Seager Distillery Housing

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Innovate UK project number	450102
Project author	AECOM for Galliard Homes
Report date	2014
[1]InnovateUK Evaluator	N/A

No of dwellings	**Location**	**Type**	**Constructed**
20 (3 detailed, 9 in less detail)	Deptford, London	Apartments	2011
Apartment area	**Construction form**	**Space heating targets**	**Certification level**
Various: 35 - 74 m^2	Reinforced concrete	Various (see SAP analyses)	Building Regulations, 2006

Background to evaluation

The project involved the performance assessment of the redeveloped Seager Buildings in Deptford. The site comprised a large number of apartments with a smaller proportion of commercial space. There were two phases to the residential scheme. Phase 1 of 173 apartments was complete and occupied prior to the study. Phase 2 was completed during the study period and comprised 130 apartments and a basement car park. The InnovateUK study focused on Phase 1 of the residential space. Three flats from the Norfolk House apartment block were used for detailed evaluation.

Design energy assessment	**In-use energy assessment**	**Sub-system breakdown**
Yes	Yes	Yes (12 dwellings)

The main heat source was a gas-fuelled 100 kWe combined heat and power (CHP) plant supplemented by a 800 kW biomass boiler and two conventional gas boilers. The apartments were ventilated using individual MVHR units. The project assessed energy performance, the efficiency of the district heating system, incidence of any overheating in the apartments, and the occupant experience and levels of satisfaction. The dwellings were tested for air permeability, and insulation tested using thermography. Actual air permeability was more than 50% better than in design-stage SAP. The heat for space heating and DHW consumed by the three apartments analysed in detail was 40 to 65% less than predicted by SAP. All three flats analysed in detail experienced periods of summer overheating against the CIBSE *Guide A* criteria. Electricity use varied widely.

Occupant survey type	**Survey sample**	**Structured interview**
BUS (domestic)	27 of 58 (47% response rate)	Yes

Only the 11 surveys from a second wave of surveys could be used to carry out the analysis as the data were captured at the same time and were therefore comparable. **Readers note: the explanation of the BUS colour coding is not correct. See note on Page 27. This misunderstanding affects much of the subsequent analysis.** However the results suggest that the occupants perceived the flats to be too hot. The occupants also rated airflow as being still in summer and winter as well as the air being quite dry during the winter. Written feedback and face-to-face meetings were held with occupants from the three dwellings studied in detail.

Contents

1 Introduction and overview

1.1 Introduction

The purpose of this project is to measure the performance of the redevelopment of the Seager Buildings site in Deptford which comprises a large number of apartments with a lesser proportion of Commercial Space. There are two Phases to the residential scheme. Phase 1 was complete and occupied prior to the study period, and totals 173 Apartments. Phase 2 was completed during the study period and comprises 130 apartments and a basement car park. This study focuses on Phase 1 of the residential space, in particular the Norfolk House block shown in Figure 1.1. Also shown is a photo of the wider Seager Distillery site, including the tower.

Figure 1.1: Photos of Norfolk House and the Seager Distillery site

The project is of interest because it is typical of many developments that came forward in the 2000's in London, reflecting the tightening standards on energy use and pressure on land use encouraging the building of flats rather than houses. It is of a larger scale than many housing developments, but typical of many of the developments that take place in urban areas, where land values are typically very high, resulting in relatively dense / tall buildings.

This project is distinctive in having a district heating system to provide heating and hot water throughout the development. The main heat source is a gas-fuelled Combined Heat and Power (CHP) plant supplemented by a biomass boiler and two conventional centralised gas boilers.

The intention of this project is to develop an insight into a number of important features of recently built housing that have not been understood sufficiently. These are in particular:

a) The energy performance of flats built to these standards
b) Whether overheating occurs in the apartments in this development
c) Occupant experience and satisfaction with the apartments
d) The efficiency of the district heating system
e) Understand differences between designed and delivered performance for both the energy consumption of the apartments and the efficiency of the district heating scheme

Project Team

This TSB project has been delivered by Galliard Homes and AECOM Ltd. Galliard Homes are the developer of the site. AECOM have provided the expertise on the monitoring and evaluation, and act as an independent reviewer as AECOM were not involved in the development. In addition, AECOM employed Ian Mawditt of Four Walls as technical advisor given his specialist knowledge of post-construction evaluation of homes.

