed? Does the timber frame system deliver effective thermal and acoustic insulation, as well as thermal storage capacity, vapour permeability and moisture control.

2.5 The Team

The study was conducted by the following organisations:
1. Hanover (Scotland) Housing Association are the lead organisation, who provide and manage an imaginative range of specialist housing for older and frail older people, as well as for families. They currently manage homes for more than 5,000 residents throughout Scotland, offering the choice of: rented; shared ownership; shared equity; and fully owned housing. HSHA have a strong history of action in relation to post occupancy evaluation and engagement, having previously worked with MEARU at the Glasgow School of Art monitoring several existing housing schemes, as well as working with EverGreen to support their residents develop sustainable communities.
2. ECD Architects, a practice with a 30 year track record in energy-efficient, sustainable design designed the Bloom Court Scheme and have wider relevant experience from delivering award winning social and extra care projects. ECD undertook the day to day management of the project, with lead design, construction and energy audit activities.
3. The Mackintosh Environmental Architecture Research Unit (MEARU), has been in operation for over 14 years and has an established track record of high quality research into environmental architecture. MEARU has a long history of working with user groups in relation to housing, but its remit now includes all aspects of construction, low energy design and sustainability. The unit also has detailed knowledge of building construction and typologies, particularly in relation to UK housing, and have undertaken a wide range of research, published extensively and is represented on several national and international committees. MEARU will be responsible for the majority of fabric testing elements indoor environmental condition monitoring and data interpretation.
4. The project M&E Engineer, Contractor and construction system supplier (NBT) were actively engaged in the project evaluation process; participating in the design/construction audit and advising on any technical issues relating to alterations/improvements proposed at the end of the first phase of performance monitoring.

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

3.0 Design

The client was keen to provide a simple energy efficient development which would meet the users' needs in terms of access and usage, as well as providing a sustainable energy efficient solution. The architects had been working with Natural Building Technologies (NBT), who specialise in timber frame technologies, providing an energy efficient building system.

3.0.1 Design Process

NBT were asked to make a presentation to the client and architect about how a modern wall and roof insulation system like Diffutherm and Pavaroof must do more than just protect building occupants from cold. They must create a comfortable and healthy environment in all possible combinations of external and internal conditions, controlling the effects of external heat, cold, noise and internal moisture generation.

It was considered that the low thermal conductivity and high vapour permeability, as well as good capillary and hygroscopic qualities, of the woodfibre insulation system would provide high thermal insulation with no short or long term moisture risk. The active "breathability" of the system would allow it to disperse high short term levels of moisture and protect vulnerable elements of the building fabric, without reduction in the performance of the system itself. It was reported that the woodfibre boards in the system allow moisture from within the structure to pass easily to the outside, thereby assisting with a good indoor air quality. These moisture qualities would also give protection against 'as built, in service' conditions over the life of the building, such as may occur if there are external building faults (for example leakage into the structure around window openings) . Vapour barriers and other membranes are unnecessary, thereby simplifying the construction and reducing costs.

The NBT systems were felt to reduce the effect of thermal bridging and the interlocking board design which achieves good wind tightness, so increasing thermal performance. The high mass and the fibrous texture of NBT systems would give excellent acoustic performance to the houses. It was claimed that the combination of high density and high specific heat capacity would give NBT systems a very high thermal mass compared to other insulations.

NBT advised that, due to the integrated simple design and multi-functionality of the system, along with the NBT design and site support, the performance gap between design and reality would be reduced or eliminated. This should ensure that in reality the energy use for heating along with the CO_2 emissions and the running costs over the life of the building would be very low. The embodied carbon locked up in the woodfibre boards would also contribute to CO_2 reduction.

3.1 Construction

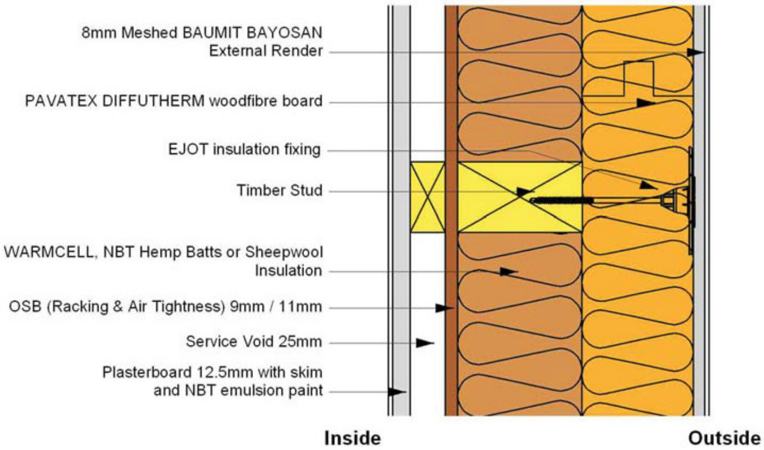
3.1.1 Structure

The building is constructed from well understood timber frame technology on a concrete site slab. The ground floor consists of battens on a concrete slab, with lightweight engineered joists supporting the first floor. The roof is constructed from softwood joists, allowing the roof space to be occupied.

3.1.2 Walls

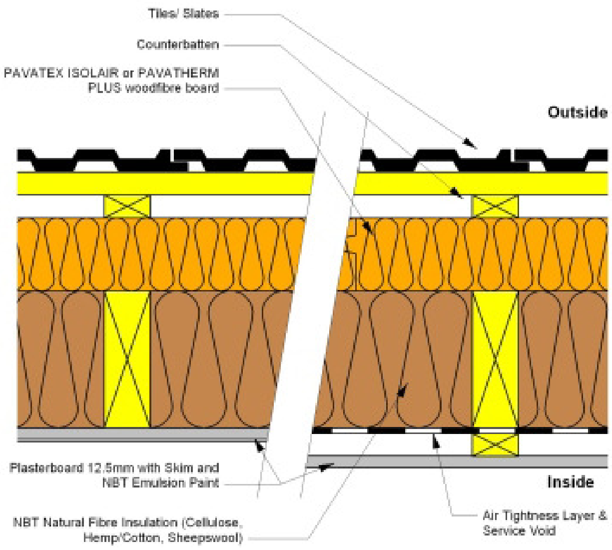
Externally, the timber wall structure is sheathed with Natural Building Technologies (NBT) 'Diffutherm' wood fibre. This high density, breathable sheathing is created with wood pulp and water, heated to allow the wood lignins to act as glue, then compressed. This is rendered with a NBT thin coat breathable render on fibreglass mesh, coated with a breathable paint finish. The frames are filled with Isonat Hemp/Cotton insulation,then faced internally with 9mm particle board for vapour and racking control. A services void faced with plasterboard completes the internal lining.

Technical design targets – U values: All calculations were done according to BS EN ISO 6946:1997 and BR 443. Studs assumed to be 50 x 140 mm at 600 mm centres. This gives a u-value for the wall build -up of **0.21W/m²k** and the roof build -up of **0.19 W/m²k** which was well below the current requirement at the time.



3.1.3 Roof

The roof is conventionally tiled on battens on 60mm 'Pavatherm Plus' sheathing from NBT. Pavatherm Plus is similar to Diffutherm, but with the addition on inert waterproofing agents. As with diffutherm, the boards are tongue and grooved for tight construction, with the use of the manufacturer's approved 'Pavatape' to ensure air tightness at cuts and penetrations. The rafters are filled between with 150mm Hemp/Cotton insulation. A breather paper is fixed across the underside of the rafters for vapour control, then faced with plasterboard on battens.



3.1.4 Glazing

Windows are high performance timber, glazed with 4/16/4 argon filled, low 'e' coated units. Velux roof lights supply light to the upper rooms. The upper hallway is supplied with natural light via a tubular 'sun-pipe'. The ground floor hallway was due to also be lit by this means, but difficulties in routing the pipe through the floor led to this being abandoned. Doors are high performance timber, chosen primarily for their security performance.

3.2 Services

3.2.1 General

Due to the domestic nature of this project, services provision was intended to be as conventional and straightforward as possible. The client has produced a design manual, including recommended products chosen for proven reliability and for simplicity of maintenance, as well as performance requirements. This formed an integral component of the briefing and initial design. Final design and commissioning to specified performance figures were the responsibility of the contractor for the works.

3.2.2 Heating/Hot Water System:

Heating and hot water provision were provided by a conventional domestic combi boiler system. This boiler is a condensing unit, (Worcester Bosch Greenstar 25 Si), located within

the kitchen. Estimated SEDBUK efficiency is 90.2%. Heating is supplied via a lthw radiator system, controlled by a wireless connected room thermostat within the ground floor hall, plus thermostatic valves in all other rooms. These systems are conventional, so easily understood by most tenants.
Hot water to sinks and washbasins are also supplied by the boiler. Thermostatic limiting mixing valves are utilised.
The showers are supplied by standalone electrical units.

3.2.3 Ventilation Systems:

Ventilation is largely natural, with trickle vents to high specification openable window systems and the wet rooms. Mechanical extract fans were installed within the bathrooms and kitchens, specified as 60 l/sec to the kitchen and 30 l/sec to the bathroom. Those to the bathrooms were to be connected to the light switches, with timer overruns.

The air permeability of the building envelope is specified by the ratio of surface area of the building to the hourly air exchange rate for a 50 Pa pressure difference. At the time of design and construction the Building Regulations air permeability of 10.0 to 20.0$m^3/m^2/h$ was allowed, whereas NBT recommended an air permeability of 3.0 to 5.0 $m^3/m^2/h$.

3.2.4 Lighting System:

Other than choice of low-energy fittings, no extraordinary measures were specified to the internal lighting. PIRs activate the external lights to front and rear entrances, the latter with a switched override.

Sun pipes were specified to provide daylighting to the ground and first floor circulation areas. Problems were experienced with routing the lower sun pipe through the first floor structure. As this hall received daylight from the front door and stair window, it was considered acceptable to omit this without detriment.

3.3 Conclusions and key findings for this section

- In general, the main sheathing and insulation materials worked well. As soon as the construction was weathertight, a notable temperature increase was discernable, even before any heating system was connected. However, most of the NBT materials were supplied from abroad, primarily from Switzerland. Apart from costs and distances involved in delivering simple materials, there were significant problems obtaining small quantities. There are questions over the durability of the thin coat render in a harsh climate, althiough unfamiliarity with workmanship may have caused issues here

- There are currently some minor problems with spalling render in two isolated locations. These are currently being investigated.

- The houses are well liked by the tenants in terms of aesthetics and overall layout.

- Generally energy bills and thermal comfort are commented favourable by tenants.

4 Fabric testing (methodology approach)

4.1 Fabric Testing Processes

As part of the BPE project, mandatory testing processes were undertaken to assess the quality of the built fabric and its performance relative to design intent. These processes included air tightness testing, in-situ U-value measurements, infra-red thermography and a whole house heat loss (co-heating) test. The most time consuming and logistically onerous of these was the co-heating test. This required that the test dwelling was unoccupied for a period of around 2 weeks during ‘heating season’ and that very particular thermal and air-tightness conditions were then created within the residence. The internal environment created during this test provided ideal steady state conditions for undertaking thermographic surveys and the in-situ U-value testing.

The above suite of tests was undertaken during a relatively short period of time in early 2014. The summarised results of each are presented below along with conclusions that can be drawn on the wider performance of the construction fabric.

4.1.1 Air Permeability Testing

At the beginning of the BPE project air permeability testing was undertaken on the two focus dwellings at LA5 and LA6. Full reports for these tests are provided as appendix 2. A summary of the test results is presented below;

Test Dwelling	Test Date	-ve Pressure Test ($m^3/h/m^2$)	+ve Pressure Test ($m^3/h/m^2$)	Stated Value ($m^3/h/m^2$)
LA5	06.02.12	3.73	not undertaken	3.73
LA6	06.02.12	3.71	not undertaken	3.71
				3.72

Table 4.1. Initial Air Permeability Test Results

As part of the co-heating test procedure further air permeability testing was undertaken in LA6 at the commencement and conclusion of the test on 13th and 24th January respectively. Full reports for these tests are provided as appendices 2 to 8 with the main findings presented below.

Test Dwelling	Test Date	-ve Pressure Test ($m^3/h/m^2$)	+ve Pressure Test ($m^3/h/m^2$)	Mean Value ($m^3/h/m^2$)
LA6	13.01.14	3.94	3.99	3.965
LA6	24.01.14	4.04	3.97	4.015
				3.99

Table 4.2. Later Air Permeability Test Results as part of Co-heating Test

A review of the air permeability test results realises many significant findings.

Over the 20 month period from the first to last set of tests there has been very little variation in the recorded values. This shows that methods used for achieving air-tightness are proving to be robust and are not deteriorating at a significant rate. What is less clear, however, is whether there was any change over the period between handover and the first test undertaken as part of this project. No air permeability testing was carried out at completion as the dwellings were designed to achieve an air permeability of $10m^3/h/m^2$ and it was not, therefore, required under the 2008 Technical Standards. While this particular assessment cannot, therefore, be made it is very clear that regardless of what the infiltration rate at handover was, the current performance far exceeds the intended. This might initially appear to be favourable result, in terms of limiting uncontrolled ventilation heat loss, but in terms of meeting other conditions relative to health and environment it is clear that this low rate of air infiltration may present problems for the dwellings.

The most recent iteration of the Scottish Building Regulation Technical Standards recognises this issue of dwellings being constructed to an inadvertently high level of air tightness but at the time of construction this phenomena was not predicted and no provision was made in terms of requirements to test air tightness or for ventilation provision allied to this. Under the current regulations (2013), section 3.14.10 states *"where infiltration rates of less than $5m^3/h/m^2$ @ 50Pa are intended, then such a [mechanical ventilation] system should be used."* With this reflecting the current understanding then it is apparent that a whole house mechanical ventilation system should ideally be installed at the properties as an approach using background ventilators only will be ineffective. The impact and potential deficiencies of this ventilation regime are further assessed in Section 7 of this report.

4.1.2 Infrared Thermography

Internal and external images (both infrared and digital camera) were taken for both subject dwellings on Friday 24th January, between 11.00 and 13.00 hours. Testing was undertaken in accordance with the requirements of TSB monitoring protocol, BRE IP 1/06 and BSRIA 39/2011.

A full report of this testing is provide on Carbon Buzz, with a summary of the main findings presented below.

Dwellings Generally

The construction generally appears to be of good quality, with few obvious defects affecting thermal integrity.

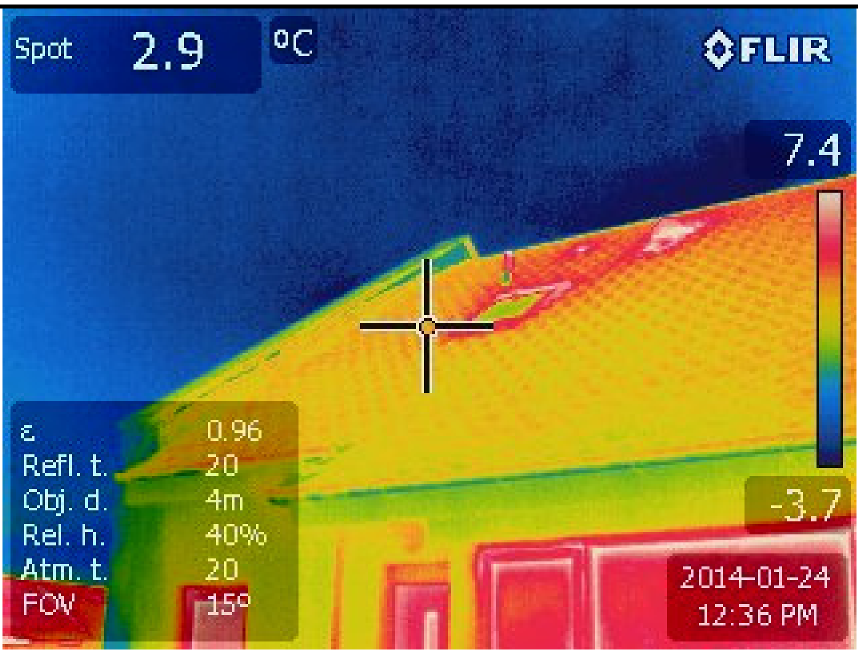
Bay windows were seen to be thermally weaker than the main fabric. In terms of the increased surface area and type of construction used this result is not unexpected but is worth noting.

The rooflight ingoes were seen to present a relative weakness in the fabric with the first floor WC presenting a case for continued monitoring, due to the high moisture load in this area and the potential risk of condensation and associated mould growth.

Insulation at some wall head/ eaves conditions may benefit from review and better fitting to improve thermal efficiency.

The 'light tube' was seen to be a relatively weak point in the roof construction. It was fitted with a surrounding insulation.

The bay window/ wall junction exhibited marked heat loss and should be reviewed for any obvious leakage paths and thermal bridges.



Sample image of the thermographic testing showing heat losses at structural opening and, in particular, at the ‘tight tube’ roof penetration.

Unit LA5

Trickle vents were found to be well used by residents but it was interesting to note the apparent effect of cooling from these. This point is raised as it is crucial that anyone reviewing the reporting does not simply view the trickle vent images and decide that they should be permanently shut during heating season. These represent a critical element in the dwelling’s ventilation strategy, particularly given the air permeability findings identified above, so should be used accordingly.

The toilet cisterns were found to be very cold and to present a condensation risk. Moves should be made to insulate these and mitigate the effects of damp and mould growth of adjacent materials. Note, this issue was only viewed in LA5 but is likely to exist in other dwellings when under normal occupancy conditions.

The evaporative cooling effect/ energy burden of internal passive laundry drying was illustrated and efforts should be made to minimise this where possible.

Unit LA6

A cold spot was identified at the ground floor toilet soil pipe penetration and should be reviewed for air infiltration/ thermal loss.

Marked heat loss was identified at the ground floor bedroom window where a cable has been passed through the opening light and a tight seal can no longer be achieved.

The kitchen extract fan appeared to be well sealed when not in operation and was not contributing to energy loss by air infiltration. In contrast, the shower room fan appears to suffer from this problem.

The cill to the living room bay window appears to be much warmer than would be expected and may be acting as part of a thermal bridge to the slab. Further review of this should be undertaken.

4.1.3 U-value Testing

To maximise the benefit of the steady state internal conditions created by the Co-heating test, the testing of in-situ u-value was undertaken over the same time period from 13th to 24th January 2014. The test endeavoured to identify 'real' u-values for the construction of the 6 dwellings by assessing the thermal performance characteristics of the wall and roof.