Energy Strategy

As highlighted above, a district heating system provides heating and hot water throughout the development. The design strategy is for the baseload energy to be generated by a 800kW biomass boiler and supplemented by a 100kWe gas-fuelled CHP unit. The biomass boiler meets renewable energy requirements and then it uses the more energy efficient CHP unit. This system is supported by two conventional centralised gas boilers. Electricity for the homes is supplied to the development via the main electricity grid.

Construction Details

In summary, the apartment buildings are constructed as post-tensioned reinforced concrete frame. There is a Metsec stick support system with insulation panels and a rainscreen cladding finish for the external envelope. Internal walls of the apartments are dry wall construction.

The apartments are ventilated using individual MVHR units.

Design intent

We have selected three homes from the "Norfolk House" apartment block for the most detailed evaluation in this study. As an illustration, Table 1.1 summarises the designed CO_2 emissions for these three apartments. They comprise one of each of the three most common types of apartments. Further details of the design intent are provided in the next Section.

Table 1.1: Breakdown of CO_2 emissions based on end-use category for the three detailed study flats, shown here as examples of the environmental performance of the development

Type	Space heating	DHW	Electricity - fan, pump, lighting
	kgCO2/m²	kgCO2/m²	kgCO2/m²
Type 1 flat	3.05	10.56	2.47
Type 2 flat	7.54	7.77	2.47
Type 3 flat	7.53	8.51	2.76

Monitoring Strategy

The evaluation of the three homes from the "Norfolk House" apartment block comprised the following.

- Design and construction audit
- Detailed energy metering
- Water metering
- DomEarm (Domestic TM22)
- Evaluating MVHR performance,
- Air permeability test
- Infra-red thermography
- Temperature, Relative Humidity and CO_2 monitoring
- In-situ U-value measurements

We have also evaluated appliance energy use ('unregulated' energy) in total of 12 homes, including the three detailed homes above. These homes are located in the Norfolk House block and the main Distillery Tower apartment block.

We have also recorded monthly electricity and heat usage for 20 apartments in the Norfolk House block, including the three detailed homes above. This provides an assessment on how representative the energy consumptions of the three detailed homes are.

We have undertaken a BUS survey. 27 responses were received from the flats in Norfolk House (albeit, in discussion with TSB, only the 11 surveys were included in the analysis). This is to gather the perceptions and experiences of the occupants living in the development.

Finally, we have reviewed the performance of the district heating system.

1.2 Summary of key findings from the study

The heat consumed by the three detailed apartments (Flats 1-3) from space heating and hot water is 40 to 65% less than predicted by SAP. Encouragingly, thermographic imaging and limited in-situ U-value measurements suggest that the actual U-values are in line with design expectations – albeit some thermal bridging problems were identified. Three key causes for the difference were identified: (i) the developer achieved a better air permeability than assumed by SAP (actual air permeability was more than 50% better than in design-stage SAP and, whilst as built SAP and EPCs were produced, air permeability was not updated to reflect final test results, (ii) the actual ventilation rates were significantly less than recommended by Part F of the Building Regulations for two of the apartments due to inadequate commissioning and dirty MVHR extract filters and (iii) the relatively low efficiency of the district heating scheme is likely to be partly attributed to distribution losses within the apartment buildings which would help heat the buildings during winter.

The electricity use for fixed building services within the three apartments is more variable in comparison with SAP. For Flat 1 the electricity energy use is 67% greater than predicted, a key contribution being that the MVHR system was constantly on boost for much of the project duration. This partly highlights feedback from the occupants that whilst a large amount of useful information was provided in the form of documentation, it did not provide all of the practical information and face-to-face orientation (e.g. operation and maintenance of the MVHR system) would have been helpful. For Flat 2 and Flat 3, the electricity consumption is around 50% less than predicted due to significantly less usage of lighting than predicted by SAP. This arises from occupant behaviour with both sets of occupants expressing their preference for standalone lighting, which uses power from the wall sockets. We were not able to determine separately the electricity use for stand-alone lighting to compare against this lower than predicted consumption of fixed lighting.

All three flats experienced periods of summer overheating against the CIBSE Guide A criteria. This occurred in both the living rooms and bedrooms monitored. This could be due to a combination of: (i) the high amount of glazing rendering the flats susceptible to excessive solar gain, (ii) the MVHR ventilation rate in some of the flats being below that recommended by Part F of the Building Regulations, which also appears not to feature the capability for a summer by-pass, and (iii) likely distribution heat losses within the apartment building from the district heating system during the summer period. The BUS confirmed these measurements in that occupants perceived that internal temperatures in summer were too hot and they have insufficient control of cooling. In addition, BUS feedback of relatively high external noise levels may have resulted in an unwillingness to open windows to reduce the temperature. It is noted that the three flats studied were all on upper levels of the building such that there was no shading from balconies of the level above, which other lower level flats benefit from. The SAP assessments showed a ‘slight’ overheating risk in Flat 3 and ‘medium’ overheating risk in Flat 1 and Flat 2 – with all assessed as passing Criteria 3 of Part L of the Building Regulations by the SAP software. None of the flats showed a ‘high’ risk of overheating.

Flat 2 exceeded the relative humidity (RH) criteria recommended by Part F of the Building Regulations on a number of occasions, particularly in the bathroom. This may be explained by the fact that the ventilation boost operation was not operating via the bathroom light switch and would be relatively straightforward to remedy.

For Flats 1 and 2, there were periods of time where in the living room the average 8-hour CO_2 level exceeded a guideline of 1830ppm which was proposed for adapted individuals. Based on a review of the data, exceedances are likely to have occurred whilst the residents entertained visitors and the normal MVHR flow rates recommended in Part F are for a standard occupancy with the potential to open windows during periods of occasional high pollutant events. Whilst there may have been some dissatisfaction from occupants from higher levels of metabolic odour, it was unlikely to be a health concern.

In general the energy consumption from ‘unregulated’ appliances was below the DomEarm benchmarks. This may suggest that the benchmarks are not appropriate for the study population.

Issues were identified with regards to the installation and commissioning of the energy plant, particularly with the system controls which have impacted on its operation. This is a combination of the design specifications for installation and commissioning not being sufficiently detailed and the inexperience of the mechanical and electrical installation company with evaluating such a system. During the course of this study, only the gas boilers have been used – in particular, the CHP has not run due to it being oversized for the Phase 1 build out of the development and the time taken to obtain a sufficiently economical price for electricity exported to the grid. Furthermore, the lowest output available from the 800kW biomass boiler is more than the daytime winter idling load of the completed scheme. This puts future use of the biomass boiler into question.

Measurements have shown a low actual overall communal heating system annual efficiency of 26%. It is expected that a key cause of this performance is relatively high distribution losses compared to the heat load – albeit some of this would be useful heat during the winter period where the heat loss occurred within the apartment building. It is noted that as part of this study we have not evaluated whether any such distribution losses are as a result of the pipework installation and/or the standards of insulation on heating pipework being below what is required to achieve a reasonable system distribution loss and to limit overheating in dwellings. It can be expected that the efficiency will improve somewhat as an increased number of buildings come on-line and greater efficiencies can be gained from the use of the CHP. As a result of the low system efficiency and the use of gas boilers only, the CO_2 emissions are significantly higher than predicted by SAP (nearly three times in the case of one of the apartments).

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

2.1 Introduction

The concept architectural and mechanical and electrical (M&E) design was developed to RIBA (Royal Institute of British Architects) Stage D by Hoare Lea. Galliards then appointed Mendick Waring to carry out the detailed design and specification of the system. CJ O'shea was appointed as the Main Contractor with overall responsibility for the base build of the site. Other contractors were separately employed for fit-out with the exception that AES controls were employed directly by CJ O'shea for the BMS and controls.

A description of the Seager Distillery development and Norfolk House has been provided in Section 2.2. A design and construction audit has been carried out for the three detailed flats in Norfolk House and is reported in Section 2.3. A review of the communal heating system that takes into account aspects of its design, commissioning, maintenance and operation is reported in Section 2.4.

2.2 About the Seager Distillery Site

Information for Section 2.2 was based on a review of the following documents:

- Galliard Homes Ltd, Old Seager Distillery, Deptford, Planning Application Supporting Statement, September 2007
- Structural Design Philosophy Statement, Walsh Group, 27 August 2008

2.2.1 Summary of the site

This brownfield site used to house a distillery and is being redeveloped to provide a mixed use development comprising of six new build blocks encompassing office, residential, commercial and business end uses. The mixed use nature of the proposed site reflects the London Plan's (adopted Dec 2006) principles of the 'compact city' concept. The total site area is approximately 0.7ha.

The six blocks vary in height between 2 floors and 27 floors. A summary of their end use is as follows

- Block A: basement car park, 7 live/work units, 1 commercial unit, 92 private flats and 38 social rented flats
- Block B (Norfolk House): 4 commercial units and 58 shared equity flats
- Block C (Distillery Tower): 2 commercial units and 115 private flats.
- Block D: 1 gallery and 5 office floors
- Block E: 1 gym and 4 office floors
- Block F: 2 office floors

2.2.2 Norfolk House (Block B)

We have focussed on Norfolk House in this Section as most of the monitoring took place within its apartments.