The methodology used for all testing and analysis is as the test procedures set out in ISO 9869:1994 and Hukseflux HFP01/ HFP03 manual version 1014 and TRSYS01 manual version 0810 both of which describe thermal resistance testing procedures in accordance with ISO 9869, ASTM C1046 and ASTM 1155 standards. A full report of this testing is provide as Appendix 6 with a summary of the main findings test issues presented below.

U-value kit sensor arrangement testing the heat transfer through the roof. Unfortunately the flux plate in this location became dislodged during the test.

Issues

The well controlled internal conditions during the test phase and relatively stable winter temperatures externally meant that robust data should have been readily available from the testing. This was the case with the wall element testing but unfortunately, the data for the roof element was found to be compromised due to equipment failure.

On collecting the equipment from the testing it was apparent that, despite careful installation, the flux plate had become dislodged from the roof element. Further investigation found that two other flux plates installed in the dwelling as part of the co-heating testing had also become dislodged during this time period. It has been assumed that the very warm and dry conditions created for the co-heating test contributed to this failure and may have dried out the fixing tape, reduced its adhesion and ultimately caused the plates to fall off.

As the dwelling was not occupied or visited during the testing period (a requirement to improve the validity of the co-heating test), it was not possible to closely identify when the plate had become dislodged and if valid data could be assumed prior to this point. From a review of the flux data no clear ‘event’ could be identified which would indicate a safe cut-off point for data analysis so the data and results should be considered invalid and unusable to prevent false conclusions being drawn.

Results

For the analysis of the wall element the first 48 hours of data were omitted to allow for settlement of the sensors. Calculations are, therefore, based on data recorded between 12.00 on the 15th January and 12.00 on the 24th January.

For a wall element this result clearly presents a favourable condition set against the current backstop value of 0.25W/m^{2}K defined in Scottish Technical Standards. Compared to the design value of 0.18W/m^{2}K it may appear that the measured value of 0.19W/m^{2}K represents some sort of minor deficiency in the fabric but for an in-situ value to come so close to the design condition is actually a very good result.

Construction Element	Full Testing Period	Analysis Sample Duration	Design U-value	Measured U-Value	% variation
LA6 External Wall	13.01.14 @ 12.00 - 24.01.14 @ 12.00	216 hours	0.18W/m^{2}K	**0.19W/m^{2}K**	**5.5**
LA6 Roof	13.01.14 @ 12.00 - 24.01.14 @ 12.00	-	0.2W/ m^{2}K	**-**	**-**

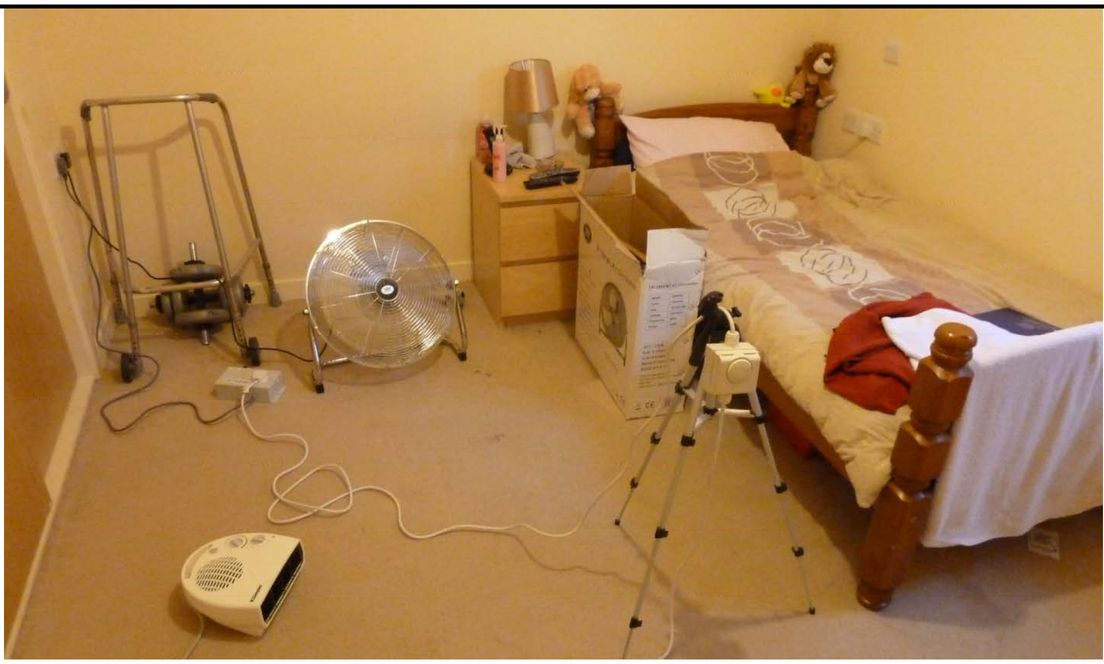
Table 4.3. U-value test results

Design values using manufacturer’s lab test results of thermal resistance are unlikely to be representative of on-site conditions, particularly relative to material moisture content. Moreover, the design calculation process does not take account of the prevailing climatic conditions, which are likely to have been experienced over the test phase. A combination of these and other factors mean that the variation in performance is negligible and the result is representative of a high quality and thermally robust design and construction.

4.1.4 Whole House Heat Loss (Co-heating) Test

The whole house heat loss (co-heating) testing was undertaken during January 2014 at LA6. The test aimed to identify a whole house heat loss parameter which can be compared to design benchmarks to assess the thermal condition of the design and construction and identify if a performance gap exists. It can also be used as a comparator to other tested dwellings to, theoretically, identify their absolute performance in terms of thermal energy efficiency.

A full report for the testing is provided as Appendix 5. This also includes an in-depth report on the analysis methodology prepared by Dr. Paul Baker of Glasgow Caledonian University's Research on Indoor Climate and Health unit. A summary of the key findings and test procedure issues are presented below.



Co-heating kit disposition in one of the test bedrooms

Test Issues

Two issues were identified from the test procedure which could impact on the results. Hukseflux flux plates were installed on the party wall to monitor energy movement through this element of construction and quantify losses. Unfortunately, as with the U-value testing, the tape holding these plates in place failed at some time during the test period as a result of the high temperatures and low RH drying out the adhesive. The point at which these plates came off the wall could not be identified thus none of the data could be used. Temperature data from the adjacent dwelling has been used in the calculation process but this does not account for energy which is lost by convection in the cavity between the two dwellings. A small degree of error is likely to result from this.

The thermostats used were placed at an altitude of 850mm above finished floor level as specified in the protocol but in the case of the living room, kitchen and bedroom 3 the associated temperature monitor was located at a different level. This was a result of using the t-mac sensors which were already installed as part of the BPE monitoring but which are at a level of 2000mm in each room. This meant that conditions might indeed have been the same between rooms, although leaves the possibility that these rooms appear to be hotter than those being monitored at the lower level. In this case it is unlikely that this has affected energy draw but the monitored environmental data may suggest this is the case.

In relation to this it is worth noting that the monitoring protocol document calls for the internal temperature to be maintained within ±0.2°C. The thermostats used in the testing are the Honeywell T4360B model as suggested in the supporting Leeds Met procedure document. The required level of accuracy may not be achievable with this particular thermostat as technical specification state a typical temperature differential of 0.5°C.

Results

Varied methods for calculating the heat loss coefficient and solar gain factors are available and accepted in this test process. Each has varying degrees of accuracy and as such the analysis process assessed the measured data against all three of these methods to not only gain the most accurate results but to also make a comparative assessment of each method and to provide outputs which could most easily be assessed against other projects within the TSB POE programme. A summary of these results is provided in Table 4.4 below.

analysis method	heat loss coefficient (W/K)	Standard error (W/K)	Solar Gain Factor (m^2)	standard error (m^2)
Siviour	67.2	6.4	10.0	10.9
Leeds Met. Uni.	67.3	6.5	10.5	11.1
LORD	64.2	4.2	7.6	0.5
(SAP Prediction)	75.94*		not part of SAP	

Table 4.4. Co-heating analysis results and SAP Prediction. *Note: SAP prediction figure is called “Total Fabric Heat Loss” on SAP sheet, while “Heat Loss Coefficient” is used to describe fabric (75.94) + ventilation losses (52.64).

The reduced error produced by the dynamic modelling of the LORD method provides the results with the greatest validity and so the final values are assumed to give a heat loss coefficient of **64.2 ±4.2W/K** and a solar gain factor of **7.6 ±0.5m^2**.

A solar gain factor is not something SAP considers, a shortcoming which means comparison is not possible, while the predicted heat loss coefficient is 18% higher (worse) than the LORD calculation. Both figures are good, that is they reflect a well insulated dwelling, and given the myriad of variables, it is not possible to highlight one or more reasons for the discrepancy. It does however mean the discrepancy between predicted and actual energy consumption is even greater (see Section 7) than it first appears.

4.2 Conclusions and key findings for this section

A collation of the key findings is presented below:

- Air permeability rate was found to be 3.99$m^3/h/m^2$ in the most recent tests.
- Air permeability results remain stable over time suggesting that means of achieving air-tightness are robust.

- The achieved level of air-tightness, under current Technical Standards, would suggest that a whole house mechanical ventilation system would be required to provide good IAQ and that the current strategy (using background ventilators) is insufficient.

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

- The use of a bay window design to the public realm was found to present a thermal weak spot but this is as would be expected and is the price to pay for increased aspect and the additional security this provides.

- Rooflight ingoes were found to be relatively thermally weak and in the case of 1st floor WCs could present an opportunity for condensation and mould growth.

- Additional slight thermal weaknesses were identified at wall head and eaves conditions, the 'light tube' roof penetration and toilet cisterns.

- Internal conditions created during the co-heating test can be very dry and can result in issues with equipment being adhered to walls as glues can dry out and fail.

- The through wall construction was found to achieve an in-situ U-value of 0.19W/m^2K. This compares well to the design value of 0.18W/m^2K as this value is derived in much more favourable conditions than those experienced on site.

- Three varied methods were identified for analysis of co-heating data and used to derive different results for this test.

- Using the LORD method a heat loss coefficient of 64.2 ±4.2W/K and a solar gain factor of 7.6 ±0.5m^2 were identified. The heat loss coefficient compares well (lower) than the SAP prediction of 75.94.

5 Key findings from the design and delivery team walkthrough

5.1 Walkthrough Summary

Dwelling Occupancy and Usage Patterns

LA1 – Mother with two daughters over 18 and one child and another expected
LA2 - Mother with two sons over 18
LA3 – Tenant with partner and 4 children
LA4 – Mother with daughter over 18 and one child
LA5 – Husband and Wife and son over 18
LA6 – Husband and wife

5.1.1 General issues with the houses' operation

In general all tenants liked staying in their house, with most commenting on how warm they were, although some mentioned feeling too warm in summer. They found the house simple to operate, However, all noted a major problem with the lack of ventilation to the ground floor shower room.

Front Elevations

5.1.2 Handover procedure and Instruction

All tenants confirmed that a handover took place with Hanover at occupation and were instructed on how to operate the systems. They also stated that they were given a user/instruction manual to retain for future reference. Some tenants did not now know where these manuals were. The tenant at LA1 stated that she did not receive the central heating instructions and had requested same from the landlord.

5.1.3 Programmers, Timing systems and controls

The use and understanding of the use of equipment and controls varied across all houses, from a full and detailed knowledge of the system to a basic understanding of the use of the thermostat and workings of the boiler. The tenants in LA5 (one of the houses being monitored in detail) have a full understanding of the house operation and monitor carefully the timers and thermostat. The tenant in LA4 was not sure of the timer and boiler controls and only uses the thermostat to control temperature. The remainder of tenants fell between these extremes with most having a good understanding of the systems operation utilising both thermostat and timer.


Danfoss Thermostat


Worcester Boiler

5.1.4 Temperature settings

All tenants confirmed that the houses were warm and controllable with a movement of 1 deg on the thermostat being noticeable. One tenant stated that in their previous house one had to alter the thermostat by 5 deg to notice any change.
One Tenancy likes different temperatures, with the thermostat used by both occupants. The main tenant likes 24deg, but the daughter 21deg, hence the temperature fluctuates throughout the day as each passes the control.
Overall, tenants set thermostat between 20 and 24 deg.

5.1.5 Lights / Natural Lighting

All light fittings have energy efficient lamps, which were installed when houses were built. Two tenants have replaced some bulbs for reading as she found the EF bulbs too dim. Another tenant would have preferred if the two lights in the living room and hall could have been individually operated.
Most of the tenants thought that the natural lighting was good, although they felt overlooked by the proximity of the path at the front of the property, requiring the partial closing of blinds or curtains which affected the quality of natural light. Other rooms and bedrooms had adequate natural light. Positive mention of the sun pipe to the upstairs internal landing was made by several of the tenants.


Sun Pipe to Upper Hall   Proximity of path to Living room

5.1.6 Ventilation

There is natural ventilation to all rooms apart from the downstairs shower room, which is mechanically vented and ducted to the outside.

Windows: All windows in habitable rooms are openable, with permavents.
All tenants confirm that their windows are opened in summer for cooling. Properties become too warm, particularly upstairs.
Permavents are open in bedrooms at night, apart from with one tenant who closes them.
All doors have 20mm gap at base for cross venting.

Extract fans: All tenants complained that the mechanical extract fan to the downstairs shower room was not effective, Draw from fan very poor. This was undoubtedly the biggest cause for concern among all tenants and had been reported to Hanover who were presently looking at solutions. The upstairs extract fan (same as ground floor) worked well, possibly indicating a blockage in the duct work from the ground floor shower room to the vent. This required further investigation. See separate detailed report on extract fan operation in Section 9.


Shower room Extract Fan   Shower room damp

5.2 Maintenance

Have there been any issues relating to maintenance, reliability and reporting of breakdowns of systems within the dwelling?

There have been some maintenance items reported and repaired:-

- Kitchen window handle replaced
- Roof leak
- Steep roof pitch. Overshooting of gutter in instances of heavy rain
- Well insulated roof – Snow build up – Falls off damaging gutter
- Two door handles replaced
- Boiler was replaced due to defective heat exchanger
- Main issue revolved around the ground floor shower room ventilation.

Steep roof pitch

What is your reporting of defects process?

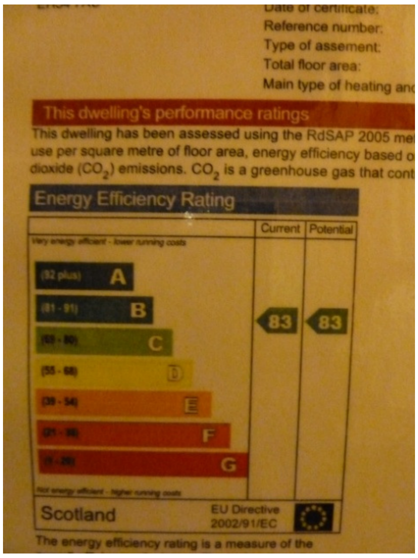
All defects identified were either phoned or letter written to Hanover offices. These defects are recorded and, dependant on severity, dealt with within stated timescales.

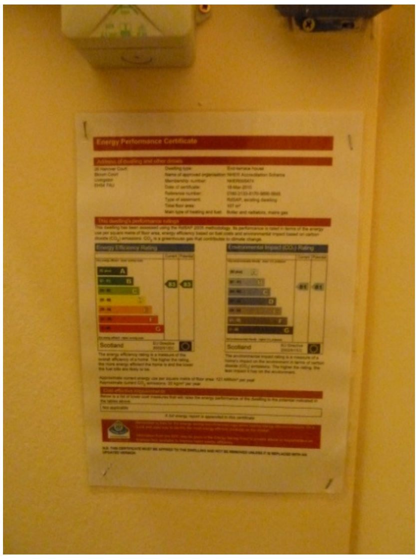
A maintenance officer also calls round approx. every 6 weeks to check whether there are any issues relative to the individual house. These are again noted and dealt with.

All tenants considered the service to be good.

5.2.1 Energy and Water Management

Does the energy consumption of the house meet your expectations?
In all instances the tenants were satisfied that their energy bills were less than previous houses. The increases in energy charges were, however, affecting this saving.
One commented that during the first year of occupation, she felt that she hardly had the heating on and that her bills were vastly reduced.
Another felt that the bills were half those previously paid.





5.2.2 Walkthrough the House and comment on usage:-

Ground:-
Living Room
All tenants liked the size and shape of the living room and that the kitchen opened directly off this room.
The main criticism revolved around the proximity of the path outside and a lack of privacy in the room. Blinds and curtains had to be closed.
Comments from LA3 and LA5 related to the position of the radiator and that it affected furniture layout, and consider it should have been behind the door.

Shower room
Internal shower room with no window and mechanical extract. All tenants complained about the lack of ventilation and the damp atmosphere following taking a shower. On inspection the 'draw' from the extract was poor indicating a potential blockage in the flexiduct to the terminal.

Kitchen
All tenants liked the size and space within the kitchen.
Worcester combi condensing boiler located in corned within kitchen unit.
All kitchens had WM, F/F Cooker and microwave.
Some criticism of layout, stating more storage should have been provided.

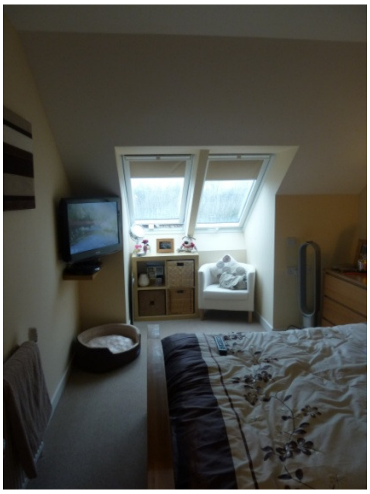


Bedroom 1
Main bedroom with double openable window with permavents.
Built in wardrobe. All tenants appreciated this
All tenants liked the size and location of the bedroom affording ground floor access without the need to climb stairs to reach toilet and shower facilities.

Storage
Large store beside shower room and stair well received and utilised.

First Floor:-
Bedroom 2
Smaller of the two upstairs bedrooms with single velux window openable with permavent.
Again built in wardrobe
Coombed ceiling

Bedroom 3
Larger of the two upstairs bedrooms with double velux windows, openable with permavent.
Again, built in wardrobe
Coombed ceiling



Toilet
Upstairs toilet and whb located off corridor.
Single velux window openable with permavent.
Coombed ceiling.
Mechanical extract fan as ground floor, although extract much improved on those.

Comments:-
How could improvements be made to:-

The Layout
All tenants were generally satisfied with the layout of the house, particularly:-

- Ground floor bedroom access
- Good space standards
- Good general Storage
- Built in wardrobes

Some tenants did not like, particularly:-

- Proximity of front path
- Would have preferred Living room to be at the rear of the property
- Internal Ground floor shower room. Would have preferred openable window
- Position of radiators as restricting furniture layout
- No bath in house
- No shower/bath facility upstairs
- Amount of kitchen cupboards provided

Energy efficiency
All tenants appreciated how the building retained the heat and that their energy bills were reduced from their previous house.
There were no proposed improvements to energy efficiency

5.3 Conclusions and key findings for this section

- All tenants generally liked their houses in terms of space standards and energy efficiency. They all liked the location and particularly their neighbours. The ground floor bedroom was particularly appreciated due to their physical needs.

- The one major issue with all tenants revolved around the mechanical extract to the ground floor shower room which is currently under investigation. See detailed report in section 9.

- Tenants comfort levels confirm airtightness and thermal efficiency of construction type.

- The simplicity of the systems and controls are easily understood and operated in efficient ways by the tenants

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

6.1 BUS Survey

- BUS Surveys issued 11th October 2012 and collected on the 16th October 2012
- 11 Returns out of possible 15
- Household Occupancy;
  LA1 – Mother with two daughters over 18 and one child and another expected
  LA2 - Mother with two sons over 18
  LA3– Tenant with partner and 4 children
  LA4– Mother with daughter over 18 and one child
  LA5– Husband and Wife and son over 18
  LA6 – Husband and wife

6.1.1 Client Building User Profile Summary

- 64% of building users surveyed were over 30 with 36% under.
- All respondents were tenants.
- 82% of respondents were normally at home.
- 100% had lived in the dwellings for over one year.
- 55% of respondents were female.

The results have been split into the following categories: -

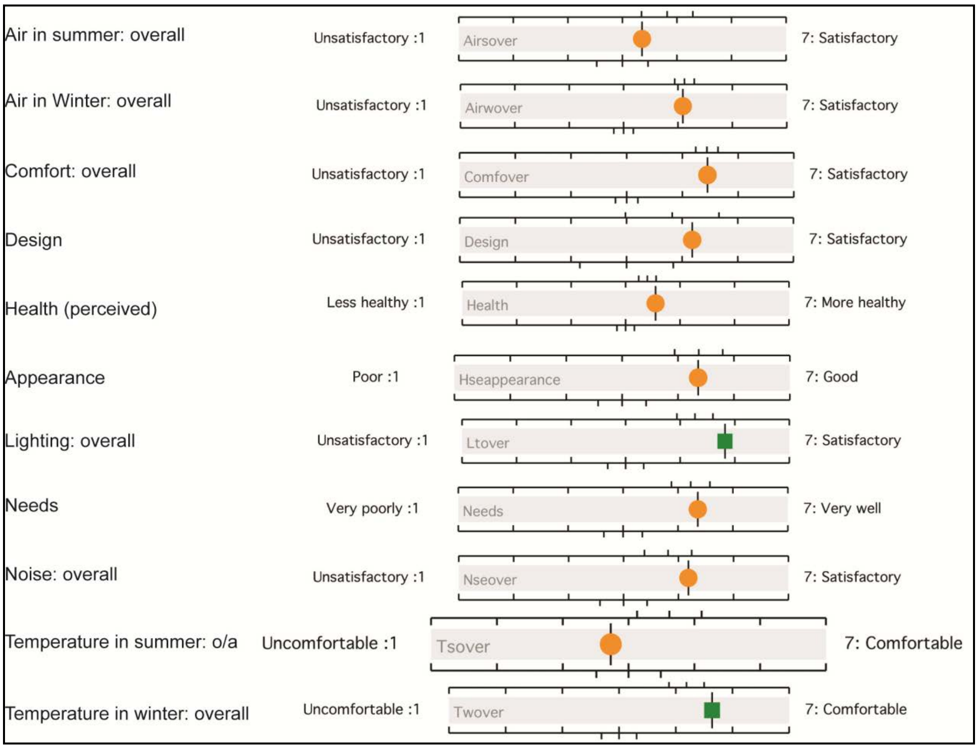
- Issues scoring better than benchmark and scale midpoint (Green Square)
- Issues scoring between the benchmark and the scale midpoint (Amber Circle)
- Issues scoring poorer than benchmark and scale midpoint (Red Diamond)

The benchmark used by the BUS survey is taken from the last 50 buildings surveyed and held on the Arup database. The midpoint is the optimum answer that can be provided by the respondent for a particular question.

The following is a summary of the results from the BUS survey.

6.2 Results

6.2.1 Summary (Overall variables)



BUS Table 1

The overall summary of the main issues in the BUS survey indicate that the building is scoring in accordance with the benchmarks of other buildings and the scale midpoints.

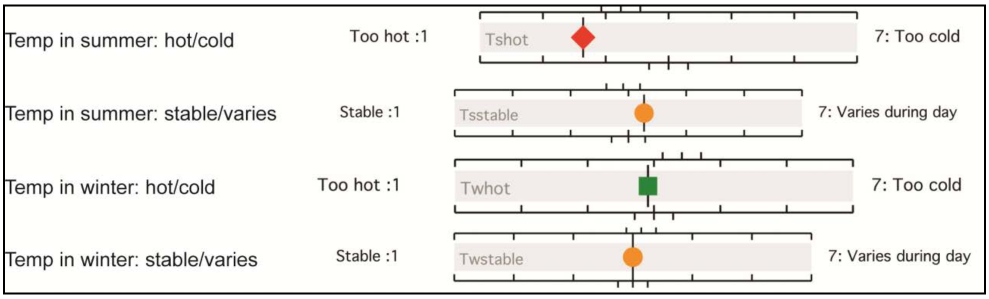
The internal winter temperature stood out as scoring particularly well.

6.2.2 Temperature

The scores for the buildings in this section are quite variable with most respondents noting a stable summer and winter temperature. However, the responses would suggest that they are prone to overheating somewhat in the summer, whilst scoring well in terms of internal temperature in the winter.

Through the questionnaire a number of comments were received regarding the heating such as: -

- Always too hot irrespective of how many doors and windows are open;
- Difficult to keep cool in Summer;
- Need windows open in Summer;
- Heating is very efficient. 1 deg change is enough to maintain comfort;
- I hardly have the heating on except in winter;



BUS Table 2

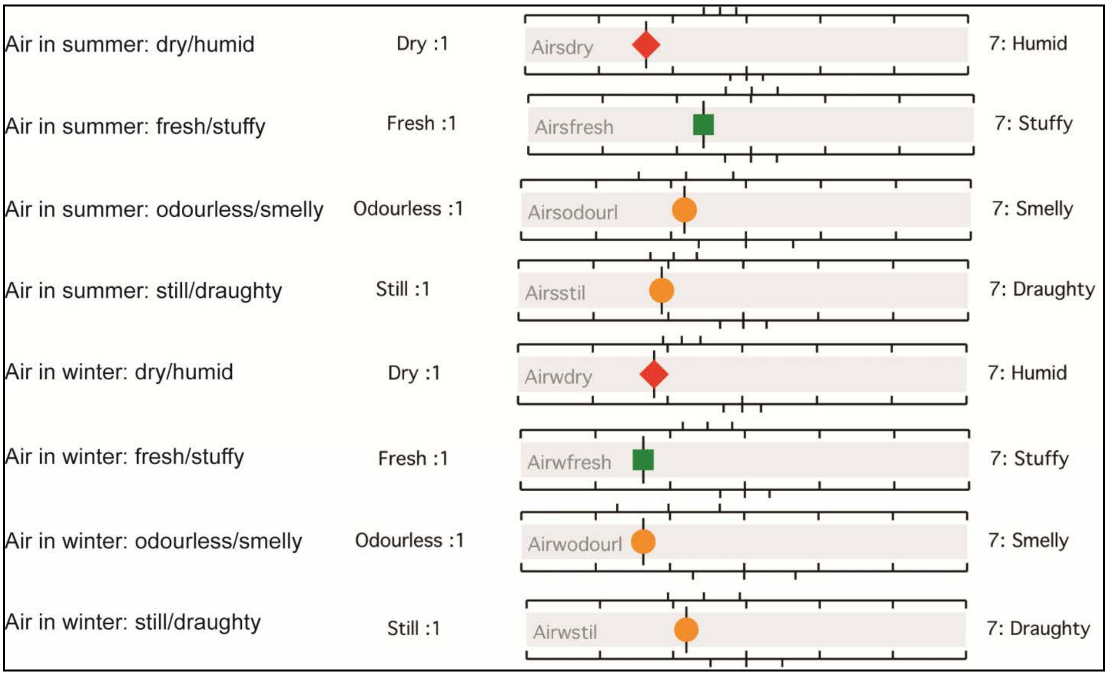
6.2.3 Air

The results in this table display a varied response for several items regarding the air quality in the building.

There appears to be a yearlong issue regarding the dryness of the air in the building. This may be down to the inherent airtightness of the building construction and it can also be noted that the building is only achieving benchmark scores in terms of still/draughty environment.

There are no major issues with odours in either winter or summer with residents generally satisfied.

Overall users reported being largely satisfied with air related issues as can be seen in BUS Table 3.



Bus Table 3

Through the questionnaire a limited number of comments were received regarding the air quality: -

- The ventilation in the bathroom is not so good;
- Ventilation is an issue. Difficult to maintain a comfortable temp;
- The ventilation in the bathroom is not so good;
- Bathroom has black mould;

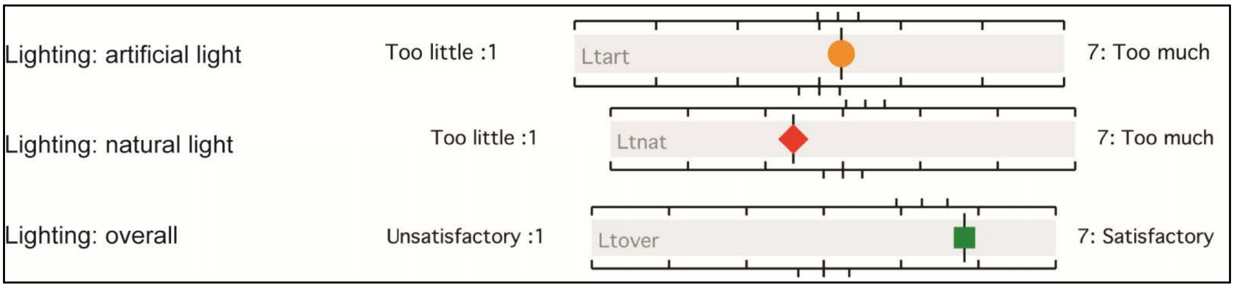
The comments appear to be mostly in relation to the ventilation installed in the bathroom. Further investigation into this may alleviate some of the problems which residents are experiencing.

6.2.4 Lighting

Although BUS Table 1 indicates that most building users are satisfied with lighting overall, this masks some individual issues users have with lighting. It also indicates a high 'forgiveness' factor which is evident throughout the results. Users have individual issues but overall are satisfied. The main issues with lighting is the lack of natural light in some areas of the building.

This may be as a result of the design being geared towards energy efficiency, thereby limiting glazed areas in certain rooms and aspects.

In addition the position of the living room to the front of the property seems to stop residents from fully utilising the available natural light for privacy reasons.



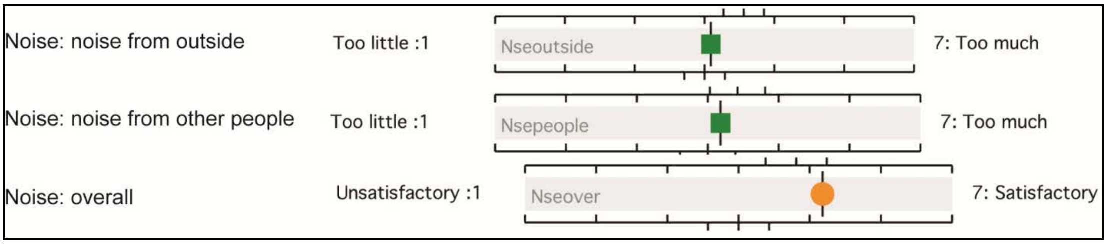
Bus Table 4

Through the questionnaire a limited number of comments were received regarding lighting: -

- Not enough light in hall and shower room;
- Only hall and bathroom need artificial;
- Can't take advantage of living room natural light due to public path proximity;
- Use more lighting but energy saving bulbs means roughly the same consumption

6.2.5 Noise

The noise results are somewhat contradictory in that the building scores well generally, however the overall score is only satisfactory.



Bus Table 5

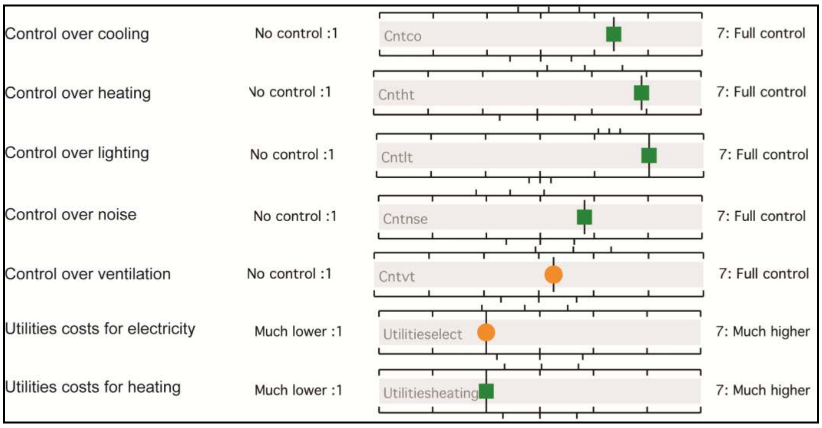
Through the questionnaire a limited number of comments were received regarding noise: -

- Noise and speaking from upstairs in house really bad. Others ok;
- Can hear neighbours occasionally on both sides. People walking past on footpath;
- The noise is ok except you can hear someone talking upstairs with door closed.

The comments regarding noise from upstairs are of interest. The building would have been designed in accordance with the building regulations in terms of noise transfer. Structural penetrations of the party walls were specifically detailed to minimise transmission.

6.2.6 Control

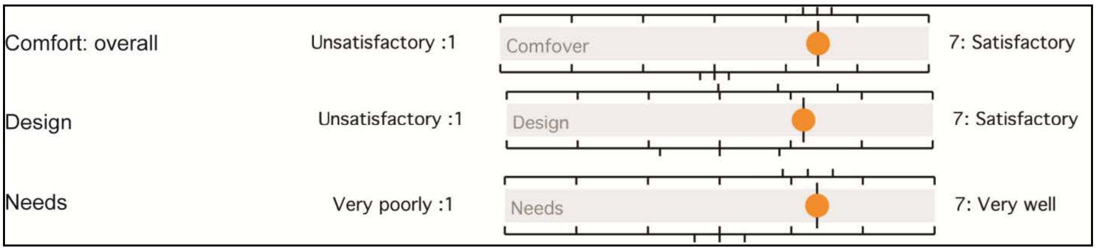
This section appears to score particularly well in relation to others, with only the control over ventilation (within the bathroom according to comments) being problematic for users. Electricity costs are in line with benchmarks whereas heating costs are reduced.



BUS Table 6

6.2.7 Design/Needs Variables

Overall comfort, building design and user needs all score within benchmarks for the building occupants. This indicates that although there are individual issues in the building that overall residents are satisfied and the building is performing within the benchmark parameters.



BUS Table 7

Generally, the main comment appears to be in relation to the position of the living room adjacent to the path at the front of the property.

6.2.8 Summary Table of all results

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

BUS Table 8: Summary of all issues

The above table shows that the main issues of concern highlighted in the Building User Survey are: -

- Air in winter: dry/humid
- Air in summer: dry/humid
- Lighting: natural light
- Temperature in summer: hot/cold

6.2.9 BUS Survey Individual Feedback Comments

A large number of individual comments have been made as part of the BUS survey. The full list can be found in Appendix B. The following is a summary of the comments made in the BUS report. This summary is focusing on frequently occurring comments rather than one off individual opinions. It may be beneficial for Client to consider all comments made in Appendix B.

Things that work well

- Bathroom being downstairs;
- Lower floor works well;
- Ground floor bedroom. Walk in shower. Ramps to front and rear. Height of work surfaces. Size of door frames;
- The bathroom and kitchen work well plus having a bedroom downstairs is good;
- Upstairs allows for some privacy.

Comfort Overall

- Bathroom lets the property down;
- The comfort is ok;
- Very comfortable

Design

- Could have been designed better outside and bathroom;
- Internal bathroom and kitchen poor. Overall satisfied;
- House is facing path;
- Roof pitch too steep. Rain misses gutter. Snow builds up and fills garden when it falls off.

Health (perceived)

- Bathroom lets the property down. Constant battle to keep mould free;
- Bathroom not healthy. Rest of house good.

Hinder (things that hinder)

- Bathroom is always damp. Black mould. No window. Ventilation poor. No bath;
- Needs a bath as I have a small child. A bath is standard in family homes but not this one. Very little ventilation;
- Not enough worktops and wall units in kitchen. Could have been better laid out. No bath;
- Upstairs windows hard to clean.

Lighting

- Not enough light in hall and shower room;
- Only hall and bathroom need artificial;
- The lights inside and outside are ok.

Noise

- Can hear neighbours occasionally on both sides. People walking past on footpath;
- Noise and speaking from upstairs in house really bad. Others ok;
- The noise is ok except you can hear someone talking upstairs with door closed.

Space

- There is enough space.