Design Philosophy

The flats were built to exceed the minimum requirements set out in Part L1A of Building Regulations 2006 to comply with the London Plan (adopted December 2006). The latter requirements stipulate that Building Regulation compliance had to be achieved through energy efficiency measures alone and that an additional 20% reduction in CO_2 emissions should be targeted via on-site measures (improved energy efficiency measures and low and zero carbon technologies). Based on what was realistically achievable, an 18% reduction in site-wide CO_2 emissions was accepted for planning permission via a combination of energy efficiency, gas Combined Heat and Power (CHP) and biomass heating.

Construction

Construction of Norfolk House was completed around September 2011 and its first occupants moved in around June 2012. The structure is made of concrete with a concrete pile foundation.

Norfolk House consists of 58 dwellings split over 6 floors. On the ground floor, space has been allocated for four commercial units which are not yet fitted out nor occupied. It has two main cores, each consisting of a lift, stairwell, a dry riser and a wet riser.

All flats have a balcony which is accessed via the living rooms. The living rooms have full height double glazing consisting of a door which leads onto the balcony. Various types of cladding have been used on the facade including, aluminium insulated panels, aluminium rainscreen cladding, aluminium infill panels, aluminium spandrel panels, and timber cladding. The balcony has a glass barrier with a metal hand rail. There are areas of the roof which are green roofs and other areas comprising shingles/sand bed and sand ridges.

The apartment buildings are constructed with post-tensioned reinforced concrete frames. There is a Metsec stick support system with insulation panels and a rainscreen cladding finish for the external envelope. Internal walls of the apartments are dry wall construction. Appendix E includes two construction details to help illustrate this in more detail.

2.3 Design and Construction audit of the three detailed flats

We have undertaken a design and construction audit of the three flats in Norfolk House which underwent the most detailed monitoring. The following documents were reviewed for the purposes of the design and construction audit:

- Seager Energy Strategy Proposals, First Draft Issue, Hoare Lea, December 2006
- Design Final SAP (2005) worksheets
- Design Final Building Regulations Checklists
- As built SAP software files

In addition, an interview was held with the Galliards Mechanical and Electrical (M&E) Services Manager.

2.3.1 Description of the flats in Norfolk House

We describe here key features of the flats in Norfolk House. Furthermore, we review how representative the three detailed flats monitored were of the flats in Norfolk House. As described in more detail elsewhere, there were difficulties in recruiting volunteers and this limited the choice of flats for this study.

Built form

The as-built SAP worksheets have been reviewed for all 58 flats in Norfolk House and compared to the accommodation schedule for Norfolk House (914-Block B-Unit-Plot-Postal no.xls, dated 26/07/2011). As shown in Table 2.1, there are 6 unique flat types in Norfolk House, with floor areas ranging from 35 to 74 sqm and between single storey and duplex flats.

Table 2.1: Comparison of flats in Norfolk House

	Detailed flats monitored within this Study	**Floor area, m^2 (SAP figures)**	**No. storeys**	**No. beds**	**No. similar flats in Norfolk House**	**% of similar flats in Norfolk House**
Flat type 1	Flat 1	45	1	1	22	38%
Flat type 2	Flat 2	74	1	2	15	26%
Flat type 3	Flat 3	63	2	1	8	14%
Flat type 4		35	1	1	6	10%
Flat type 5		73	2	1	4	7%
Flat type 6		45	1	1	3	5%
Total					**58**	**100%**

Of the 6 unique flat types in Norfolk House, the three flats participating in the detailed study (Flats 1 to 3) account for the three predominant flat types which together account for 78% of flats in Norfolk House. Therefore, in terms of built form, the three detailed flats are representative of those in Norfolk House.

Location of detailed Flats in block and orientation

The location and orientation of the three detailed flats has been compared to the location and orientation of all the flats in Norfolk House.

- Table 2.2 shows the percentage of ground, mid and top floor flats in Norfolk House.
- Table 2.3 shows the orientation of flats in Norfolk House
- Table 2.4 shows the location and orientation of the three detailed flats monitored in Norfolk House

Flat 1 is located on the mid-floor and as shown in Table 2.2 it is the most common floor type in Norfolk House. Flats 2 and 3 are both top floor flats in Norfolk House which only make up 17% of flats in Norfolk House. Whilst, we have not included a ground floor flat, we expect that this work will still highlight key building performance issues associated with Norfolk House.