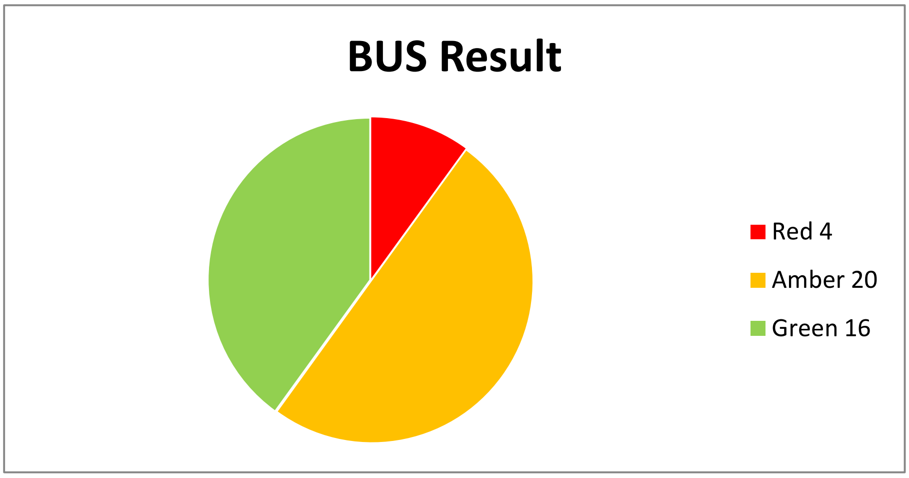
Storage

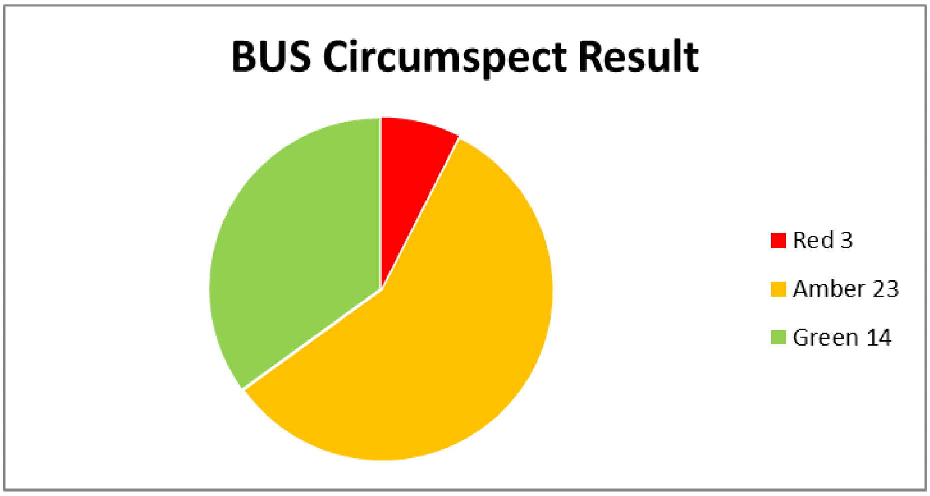
- Adequate wardrobes good in bedrooms;
- Could do with more cupboard space;
- There is more than enough storage;
- There is no facility for external storage. No shed or garage.

.

6.3 Conclusions and key findings for this section

Overall Result





The 4 Red flags relate to:-

- Air in winter: dry/humid
- Air in summer: dry/humid
- Lighting: natural light
- Temperature in summer: hot/cold

Things that the tenants think work well:-

- Ground Floor Bedroom
- Walk in Shower
- Wide Doors
- Control of services
- Economy of energy bills

Things that the tenants think don't work well:-

- Ventilation in the downstairs Shower room.
- Too hot in Summer
- Would like a bath upstairs
- Front path too close to living room window

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

From the outset, all systems and services were intended to be as conventional as possible. This simplifies requirements for maintenance, repairs and supply of spare parts. No specialist knowledge is required. Natural gas is used to fuel heating, hot water and cooking. Ventilation and lighting used grid supplied electricity. Refer to Section 3.2 for details.

No renewables have been utilised. Due to the requirement for windows in the roof, particularly on the southern aspect, the opportunity for use of photovoltaic panels was lost. As the neighbouring houses are owned by the same client, opportunities for creating a district heating system in the future may be available. However, the economics of this were limited by the different build periods of the estate.

7.1 Commissioning

The contractor carried out initial commissioning and certification of the systems prior to handover. As no tenants were appointed at this time, commissioning was carried out in the presence of technical and management officials of the client organisation. They, in turn, would be responsible for induction of tenants, as well as for providing an initial point of contact for any complaint or query. Manuals and certification were provided at handover, for onward transmission to occupants as necessary during the induction process. The landlord would set up the systems for the tenants at the outset of occupation. They would act as the first point for any repair works, as well as ensure that servicing is carried out regularly.
On the presumption that initial commissioning tests were accurate and, in view of the subsequent failure of the bathroom vent performance, it is suspected that the flexible ducting was inadequately supported and has since dropped. Otherwise, the tests may have been poorly undertaken by the contractor.

7.1.1 Follow-on testing: Following on from tenant comments as noted in Section 6, further testing of the mechanical ventilation was carried out to explore the root cause of any issues. This was in addition to any monitoring/testing required for this study. Refer to Section 9.1.

The most significant systems issue was with regard to the ventilation performance from the ground floor shower rooms. MEARU tests showed a notable failure here. On the presumption that initial commissioning tests were accurate and, in view of the subsequent failure of the bathroom vent performance, it is suspected that the flexible ducting was inadequately supported and has since dropped. Otherwise, the tests may have been poorly undertaken by the contractor.

The bathroom vents were to be routed through the roof, but on-site difficulties with achieving this resulted in them being run across the ceiling to the eaves. The post- handover testing has since proven this to be a poor solution from noise and performance aspects. It also appears that these fans did not meet the specification, although they have proven to fail in meeting even their own rating of 15 l/sec. During the construction, the kitchen extract fans were considered undersized, so had been uprated prior to installation.

7.2 Dom EARM Evaluation:

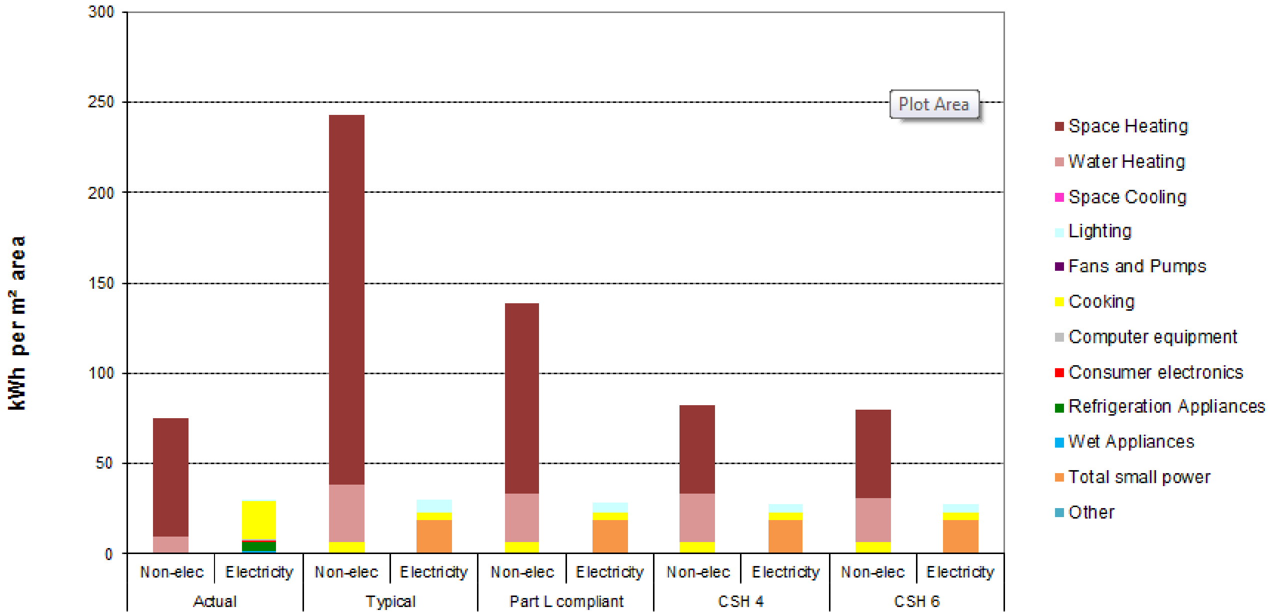
MEARU carried out energy utilisation assessments of two of the properties identified as LA5 (mid-terrace) and LA6 (end terrace). After carrying out and audit of appliances and general energy use, the data was run through the Dom EARM engine to provide comparisons with the in-built benchmarks. Refer to Appendix 3 for summary details. The observations were as follows:

LA5;

Simplified Assessment;

In the annual energy comparison against benchmarks it can be seen that this dwelling has a significantly better electrical performance than the UK average (32% improvement) but is some 99% worse than the best practice case. With respect to gas consumption the improvement on UK averages is even greater (57% better) but the comparison to the best practice is poorer by some 102%.

In real terms what this would seem to suggest is that the thermal performance of the dwelling is well above UK average standards (as gas is used for space and water heating) but that electrical performance has made a more limited improvement as this is less controlled by the design and with the exception of energy saving lighting little has been done to manage consumption. Notwithstanding this it would seem that the residents are still reasonably frugal electrical consumers.

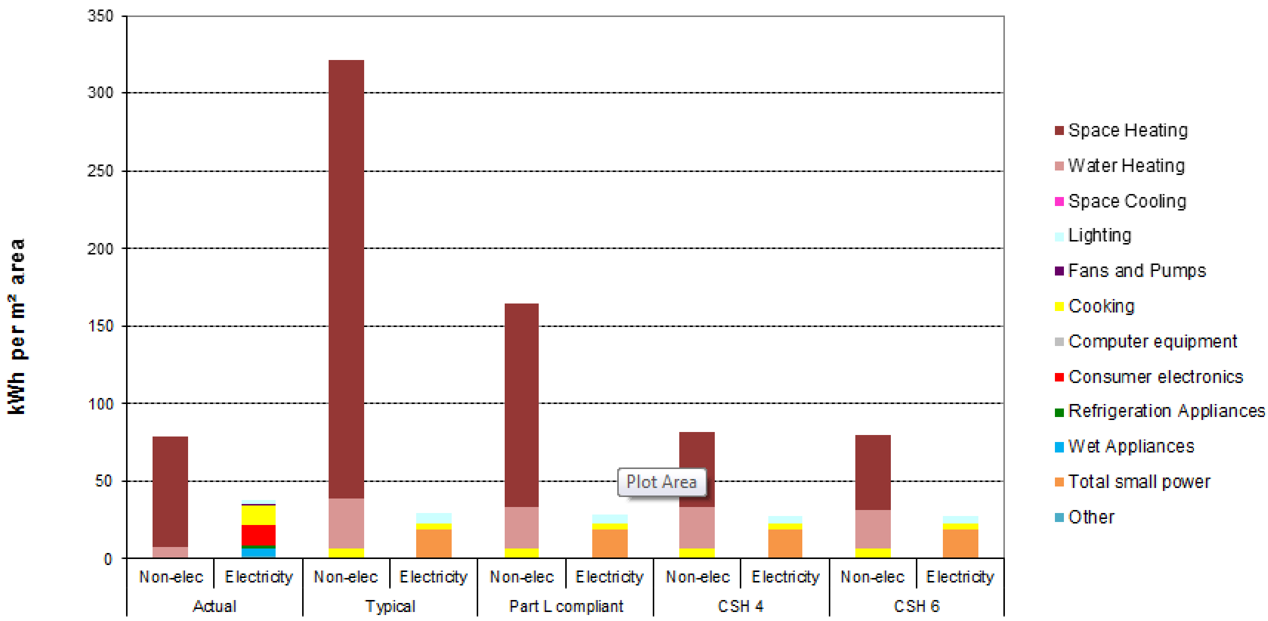


Detailed Assessment;

This shows that for space and water heating the dwelling compares very favourably to even the CSH Level 6 benchmark dwelling and actually uses less energy for these process than is assumed for this very high performance 'simulated' house. With respect to electrical energy the performance of the dwelling is marginally poorer than the other 4 benchmarks but this does not necessarily present a fair comparison as the assumptions made against unregulated energy use are liable to be lower than the detailed information input for the dwelling.

LA6;

Simplified Assessment -
In the annual energy comparison against benchmarks it can be seen that this dwelling has poorer performance than the UK average (17% worse) and is a significant 173% worse than the best practice case. With respect to gas consumption the improvement on UK averages is 57% better but the comparison to the best practice is poorer by some 80%.
In real terms what this would seem to suggest is that the thermal performance of the dwelling is well above UK average standards (as gas is used for space and water heating) as might be expected given the design intent of the project. The fact that the residents spend a lot of time at home and have a lot of electrical appliances would seem to have had an impact on their electrical consumption compared to UK averages.



Detailed Assessment -
As with LA5 the energy used for space and water heating compares very favourably to all other comparative dwellings and is better than the CSH Level 6 dwelling. Again the more robustly quantified electrical audit shows the dwelling to have a much higher energy demand than the other benchmarks but it is also much higher than the counterpart dwelling (some 6.7kWh/m2) and this is something that could perhaps be looked at and improved upon by occupant behaviour.

In general the result from this process and their significance should not be overstated as the usefulness of the outcomes is far less than the quality of real time monitored data which has been collated elsewhere in the project.

7.3 Conclusions and key findings for this section

The systems are conventional domestic designs. However, they fail to appreciate that the buildings would be so airtight. The major failings are with ventilation. The buildings would benefit from active ventilation or some form of natural 'stack' facility, controlled by the tenants.

The boilers and hot water installations have proven to be reliable and efficient thus far as shown by the consumption studies. However, the electric showers must be heavily used in the house with 5 occupants, contributing to high energy usage. There may be a point where a higher number of occupants dictate a different design, although this is difficult to anticipate at briefing stage.

As the ground floor bathrooms are internal without windows, poor performance of the extract fans are a significant issue. The revised extract route choice is poor. Not only does it restrict efficient operation, it can be noisy while doing so. Perhaps a higher power fan, as specified, set to slow speed, would perform better. A humidistat may also be beneficial. The results of the original commissioning are sought for investigation. Refer to MEARU extract fan report (Appendix 2).

No form of whole house ventilation, either mechanical or natural, was specified. Given the actual efficiency of the fabric performance, this would have been merited to deal with overheating issues. A simple passive stack ventilation, venting through the roof, may have been beneficial.

Many of the residents are at home throughout the day. The buildings were designed with large windows to maximise daylighting. However, energy use will be at all times during the day.

8 Monitoring methods and findings

8.1 Introduction - Monitoring Methods

Monitoring of the dwellings has been undertaken to provide two varying levels of data capture which can be used for analysis. At the lower level, 'fiscal' meter data is being collated for the 6 number dwellings. This data, for water, gas and electrical use, is being captured at the point of incoming service distribution and is being sent wirelessly to the secure servers of Orsis UK. Here it is simultaneously stored and then redirected to T-mac Technologies who provide access to the data via their web based portal (see below).

Fig.8.1 A wireless temperature, relative humidity and carbon dioxide concentration monitor. These units are less intrusive than other monitoring kit and also benefit from operating using solar power and battery backup.

For two of the dwellings ('LA5' and LA6') a second, more in-depth level of monitoring is being undertaken which also records the electrical use of specific sub-metered circuits and the environmental parameters (temperature, relative humidity and carbon dioxide concentration) of three key spaces within the dwelling. This environmental data is sampled at 5-minute intervals by wireless monitors (Fig. 8.1) in the living room, kitchen and main bedroom and is then transmitted to the t-mac base station located in the ground floor store cupboard (Fig. 8.2). A wired connection from this 'base station' monitors the electrical sub-circuits and then all this data is the sent via GSM connection to the secure servers of T-mac Technologies.

Fig.8.2 The t-mac 'gateway' unit. This collates the data from environmental monitors and sub-metered circuits and transmits wirelessly to t-mac technologies.

The collated data is presented for viewing and analysis via two tools contained within the t-mac web portal. The Configure tool (Fig. 8.3) contains options for controlling the settings of each dwelling's monitoring equipment and also allows access to all data monitored data for the project (energy and environmental parameters). Individual reports can be created and manipulated for any time range or set of parameters and resultant data can be viewed as a graphic illustration or a 'raw' data file. The Energy Analysis tool (Fig. 8.4) works in a similar way to Configure but, as the name suggests, only deals with the fiscal and sub-metered energy data. This tool has been created more recently than Configure and has a more user-friendly interface and operation. T-mac are currently working on developing a version of this tool which will also house the environmental data and will make access to this more simple and efficient.

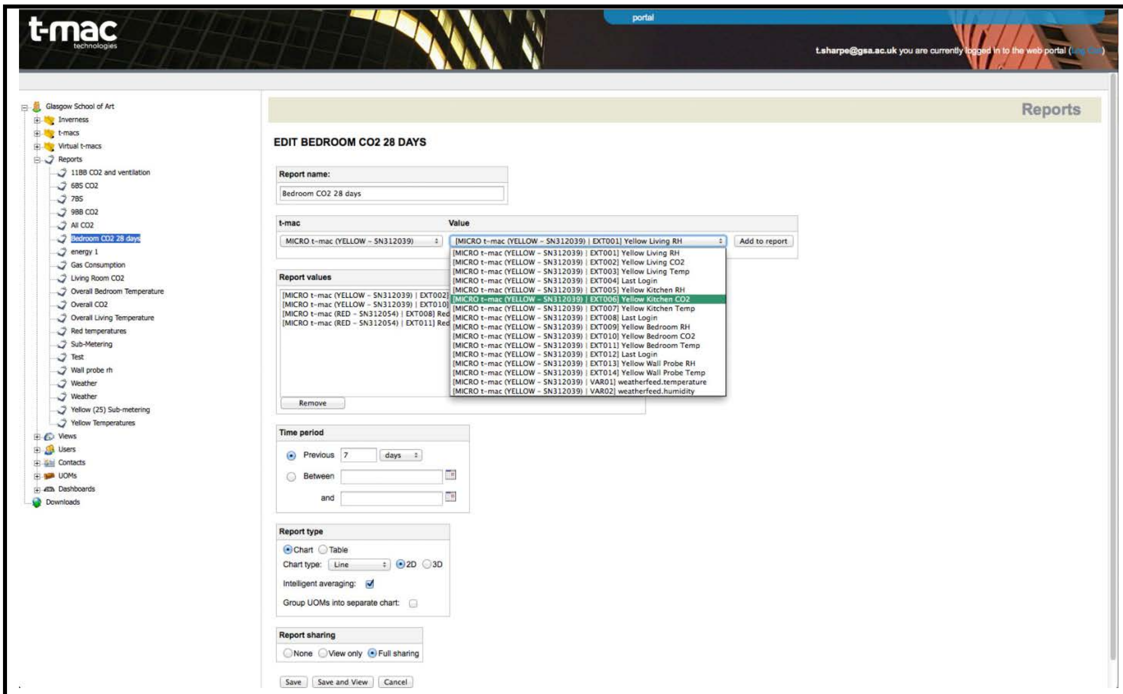


Fig.8.3 Layout of the Configure tools showing creation of date report

The use of this approach and technology for monitoring represents a departure from the core business of the manufacturer and also a new approach for MEARU when undertaking BPE projects. As an approach it has not been without its teething problems but as improvements have been made it has become invaluable in providing a single point where *all* project data can be easily accessed, manipulated and analysed on one platform. To this end it has marked a step forward in BPE process itself and is a significant outcome from this project – where the equipment was tested for the first time.

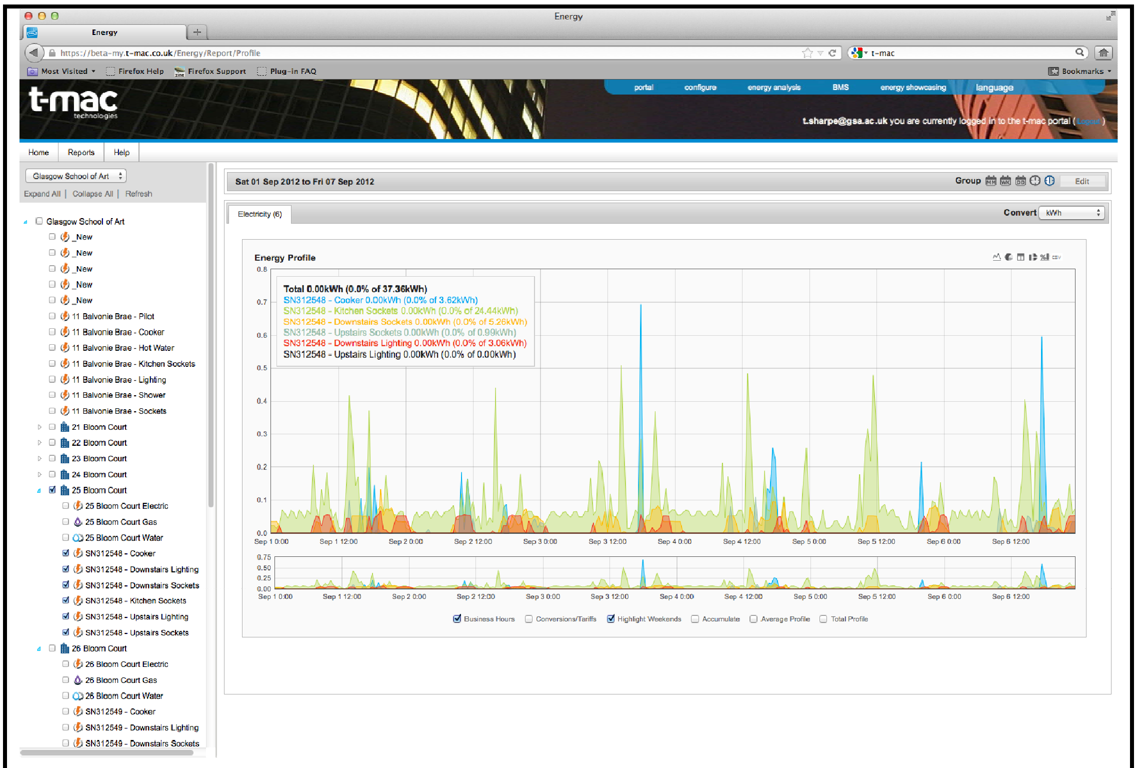


Fig.8.4 Energy Analysis tools and sample data output

8.2 Energy Findings - 6 Dwellings

Using the annual fiscal metering data for the six dwellings a comparison can be made of their relative energy performance against each other and their performance in relation to resource consumption expectations.

The charts below illustrate the visual relationship between the combined gas and electricity consumption of each of the six dwellings. From this it can be seen that five of the six units have a similar level of gas consumption which lie close to or below the mean level (10,288 kWh) for the whole development. This mean value is pushed to this higher level by the markedly higher use of LA1 which consumes 2.06 times that of the lowest user (LA5) and 1.65 times that of the mean. With respect to electrical consumption there is a slight reshuffle of the higher consuming households with LA6 taking a more significant position but, again, LA1 has significantly higher use than all other dwellings.

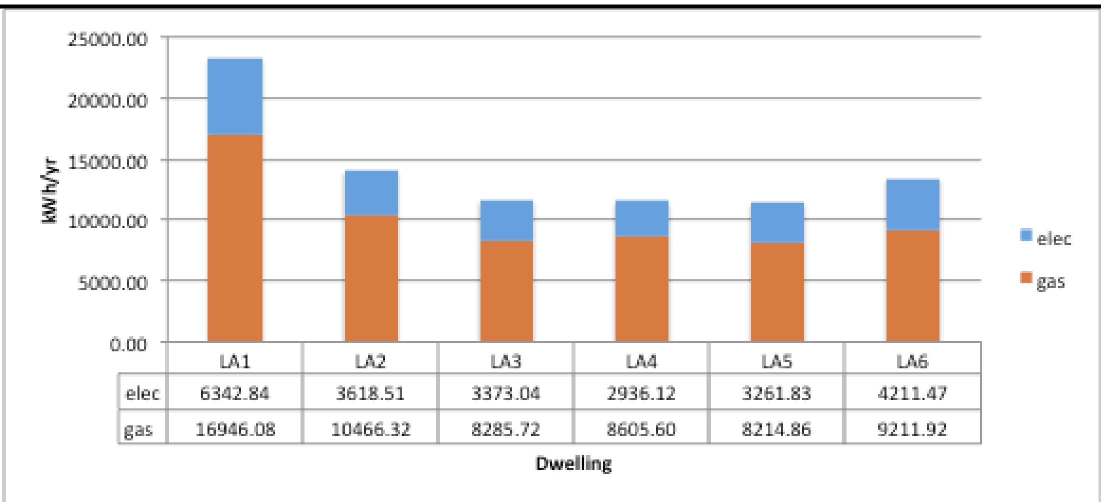


Fig.8.5 Stacked bars illustrate the relationship in combined annual energy use between the 6 properties

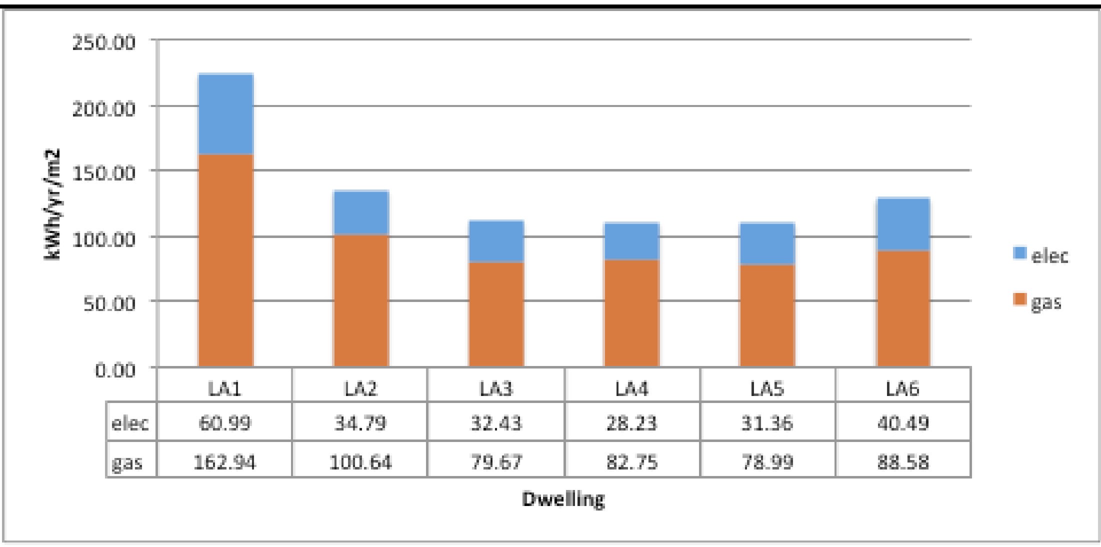


Fig.8.6 Annual energy use represented per square meter of dwelling floor area

The chart below indicates how the dwellings meet the design expectations. The figures below are the converted CO2 emissions figures for gas and electricity combined.

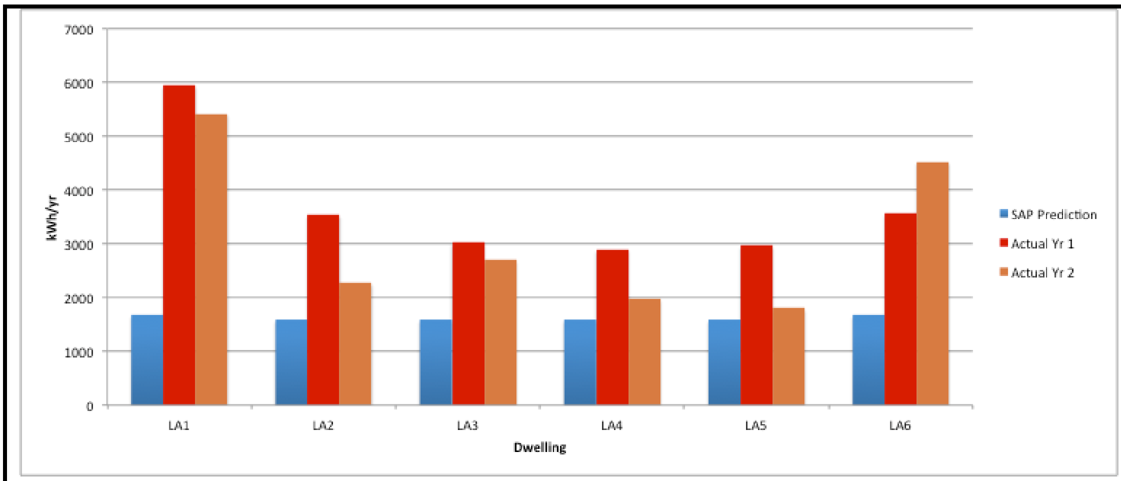


Fig.8.7 SAP Predictions vs Actual Energy Consumption across 6no Units

Whilst a number of the properties are approaching the predicted levels, the above chart indicates the risks of placing too much faith in SAP predictions. The obvious discrepancy between figures is not necessarily an indicator of a failing on the part of the building, but more a representation of the limitations of SAP and the effects of occupant behaviour. It is important that the relatively 'blunt' nature of SAP is realised particularly if it is being used as an indicator of how a building *will* perform, as if often the case. This should not come as a surprise however as the data itself indicates that occupant behaviour can impact on energy use in these dwelling by a factor of almost 2 – in a condition when we are dealing with dwellings that should theoretically perform identically.

It is worth noting that units LA1 and LA6 are the two end-terrace cottages so these will suffer greater relative heat loss. Whilst this no doubt contributes to the greater gas consumption, this cannot wholly account for the variations noted.

An examination of why the variations in consumption exist shows interesting patterns of gas use. A review of the first year profiles of each dwelling (Fig. 8.8) begins to show why particularly LA1 has higher consumption values, and this is further supported by the monthly energy use values presented (Figs. 8.9 and 8.10).

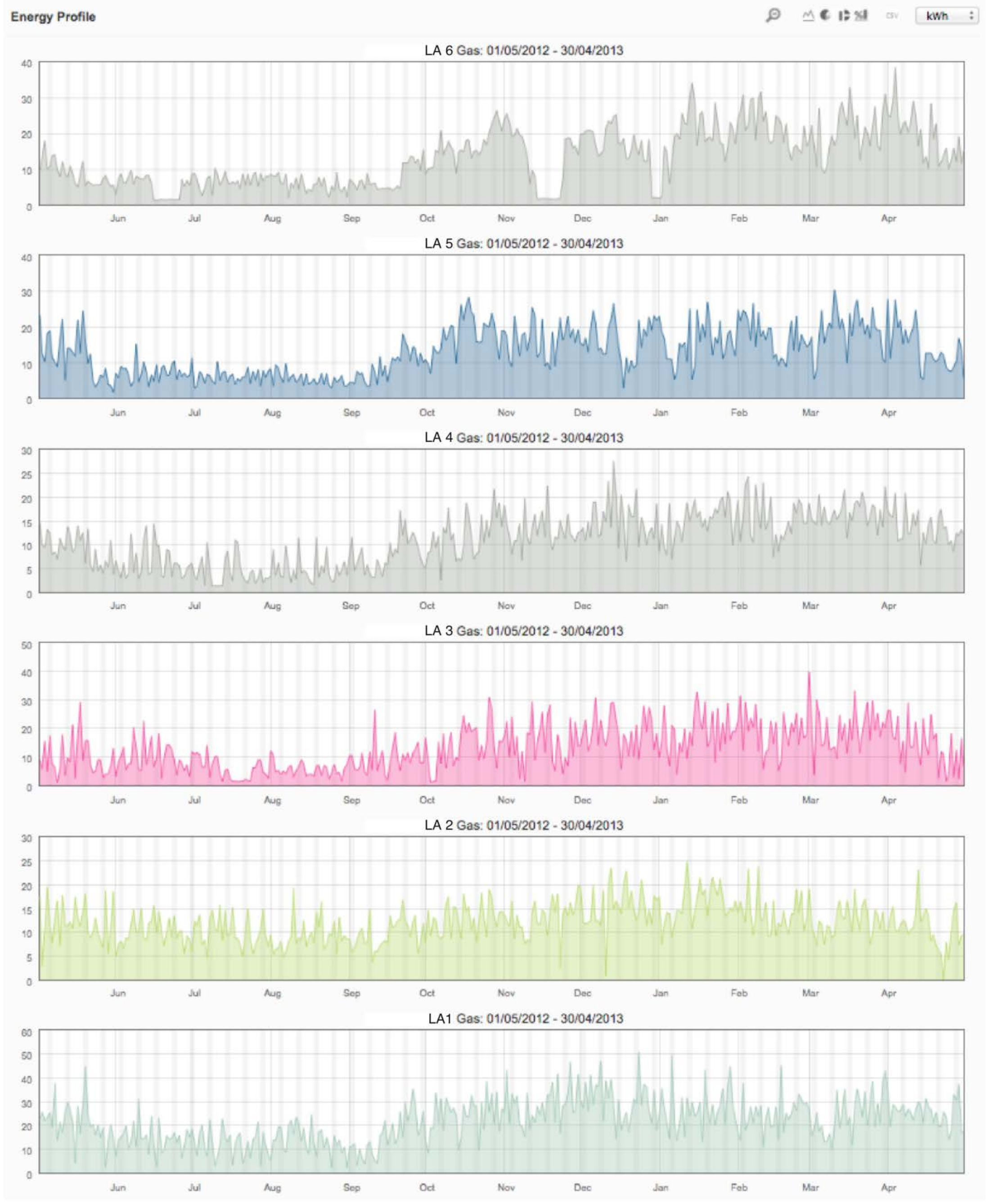
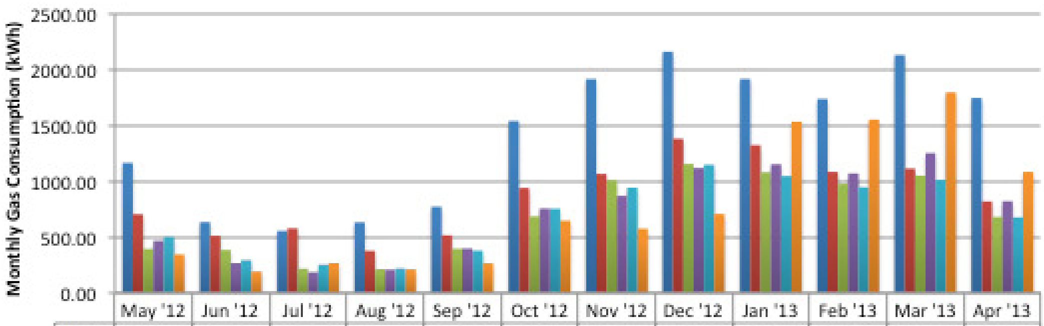
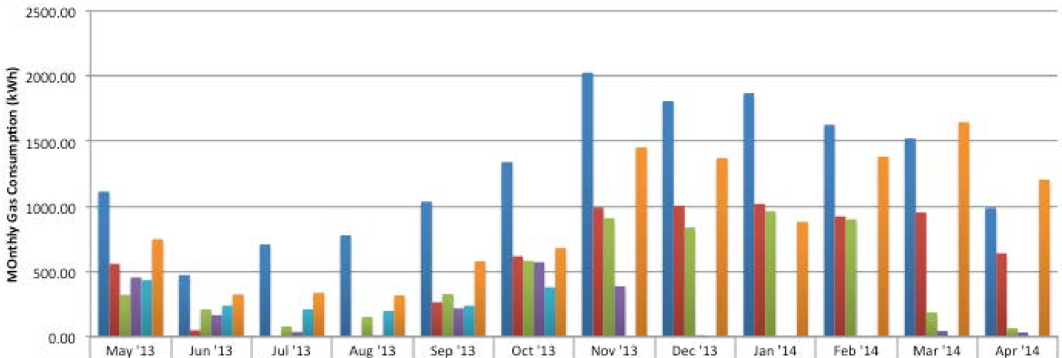


Fig.8.8 First Year Annual gas consumption profiles for all dwellings



	May '12	Jun '12	Jul '12	Aug '12	Sep '12	Oct '12	Nov '12	Dec '12	Jan '13	Feb '13	Mar '13	Apr '13
LA1	1168.61	638.74	560.03	637.06	776.72	1543.14	1917.89	2162.83	1918.97	1740.29	2133.15	1748.66
LA2	708.85	515.98	583.55	381.81	520.91	943.94	1069.26	1384.62	1327.46	1087.52	1118.21	824.21
LA3	398.94	389.16	218.40	213.58	400.74	689.92	1013.49	1158.30	1084.27	980.34	1053.70	684.88
LA4	472.08	267.23	185.55	209.18	403.01	760.48	873.57	1122.39	1155.84	1074.53	1255.86	825.89
LA5	506.06	294.52	254.05	220.30	383.60	758.88	947.11	1151.81	1050.45	950.29	1016.43	681.37
LA6	349.60	193.04	267.71	212.80	266.64	651.65	580.05	711.54	1536.75	1555.57	1798.94	1087.63

Fig.8.9 Monthly gas consumption per house for the first year of monitoring.



	May '13	Jun '13	Jul '13	Aug '13	Sep '13	Oct '13	Nov '13	Dec '13	Jan '14	Feb '14	Mar '14	Apr '14
LA1	1116.98	474.10	707.36	779.78	1037.01	1341.65	2025.86	1809.47	1868.05	1627.47	1523.09	989.97
LA2	559.33	51.52	0.00	0.00	263.65	618.35	991.20	1004.83	1018.86	924.93	955.36	642.10
LA3	322.78	210.90	80.42	152.43	328.24	582.21	911.46	837.31	965.22	901.60	187.71	67.31
LA4	454.83	165.87	37.86	0.66	218.97	571.65	390.29	0.34	0.00	0.00	45.36	34.50
LA5	433.70	241.14	212.02	198.46	240.46	381.81	0.00	0.00	0.00	0.00	0.00	0.00
LA6	749.13	325.62	338.24	318.05	579.52	683.42	1452.64	1372.22	881.89	1383.54	1648.08	1205.68

Fig.8.10 Monthly gas consumption per house for the second year of monitoring. Zero readings are due to faults with monitoring equipment and can be ignored.

Examination of the spread of gas consumption clearly illustrates two issues. One is that the early higher consumers (LA1 and LA2) have higher and more significant use in the summer (when it might be anticipated that the heating would not be required). This would seem to indicate a base water-heating load. The other is the abrupt change in gas consumption evident in dwelling LA6 (yellow bars) which occurs between December 2012 and January 2013. Throughout 2012, dwelling LA6 is consistently one of the lowest consumers of gas, but throughout 2013 to the end of the monitoring period in April 2014, it is consistently the second highest. The reason for this is simple: a change in occupants which took place at the start of January 2103.

Examining electrical use, a similar distribution emerges between highest and lowest use, but there is more consistent consumption across the houses. Once again though LA1 (blue) is the highest, and, starting from January 2013, LA6 (yellow) is second highest.

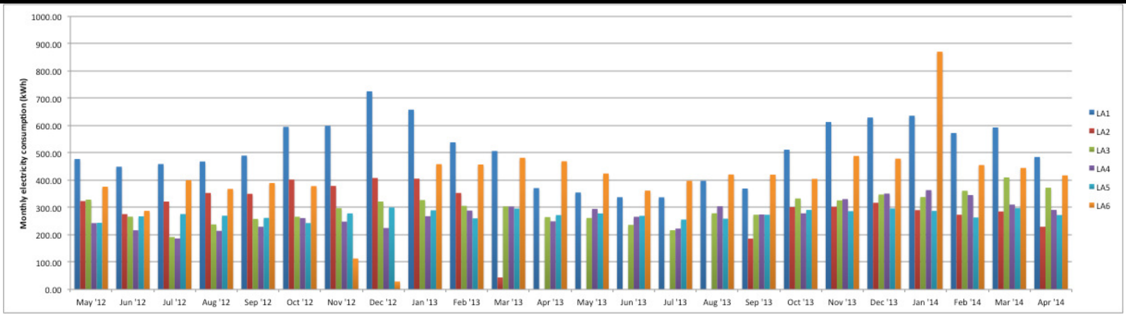


Fig.8.11 Monthly Electricity consumption for all dwellings over the 2 year monitoring period.

With the apparent association between gas use and the requirement for water heating in the higher consuming households discussed earlier it could be expected that this would be borne out in the water consumption data which is also being recorded for each dwelling.

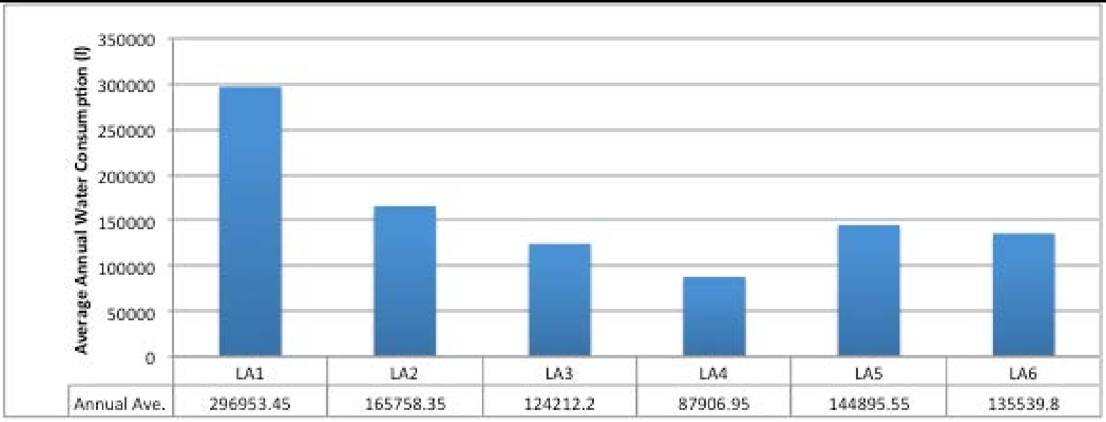


Fig.8.12 Annual water consumption for all dwellings, averaged across the two year monitoring period.

As expected, there is a clear relationship between the largest consumer (LA1) of both gas and water which supports the supposition that this relates to the use of hot water, however this does not apply across all dwellings, with LA5 bucking the trend. Clearly there are water uses in dwellings which do not require heat input and where they do, it is becoming more common to deliver heat electrically (electric showers, cold feed washing machines etc.)

If the water data is looked at in terms of resource consumption, and not as supporting information for energy use, then a slightly different picture emerges regarding the houses with the most economic behaviour.

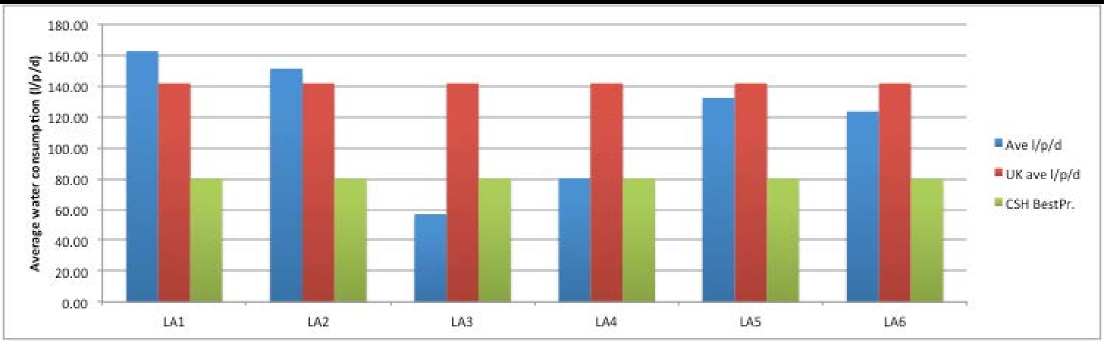


Fig.8.13 Averaged daily water consumption per person for all dwellings, compared to the UK average and Code for Sustainable Homes Best Practice Consumption rates. (LA6 occupation taken as 3 but was 2 for a period of time which slightly distorts the result (positively) in this case)

Table **8.13** above looks at the total water consumption against the occupation density. Compared against a UK average consumption of 142l/p/d (Energy Savings Trust) (red) it can be seen that the majority of dwellings are around or below this figure. With this new metric it can be seen that the consumption of LA1 is perhaps not as bad as the total values may show. The most impressive result is, however, with the extremely frugal water use shown at LA3 and LA4 which can be compared to the Best practice figure of 80 l/p/d assocaited with the highest levels of the Code for Sustainable Homes.

8.3 Energy Findings - 2 Focus Dwellings

As part of the project, a much greater level of data collection and analysis has been undertaken in Units LA5 and LA6. This provides comparative data which is of interest in terms of more detailed energy use figures and indoor environmental performance. As the tenants of LA6 changed in December 2012 it also provides information which is invaluable in identifying the impact that different users can have when occupying the same dwelling.

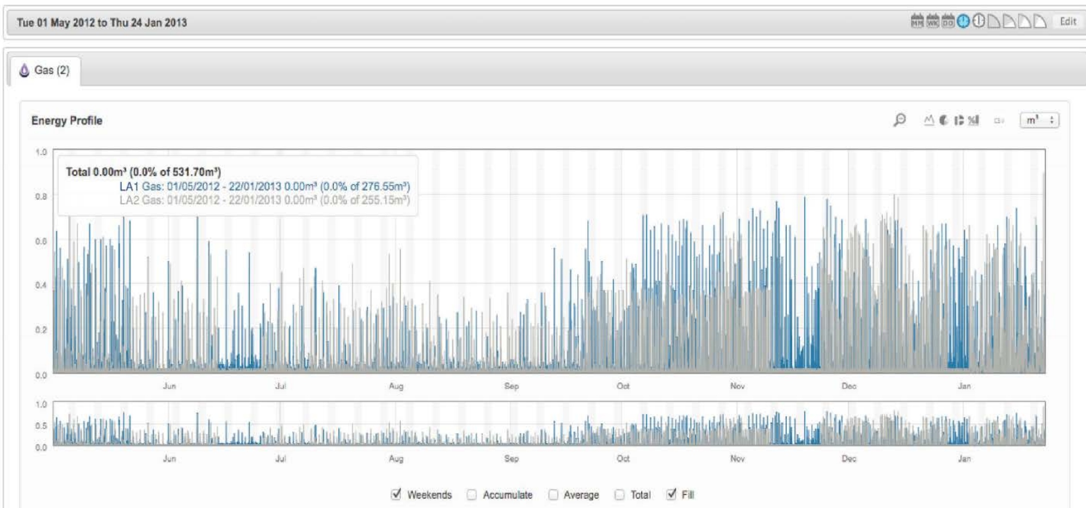


Fig.8.13 Gas consumption profiles for LA5 and LA6 – May '12 to January '13

When gas consumption is considered up to the point the new residents moved in it appears there was a general parity in total consumption between the two dwellings over the monitoring period. A similar seasonal pattern was also identified with both dwellings showing increased gas use over the winter months in no doubt due to heating demand.

In December, LA6 was unoccupied for a period, easily seen in the above graph and evident in the 'dip' in the red line in the graph below, before new occupants moved in (18th December 2012). From this point onwards it is clear to see that gas consumption in LA6 immediately and steeply rises and remains the higher of the two throughout the remainder of the monitoring period, although both properties still show a seasonal reduction in gas consumption through the warmer months.

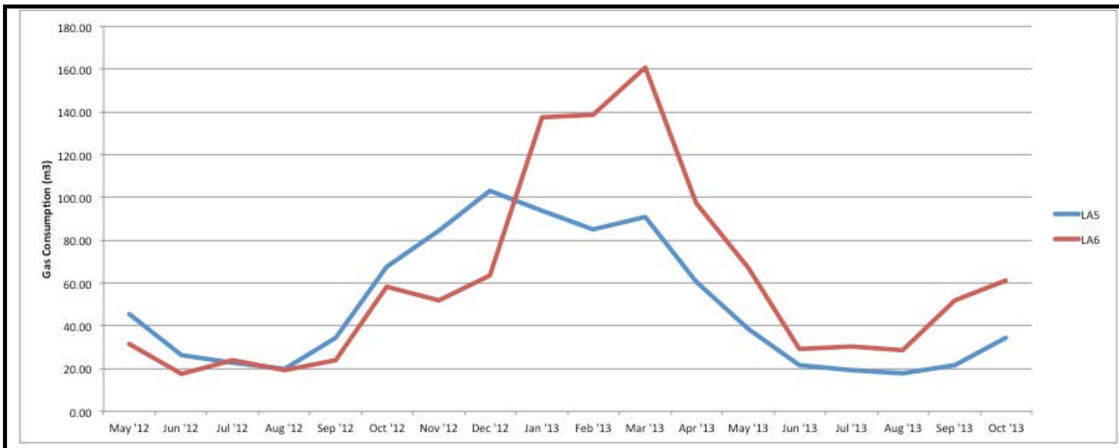


Fig.8.15 Gas consumption profiles for LA5 and LA6 – May '12 to October '13

It is worth noting that during the period May '12 to December '12, LA6 had only 2no residents as opposed to the 3no at LA5. This will partly account for the higher consumption in LA5 due to higher hot water consumption and greater gas use associated with a more populated dwelling. It is also worth noting that internal temperatures within LA6 during the same period tended to be lower than LA5, so part of the jigsaw was that the house was not being heated to the same degree. In addition, it is worth remembering that LA6 is the end terrace with a greater proportion of external surface area and thus heat loss.

With the second set of tenants the dwelling density was brought up to the same level as LA5, yet the proportional gas consumption has been seen to increase dramatically so the residents of LA5 now seem the more economic (8765kWh vs 5363kWh from January '13 to October '13). This can be seen as a function of a constant heating regime for the new residents as illustrated by Fig. Fig.8.16, below, which shows gas consumption over a 2 day period in March '13. This illustration clearly shows the variation in demand between the two dwellings and, interestingly, now shows LA6 to have a similar heat demand and profile as the previously identified highest consumers in LA1 and LA2.

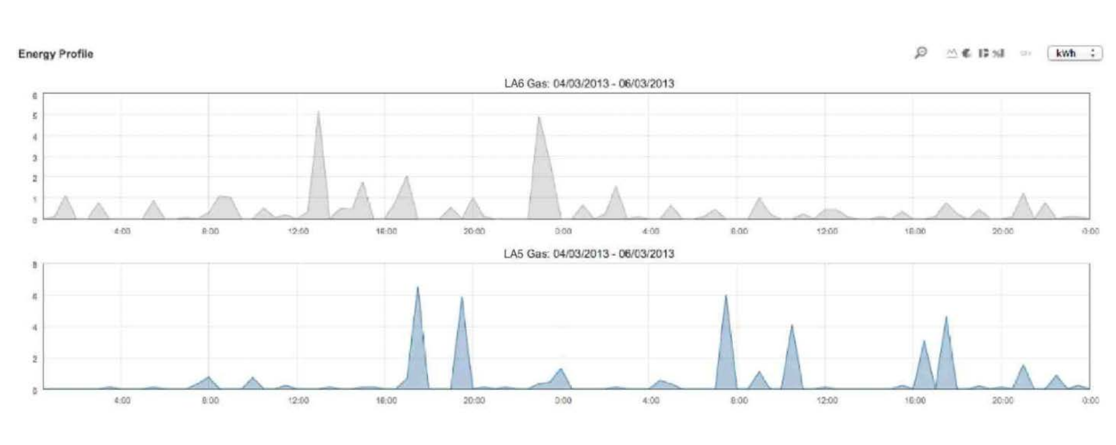


Fig.8.16 2-day gas consumption March ’13 (note y-axis scale varies)

Where electricity consumption is concerned, despite a change in residents LA6 remains the highest user and, proportionally, has slightly increased compared to LA5. From this ‘fiscal’ level of data it can be reasonably concluded that both sets of residents of LA6 are simply high level consumers. What is interesting, however, is that each set of occupants is consuming electricity differently. Almost half (46%) of the consumption by the first residents (light blue in the left pie chart below) is via the downstairs sockets, with only 17% used in the Kitchen (pink). This is likely to be down to high consumption Living Room gadgetry such as a large TV and associated equipment, as well as long periods of use.

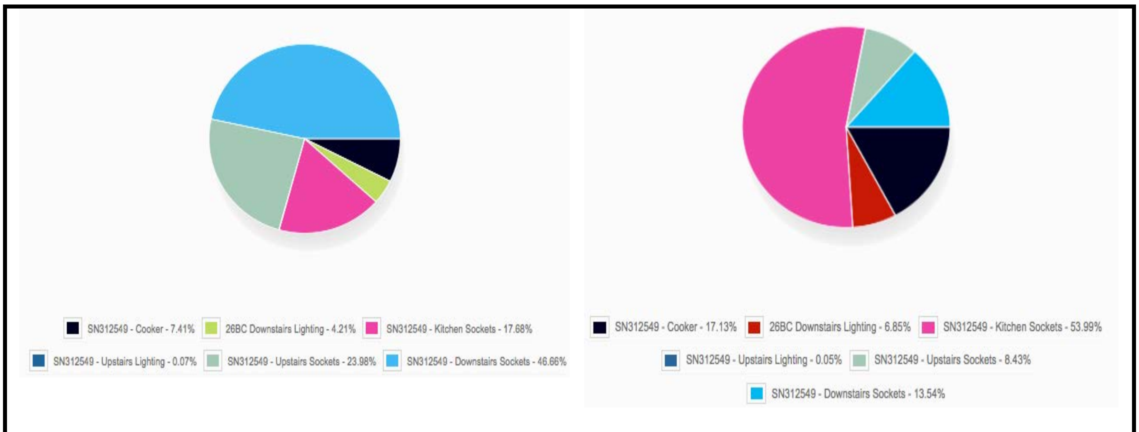


Fig.8.17 LA6 Electrical consumption – September ’12 vs March ‘13

The new residents on the other hand, consume over half (57%) of their electricity in the kitchen, with only 17% attributable to (other) downstairs sockets. This in turn suggests a lifestyle involving more food preparation / washing, etc. and high consumption appliances.

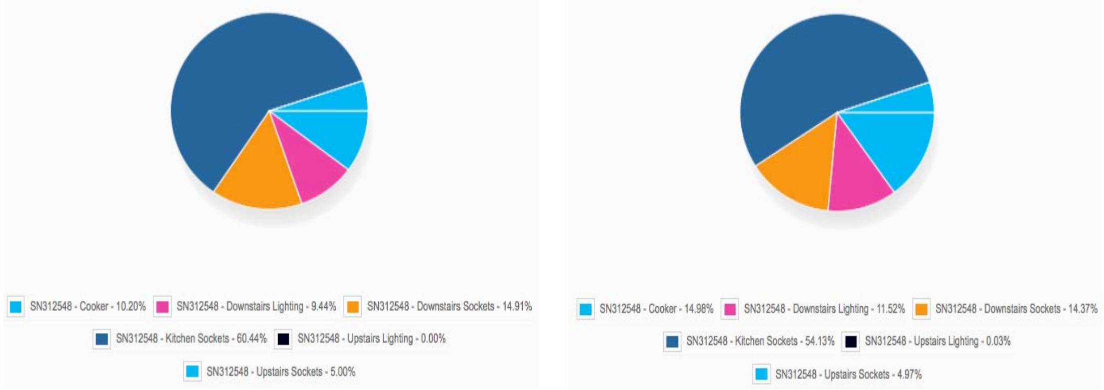


Fig.8.18 LA5 Electrical use– September '12 vs March '13

When these are compared to the same two months in next-door LA5, it can be seen that the behaviour remains consistent and involves the greatest consumption via the Kitchen sockets suggesting a similar lifestyle.

The important issue to take from this is that when targetting energy efficiency, it is worth knowing the areas of greatest consumption in order to be able to tailor advice to best effect.

8.4 Environmental Findings – 2 Focus Dwellings

Annual temperature profiles for both properties are shown in Figs. 8.19-8.21. It is hard to make out detail at this scale so the title blocks contain a narrative in each case.

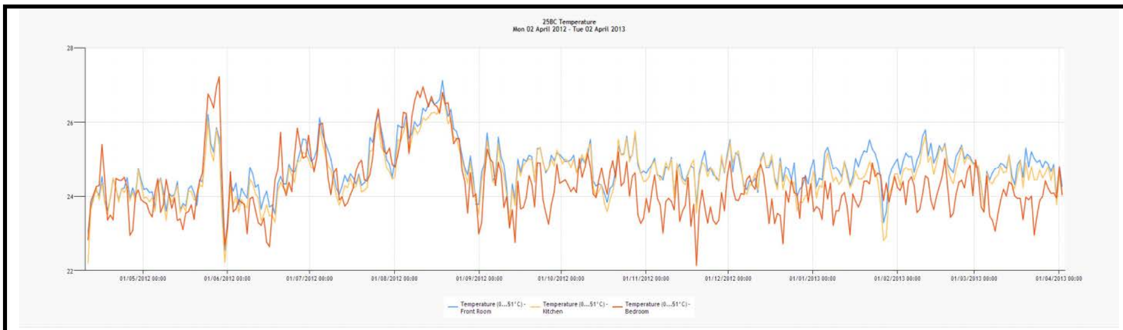


Fig.8.19 LA5 annual temperature profile, kitchen (yellow), living (blue) and bedroom (red). Baseline is 22°C rising through 24 and 26, with 28°C at the top of the vertical axis. Early summer temperatures average around 24°C, peaking over 26°C in late summer, then returning to remain fairly constant around 24/25°C for the rest of the year.

Fig.8.20 LA6 annual temperature profile, kitchen (blue), living room (yellow) and bedroom (red). Note there is greater variation here and the vertical scale starts at 12^{o}C, with the peak at 28^{o}C. Starting around 22^{o}C in May and June the temperatures rise over the rest of the summer, remaining fairly constrant around 22^{o}C again in October and November before dropping in December and January while the property was unoccupied. In January, the high temperatures resume, averaging around 24^{o}C for the remainder of the monitored period.

As mentioned in the section on energy, internal temperatures remain consistently high throughout the year. The effect of LA6 being empty over the Christmas period is apparent, as is the period of heating only. This period is actually very significant as it represent an un-occupied but heated period where temperatures vary between approximately 18^{o}C and 20^{o}C. What this suggests is that the difference in temperatures become due to incidental gains from people and electrical use. There appears to have been some interventions on or around the 23rd November – this may perhaps have been a visit by the housing association who turned the heating on to protect against frost damage, and further interventions were made at 3 points over the Christmas period, again appearing to be adjustments to the thermostat of the heating system, including the system being turned off again prior to occupation.

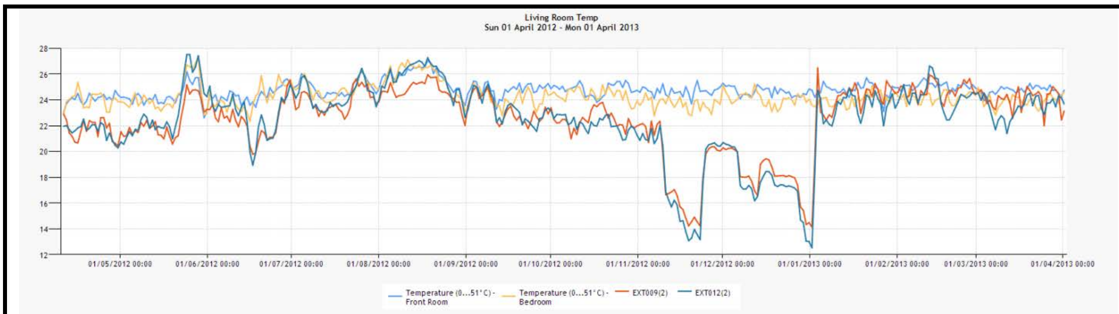


Fig.8.21 Comparison of annual temperature profile LA5 and LA6, living rooms and bedrooms only.

It is clearer to see above the relative temperatures of the two properties. While it gets a little messier during the later summer, during both the early summer and autumn, LA5 retains a higher and noticeably more consistent temperature, whilst the two properties are indistinguishable once the new residents are settled in, in early 2013.

Overall Relative Humidity (RH) is shown in the following Figures:

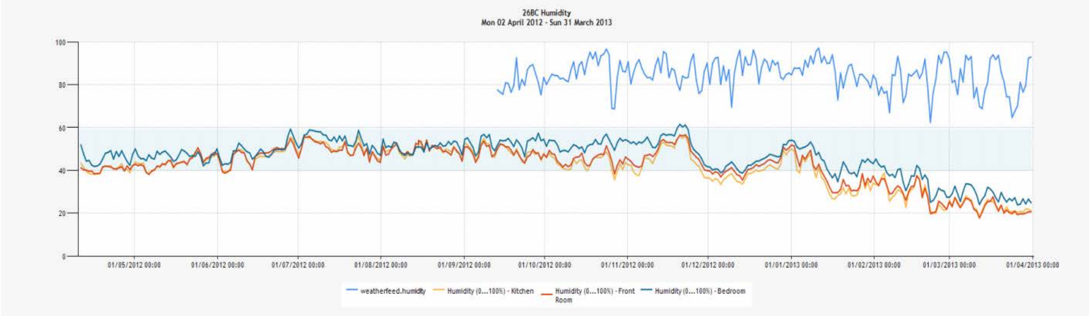


Fig.8.22 LA6 Annual relative humidity profile. The pale blue horizontal band represents the desirable range of 40-60% RH, while the light blue line above represents external RH.

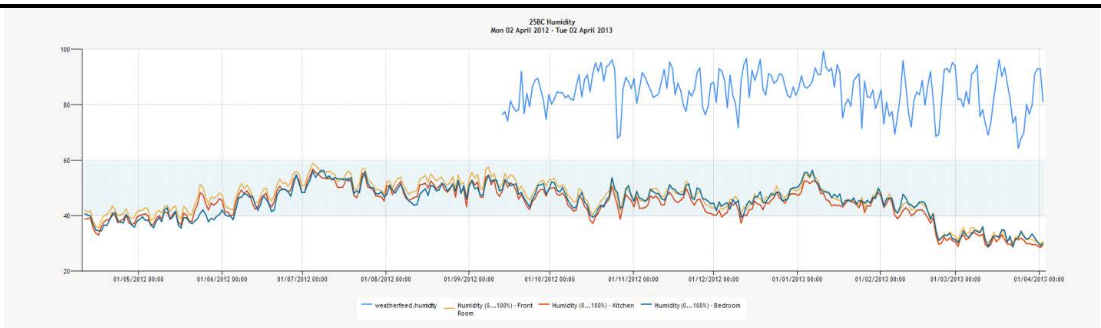
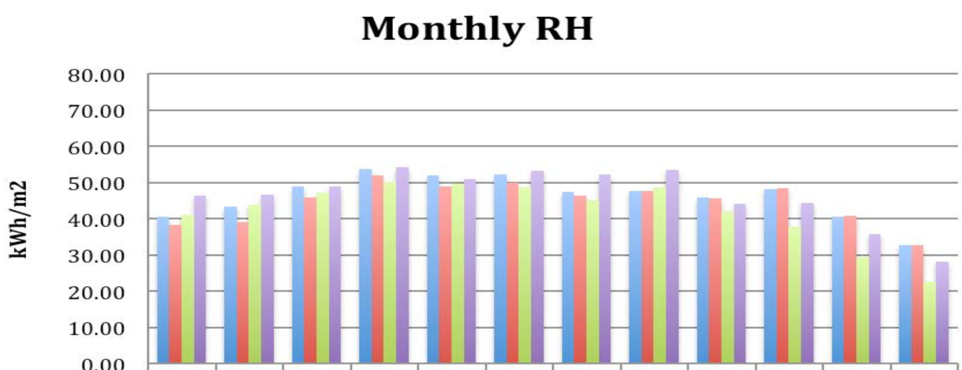


Fig.8.23 LA5 Annual relative humidity profile

Observations of this data are that RH levels generally remain with acceptable limits, but that low levels of RH are experienced in the spring periods. This is a commonly observed phenomenon whereby winter heating regimes and ventilation habits are maintained well into warmer drier weather periods, resulting in high internal temperatures and consequently low internal RH levels. These levels of RH are a cause for concern because low levels of RH can lead to health problems, particularly associated with skin, eyes and respiratory systems in occupants.



	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Living	40.54	43.29	48.89	53.64	51.83	52.04	47.46	47.69	45.80	48.16	40.58	32.78
Bedroom	38.16	38.97	45.88	52.01	48.84	49.83	46.22	47.56	45.59	48.39	40.80	32.53
Living	40.89	43.73	47.12	50.08	49.56	48.67	45.16	48.51	42.01	37.70	29.33	22.52
Bedroom	46.27	46.64	48.95	54.05	50.81	53.10	52.13	53.53	44.16	44.42	35.78	28.10

Fig.8.24 LA5 living and bedroom (blue / red), LA6 living and bedroom (green / purple)

8.4.1 Vapour permeable construction

An interesting observation can be made in LA6, which was empty between December and early January (Fig. 8.25). The lack of occupancy can be seen to affect internal RH, which is generally lower and without resultant spikes. However, observation of the interstitial RH shows that it continues to fluctuate and there is a general, but not direct, correlation with external RH. This would appear to suggest that there is vapour permeability across the wall, which can act in either direction, but on these observations there is no evidence to suggest this may be problematic.

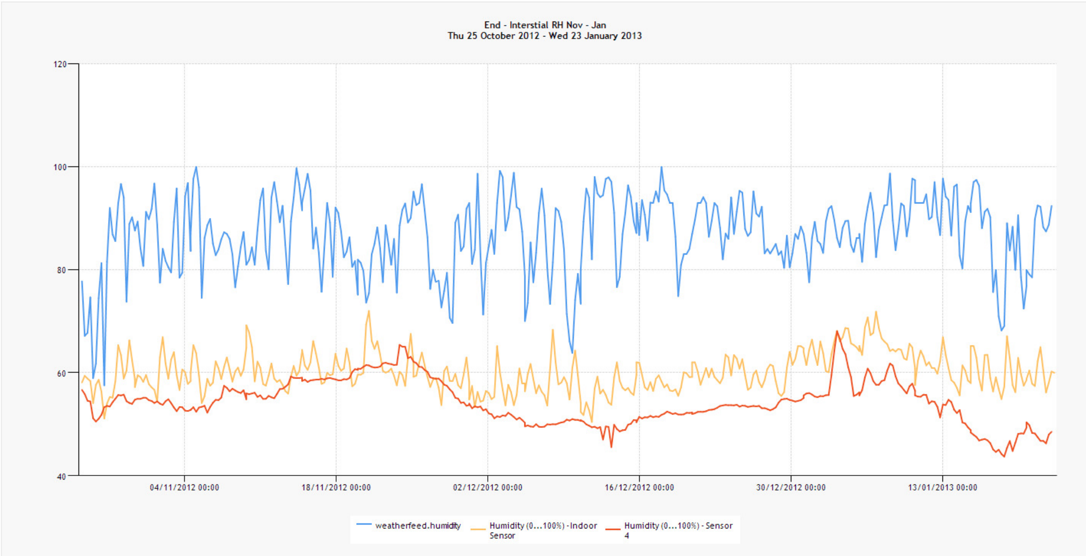


Fig.8.25 LA6 RH levels Oct '12 – Jan '13 externally (blue), living room (red) and interstitial (yellow) before, during and after a period of non-occupation.

Observation of the same period in the occupied house showed that the relationship is more derived from the internal conditions (Fig. 8.26). External RH levels were high during this period.

There is no obvious indication of sustained high humidity levels in the monitored rooms. Issues with dampness in the bathrooms identified in the BUS survey would therefore appear to be localised and due the ventilation performance of those spaces.

Humidity levels in this period have, in general, remained within an acceptable range.

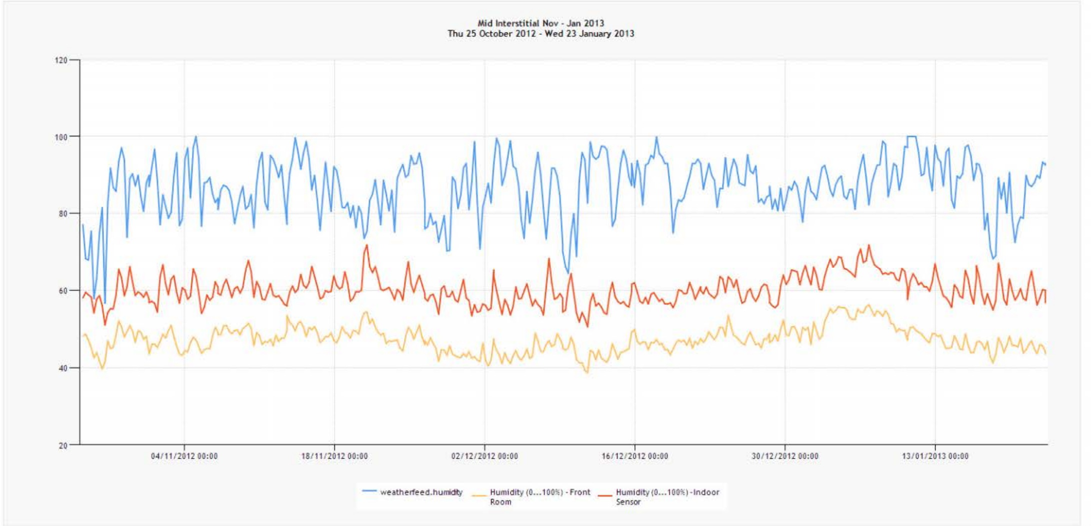


Fig.8.26 LA5 RH levels Oct '12 – Jan '13 externally (blue), living room (red) and interstitial (yellow) in LA6 before, during the same period as above.

The effects of the lack of occupancy can be observed at the end of the period, when LA6 is empty. RH levels increase slightly after the house is first empty, but then drop, to lower levels. This is explained by the house being heated whilst it was empty. Without occupants there is no moisture being produced and the heating then reduces RH levels.

What this does suggest is that very low levels of heating are required during unoccupied periods to protect against frost, but to also avoid potentially damaging low levels of RH that could result in drying out of materials from excessive heating.

8.4.2 Indoor Air Quality

CO_2 concentration is being monitored in the living room, kitchens and upstairs bedrooms.

The diurnal pattern remains consistent throughout the year, with CO_2 levels rising during occupancy. It is clear from the graphs below that CO_2 levels in bedrooms reach higher levels and for longer periods than the Living Rooms and Kitchens which peak occasionally but tend to remain below 1000ppm. Ventilation levels in the bedrooms are a cause for concern, with extended periods over the accepted limit of 1000ppm in both properties.

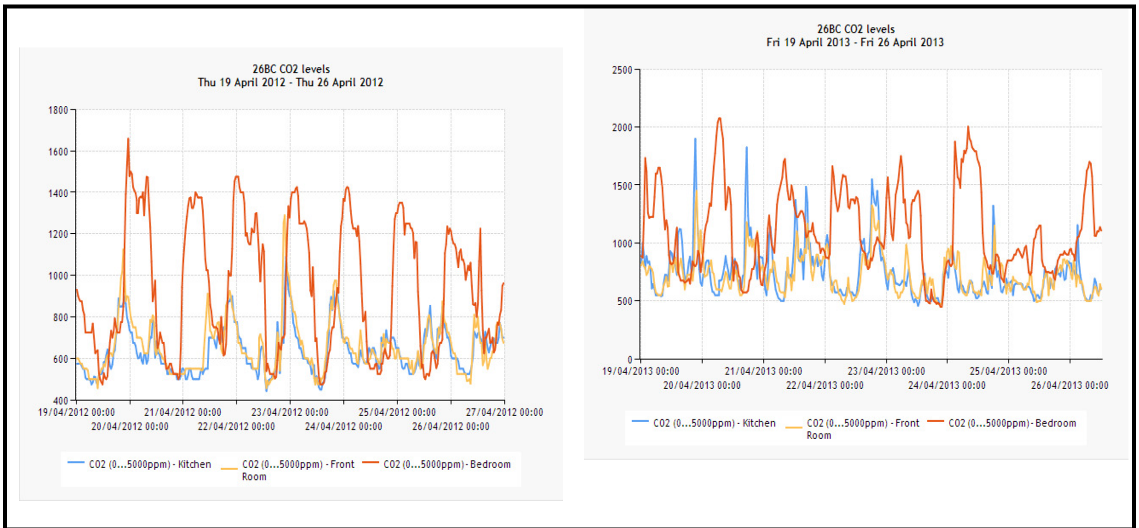


Fig.8.27 LA6, CO_2 Concentration for all rooms – April '12 vs April '13

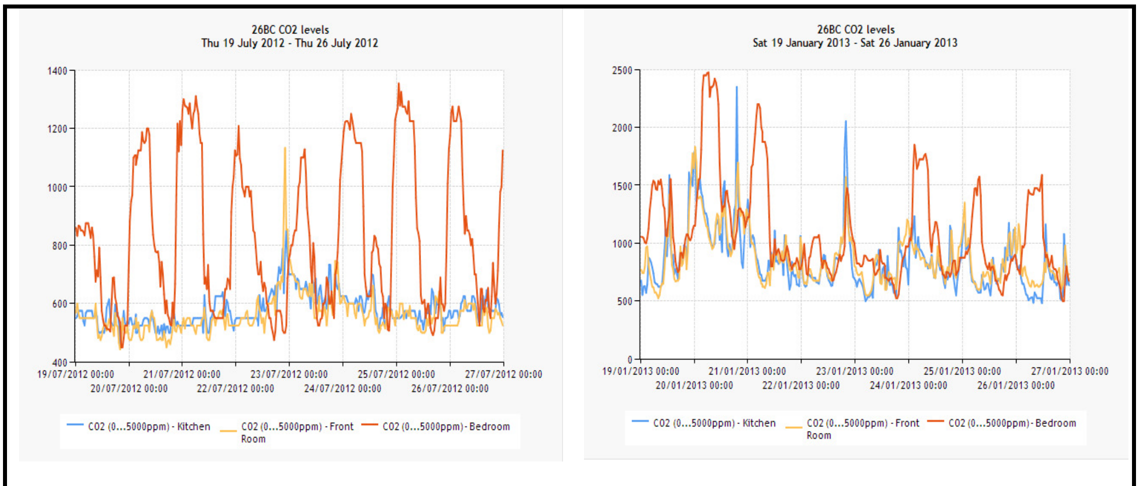


Fig.8.28 LA6, CO_2 Concentration for all rooms – July '12 vs January '13

The unoccupied period in LA5 can clearly be seen below (Fig. 8.29). What this does indicate is the value of CO_2 as a measure of occupancy. On re-occupation, high levels of CO_2 are again observed. The findings from previous quarterly reporting analysis highlighted that these issues are primarily due to room occupancy, volume and ventilation strategy.

It is recommended that interventions be made in the houses to test these observations. This would include gathering data on bedroom ventilation habits, more detailed information on bedroom area, volume, net volume, and background ventilation provision. However, some intervention could also be made with occupants to test particular behaviours; for example asking them to open trickle vents, and/or keep windows open at night, to observe whether these significantly affect CO_2 levels.

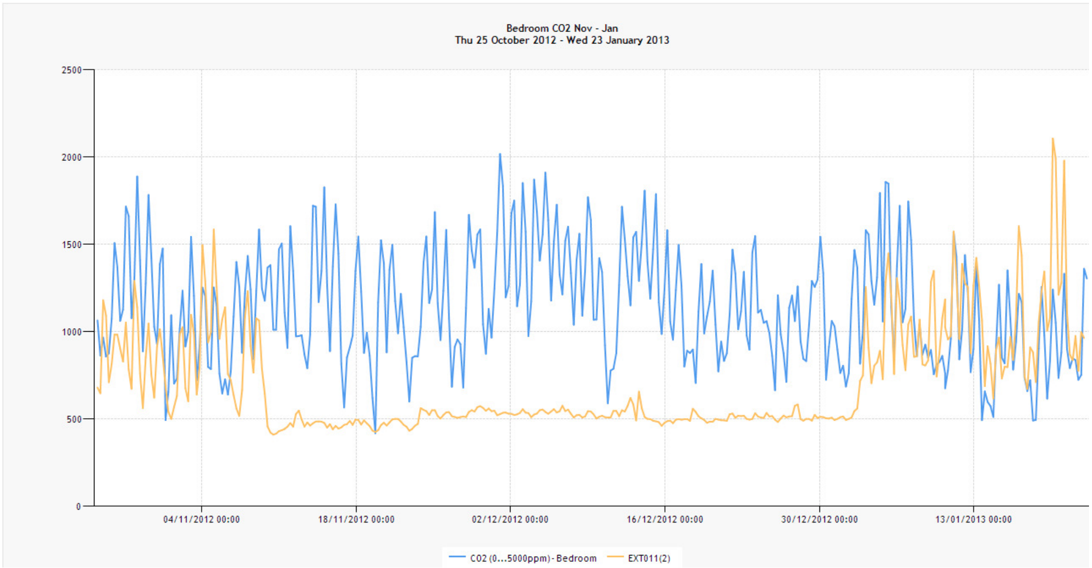


Fig.8.29 LA5 (Blue) and LA6 (Yellow) comparative CO_2 concentrations over unoccupied period in December ‘12

8.5 Next Steps

The high levels of CO_2 concentration and poor air quality identified as a constant phenomenon warrant further investigation. This could involve running further tests for the air quality in the dwellings and could be organised as a series of time limited control tests on ventilation methods. For example, getting residents to leave bedroom windows open over the course of one know night to assess the impact on air quality and energy use against a control data set.

8.6 Conclusions and key findings for this section

A series of key outcomes are identified through the monitoring and analysis data. The most significant of which are;

- The importance of development of the use of t-mac monitoring kit and the complimentary portal as a tool for use in BPE projects.
- Actual building performance compared to SAP values and the recognition that this tool is not suitable for making such predictions.
- Water use is generally comparable across dwellings and with national norms but more could be done to educate residents and improve this.
- Large variations in energy consumption are observed across the dwellings and are a function of user behaviour.
- Usefulness of CO_2 concentration as an indicator of occupancy and behaviour.

- CO_2 concentrations in the dwellings are overly high and this is particularly so during the heating season and in bedrooms.
- Internal temperatures are high throughout the year but this is perhaps what could be expected given the sedentary nature of many residents. This in part explains higher than expected gas use.
- The permeable wall construction is performing well

Internal RH is normally good and supports the use and efficacy of the vapour permeable construction but in periods without occupation RH has the potential to fall too low and potentially dry out and damage internal materials if heating is retained at the same levels.

9 Other Technical Issues

The major Issues arising from this study relate to the following:-

a. Extraction to the downstairs internal shower room

b. Render defects at gables

9.1 Detailed Extract Fan Report prepared by MEARU

9.1.1 Introduction

This report sets out the findings from testing the performance of intermittently operated extract fans installed in two of the dwellings monitored as part of TSB POE study 450054. The testing took place on 11th June 2014.

9.1.2 Methodology

The objective of the test was to ascertain whether the performance of the extract fans, located in bathrooms, WCs and kitchens, in each dwelling are operating in compliance with the Building (Scotland) Regulations.

Volume flow rates were measured using the volume flow meter and accessories detailed below;

Observator Instruments - Automatic volume flow meter with pressure compensation Type: Diff Automatic
Cert No: UK08111MN
Calibrated: 20th June 2013

Observator Instruments - Light extension hood
Type: AT-242
Cert No: UK08111MN
Calibrated: 20th June 2013

The apparatus used, as noted above, allows values to be derived using the “Unconditional Method” of measurement. The powered flow hood eliminates back pressure and places no additional restrictions on fans under test, therefore results displayed on the equipment can be taken as the correct without any further need to apply pressure drop correction factors.

Fig 9.1: Powered flow hood in operation showing volume flow rate of kitchen fan

The equipment was operated as per the manufacturer's instructions. Fans were switched to operate and three volume flow measurements were taken at each fan inlet (in litres per second), once the air flow had stabilised. The exception from this was one kitchen extract fan, due to arrangement of appliances it was not possible to take measurements one the fan inlet, therefore for this fan air flow measurements were taken on the air outlet. The final result of the testing for each fan was an average of the three measurements taken.

9.1.3 Fan Test

In each of the two test dwellings the ventilation strategy is for natural ventilation to all rooms via openable windows and background ventilators (trickle vents at window heads) with intermittent mechanical extraction for 'wet' spaces.

In each kitchen an 'Airflow Icon' fan is installed in locations away from the hob. These are operated manually by a separate isolation switch adjacent to the fan unit. The WCs are fitted with 'Airflow Icon' extract fans operated on the light switch with run-on timer, isolation switches are wall mounted in the adjacent landing.

In one house, the bathroom is fitted with an Addvent wall mounted extract fan; this is fitted with a 'wall kit' and discharges through a louvre mounted on the gable wall. The bathroom in the second property is fitted with a ceiling mounted 'Airflow Icon', extract air is ducted approximately 4 meters to discharge louvre. The duct is concealed within a ceiling. The isolation switches for both of these fans are immediately adjacent to the fan units within the bathrooms.

A summary of these conditions and test results is provided below:

ADDRESS	ROOM	FAN TYPE	OPERATION	TEST 1	TEST 2	TEST 3 (l/s)	**MEAN (l/s)**
LA5	WC	Airflow Icon	Lightswitch with overrun	n/a*	n/a*	n/a*	**n/a***
	Kitchen	Airflow	Manual switch	70.1	69.9	71.5	**67.8**
	Bathroom	Airflow Icon	Lightswitch with overrun Ducted to discharge	4.6	4.6	4.6	**4.6**
LA6	WC	Airflow Icon	Lightswitch with overrun	n /	n/a*	n/a*	**n/a***
	Kitchen	Addvent	Manual switch	7	73.8	73.3	**73.8**
	Bathroom	Airflow Icon	Lightswitch with overrun	7.7	7.1	7.5	**7.4**

**fan could not be tested due to proximity to wall/ceiling*

Table 9.2: Extract flow rate test results

9.1.4 Results

Table 9.3 lists the average measured flow rate of each fan and provides comparison with the Building (Scotland) Regulation recommended flow rates. The final column indicates whether the measurement meets the Building (Scotland) Regulation criteria.

ADDRESS	ROOM	FAN TYPE	MEASURED FLOW RATE (l/s)	DESIGN RATE (l/s)	MEETS MIN. FLOW RATE?
LA5	WC	Airflow	**n/a***	3ACH	n/a*
	Kitchen	Airflow	**67.8**	60.0	Yes
	Bathroom	Airflow	**4.6**	15.0	No
LA6	WC	Airflow	**n/a***	3ACH	n/a*
	Kitchen	Addvent	**73.8**	60.0	Yes
	Bathroom	Airflow	**7.4**	15.0	No

*fan could not be tested due to proximity to wall/ceiling

Table 9.3: Extract flow rates vs minimum technical standards

9.1.5 Discussion

Background:
The need for extract ventilation is to ensure that excess water vapour produced in sufficient quantities is extracted quickly and effectively at source, e.g. from bathing and cooking activities. This is to reduce the risk of creating conditions that are able to support germination and growth of mould, harmful bacteria, pathogens and allergies.

Property LA5:
Only two of the three fans in this dwelling were tested due to inaccessible nature of the WC extract. Of the two that were tested the bathroom extract was found to be deficient in terms of meeting the minimum requirements of the technical standards. The bathroom extract rate was found to be just 30% of the minimum standards.

This exceedingly poor performance would seem to provide some explanation for the occupant's recognition that the fan is required to be used for extended periods exceeding the already 'long' run-on time and their need to frequently wipe away condensation and mould. While this behaviour is correct in the circumstances, the fan noise causes the occupants to disable the fan at night time (using isolator) as if it runs during the night, it affects their sleep. The reduced air circulation and relatively warm temperature in this room creates potential for mould growth. The un-insulated WC cistern was found to be running with condensation at the time of the test.
The fan is ceiling mounted and ducted, via a concealed route, over the master bedroom. It was not possible to inspect the duct installation to determine duct type and installation quality i.e. joints sealing, duct supports, presence of kinks in ductwork and number of bends in the duct. It was also not possible to determine whether insulation of appropriate thickness is fitted to the duct, to assist in reducing condensation build-up in the duct. There was no evidence to suggest a condensation drain is fitted to avoid condensation pooling within the duct.

In this dwelling, it is clear the performance of the bathroom extract fan should be improved either by re-commissioning or replacement. It is vital for the technical details and fan performance curves to be consulted to verify the selected fan is capable of overcoming additional static pressure, on the system, caused by the duct (the actual duct route is required to be known to determine this accurately). As the duct route extends over the occupants' bedroom to discharge point, fan noise should be considered if a replacement fan is selected.

Figure 9.4: Condensation of WC cistern with pooling just visible at cistern and seat.

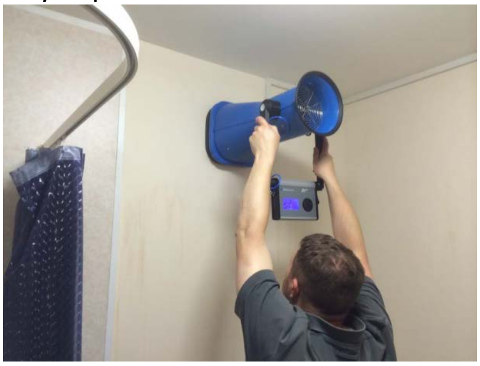
Figure 9.5: Inaccessible (for testing) WC extract fan

Property LA6

It was not possible to test the WC extract fan, as it was found to be inaccessible for the testing equipment. The extract rate of the kitchen fan was found to be sufficient, while the bathroom extract was found to be defective, operating at 50% of the minimum extract rate set out in the Scottish technical standards.

The poor extract fan performance would seem to provide some explanation for the smell which exists in this bathroom and the water staining to the painted wall surfaces. The bathroom itself felt rather humid, however, there did not appear to be mould growth present at the time of the test. This fan is wall mounted using a 'wall kit' with a short section of duct to the external louvre, mounted on the gable wall. When artificial lighting was switched off, daylight could be seen through the fan. The addition of back-draught damper would assist in reducing drafts into the bathroom through the fan. This potentially helps to maintain a constant temperature and not create cool surfaces for water vapour to condense on and limit conditions that support mould growth.

It is recommended that the fan is improved or re-commissioned so it provides a minimum of 15 litres per second to reduce the risk of damage to the building fabric through moisture overload and any mould growth issues that can also occur in these conditions. Any replacement fan should be fitted with backdraught dampers.



9.2 Render Defect

The render to both gables to the development are showing signs of cracking and minor spalling, causing a reduced aesthetic appeal to the building. It is considered a material or workmanship issue, and the contractor is currently investigating. This will be repaired in due course. This would have no impact on energy consumption.

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9.3 Summary and Conclusions

9.4.1 It is evident from the testing undertaken that deficiencies exist with the ventilation strategies used in the bathroom at Bloom Court, this is characterised by the under-performance of the bathroom mechanical extraction units (50% of fans tested). The correct ventilation to these bathrooms is essential as there is no access to windows for intake of external air. This makes a case for further investigation by the Housing Association throughout the development to assess whether the fan installations should be re-commissioned or replaced to provide good internal air quality for the residents. Alongside other similar results from testing in other properties this also provides further evidence that this issue could be endemic within Scottish housing and highlights deficiencies of the Building (Scotland) Regulation themselves.

9.4.2 The Building (Scotland) Regulations provide recommendations for minimum extract flow rates for intermittent mechanical extraction for kitchen, bathrooms, utility and toilet rooms without shower. Their guidance does not, however, require inspection, testing or commissioning of these extract systems (unlike Approved Doc F in England) or provide recommendations for fan controls or run-on times for intermittent mechanical systems. Both would seem to be critical requirements in understanding performance if sufficient volumes of moisture are to be removed from internal spaces. Building users need to understand correct operation of the extract fans as too many occupants override light switch control with run-on timer control with manual switching using the adjacent isolation switch, as fans are reported to be too noisy or perceived expensive to run. It is recommended that a performance specification is provided setting our minimum requirements for extract fans. This should cover items such as extract rate, a delayed start, noise level criteria, low energy, backdraught dampers, control method, timers, duct design, insulation, condensation traps, static pressure etc. Correct specification and control methods could increase the chances the fan is operated correctly to assist in maintaining good indoor air quality

10 Key messages for the client, owner and occupier

10.1 Study Objectives

The primary objectives of the study can be summarised as follows:-

10.1.1. In Scotland there is a serious shortfall in housing suited to people who are less able than the majority. Changing demographics and approaches to social care provision will likely see increasing demand for dwellings that allow persons to live as independently as possible

It is clear from the tenants interviews and the BUS survey that the tenants are both comfortable and happy in their houses. The split of bedroom provision between ground and upper floor allows the flexibility of use required with ground floor shower facility for whole house use. The simplicty and ease of controls of traditional efficient systems was evident by the positive tenant feedback received.. There was a marked reduction in utilty bills experienced from their previous house, although sharp increses in eregy costs were eroding their perception. This should certainly be considered a model for future developments

10.1.2. The materials and method of construction used for these dwellings, NBT Diffutherm, were a departure from more traditional options normally used by HSHA and the construction contractor, and indeed are novel for the UK construction sector as a whole.
In general, the main NBT system worked well. The use of the newer Natural Building Technologies (NBT) 'Diffutherm' wood fibre, Pavatherm Plus materials and the Hemp/Cotton insulation has had a positive impact on energy use and environmental quality. Where such materials are used, review of heating during periods of un occupation should be reviewed, to avoid detrimental drying out. As soon as the construction was weather tight, a notable temperature increase was discernable, even before any heating system was connected. However, most of the NBT materials were supplied from abroad, primarily from Switzerland. Apart from costs and distances involved in delivering simple materials, there were significant problems obtaining small quantities. If greater quantities are used in the UK and the supply chain and demand increases, then ease of supply and cost will improve. However from the various tests, the system has performed as expected, meeting U value and performance levels. The through wall construction was found to achieve an in-situ U-value of 0.19W/m^{2}K. This compares well to the design value of 0.18W/m^{2}K as this value is derived in much more favourable conditions than those experienced on site.
Where new materials are utilised with the aim of reducing energy use, consideration should be given to other implications. For example, warmer buildings increase periods of cooling demand. Addressing this has implications on building complexity, with the effect on maintenance programmes and training.

10.1.3. The dwellings incorporate a range of design features, the study of which would inform the ongoing industry debate on appropriate solutions for delivering comfortable and manageable energy efficient dwellings. For example, the decision to adopt a natural ventilation strategy in place of MVHR, a decision supported by the use of natural,breathable materials due to the expected lack of 'off-gassing' and low internal air pollutant levels.

The ventilation to these houses is perhaps the one area requiring further investigation as the extract fans to the ground floor shower rooms are not performing as anticipated. A separate check on these fans perfomance indicate that these fans are providing extraction rates far below the rates indicated by the manufacturer. Hanover are currently looking to replace these existing fans.
With regards the ventilation strategy for the houses, results indicate that perhaps additional ventilation would improve the air movement throughout the dwellings. The achieved level of air-tightness, under current Technical Standards, would suggest that a whole house mechanical ventilation system would provide good IAQ and that the current strategy (using background ventilators) is insufficient.

10.2 Specific Design Issues

10.2.1 The requirement for large, deep windows to living areas, in order that the tenant enjoys daylight and communication with the outside. This is a desirable element, which should be complied with where possible. However, where the site requires properties to be in close proximity to public vehicular and pedestrian routes, tenants prefer greater privacy. They tend to close blinds and curtains, losing the advantages. Flexibility on this issue is required, according to site conditions.

10.2.2 Internal bathrooms and shower rooms allow the designer to maximise available external wall area for habitable rooms. These have to be carefully considered. Although shower or 'wet' rooms are more suitable for elderly or less abled residents, they seem to be less popular with families, and certain family members would prefer a bathincorporated.

10.2.3 The client prefers a mix of tenant mix and sizes within developments. Different use of electrical equipment results in varying energy use, which can be difficult to reconcile. The buildings are low energy users with regards to heating. However, electrical use is little different from typical.

10.3 Operational Issues

10.3.1 Tenants have either lost or claimed that documentation/instruction was not received. Whether this is the case or not, the process may require review. In some cases, follow up training may be required, particularly where building systems increase in complexity.

10.3.2 Greater involvement in commissioning tests would seem to be beneficial, as the self-certification process by installers may be unreliable. This also applies to designers and contract administrators.

11 Wider Lessons

11.1 Use of Low Energy Materials

This development places an emphasis on the use of low energy materials, such as wood fibre cladding, hemp insulation and breathable render. In general, these products performed as promised. They encourage air tight building and a degree of breathability.

However, at the time of construction, the distribution network for these materials was still in its infancy and a robust supply chain had not been developed. Products were delivered to site from abroad, with almost no stocks maintained in the country. This caused difficulties with delay and expense in obtaining small amounts of these materials.

The cladding materials are intolerant, in that they do not support significant loads. To maintain the integrity of the waterproofing and air tightness, detailing with openings and fixtures, e.g. gas meters, satellite dishes, have to be very carefully considered. The general erection of the panels is quick and simple, but corners and reveals require careful use of tapes and sealants. As with most construction forms, these are weak points, where failure is most likely.

It was discovered that the insulation materials were only available to continental sizes, which had to be cut down to fit structural spacings. Not only did this increase time and waste (causing a shortage during the build), but created an uncomfortable atmosphere for the installer.

11.2 Energy Efficiency

As identified by the monitoring process, the buildings demonstrate low energy consumption, scoring well against the DomEARM typical and part L benchmarks, although not up to theoretical best practice.

Airtight buildings place an onus on ventilation systems to work as intended. Commissioning and testing, in accordance with normal practice, is inadequate considering their importance. Processes need to be reviewed.

Greater understanding of whole house mechanical and passive ventilation systems is required as buildings grow in efficiency. This would also increase client commitment to understand and maintain such systems.