In terms of orientation, the three detailed Flats provide a good representation of flats in Norfolk House – one with glazing facing East, one with glazing facing West and one with dual aspect.

Table 2.2 Breakdown of the number of ground, mid and top floor flats in Norfolk House

	No. flats	**% of total**
Ground floor	4	7%
Mid floor	44	76%
Top floor	10	17%

Table 2.3 Orientation of flats in Norfolk House

	No. flats	**% of total**
East	21	36%
West	21	36%
Dual aspect (East/West)	16	28%

Table 2.4 Location in block and orientation of detailed Flats in Norfolk House

	Location in block	**Orientation**
Flat 1	Mid-floor	West
Flat 2	Top floor	Dual aspect
Flat 3	Top floor	East

Occupants and occupancy patterns

Another key variable in terms of the performance of the building is their occupancy. At the commencement of this study, all three flats had two occupants. This appeared reasonably representative as both Flat 1 and Flat 3 had one bedroom whilst Flat 2 had two bedrooms. It is important to note that a short time into the study, one of the occupants of Flat 3 moved out, resulting in only one occupant for the rest of the trial. This appears to have implications as discussed later in Section 7.

All of the occupants worked. In Flat 2 and Flat 3, the occupants worked normal office hours. In Flat 1, one of the occupants was a shift worker, which resulted in regular occupation of the flat during the day. This appears to have implications as discussed later in Section 7.

2.3.2 Comparison between the original specifications and the final dwelling design

To assess how closely the final design meets the original specifications, the original and final design has been compared.

Table 2.5 provides a comparison between the original and final design ('pre-constructed design'). The original design is based on the energy strategy proposal report (Seager Energy Strategy Proposals, First Draft Issue, December 2006). The Final design is based on information contained in the "Design Final" SAP worksheets and the Building Regulations Compliance Checklists. The original design did not include all of the information that we were able to obtain from the final design SAP worksheets.

In terms of fabric, lighting, and air permeability specification, with the exception of the roof, the final design either meets or exceeds the original design. The final design roof value of 0.25 W/m^{2}K is poorer than the original design value of 0.16 W/m^{2}K. It is not clear why these changes were made. A more detailed discussion of the communal heating system is provided later in this Section.

Table 2.5: Comparison of key design data between the original and final design.

	Original design	**Pre-construction design**	**As-built SAP**
Element	**U-value (W/m^{2}K)**		
Roof	0.16	0.25	0.25
Walls	0.25	0.24/0.25	0.25/0.23
Ground floor	Dwellings assessed not on ground floor		
Windows	1.7	1.59	1.7
Doors	n/a	n/a	n/a
Factor			
Air-tightness (m^3/m^2/hr @50Pa)	8	5	8 (Test results: for flat type similar to Flat 1: 4.52; for flat type similar to Flat 2: 4.18; for flat type similar to Flat 3: 5.62)
Fixed lighting	At least 30% of fittings to be energy efficient	100% low energy lighting	100% low energy lighting
Heating system/Other			
Heating system overview	Heating and hot water to be provided by biomass, CHP and gas boiler communal heating	Biomass, CHP and gas boiler communal heating	Biomass, CHP and gas boiler communal heating
MVHR	MVHR	Nuaire MRXBOX95 Flat 1&2 SFP: 0.59 W/l/s; HR: 92%; Rigid ductwork Flat 3: SFP: 0.68 W/l/s; HR: 91%; Rigid un-insulated ductwork	Nuaire MRXBOX95 Flat 1&2 SFP: 0.59 W/l/s; HR: 92%; Rigid ductwork Flat 3: SFP: 0.68 W/l/s; HR: 91%; Rigid un-insulated ductwork
Summer overheating	Data not available	Blinds/curtains: Dark coloured venetian blinds Overheating risk: Medium (Flat 1); Slight (Flat 3)	Blinds/curtains: Dark coloured venetian blinds Overheating risk: Medium (Flat 1); Slight (Flat 3)
y-factor	Data not available	Data not available	0.08
Dwelling emission rate/ Target emission rate kg/m2/yr	Data not available	DER Flat 1: 12.31 TER Flat 1: 21.34 DER Flat 2: 13.12 TER Flat 2: 21.12 DER Flat 3: 14.34 TER Flat 3: 23.90	DER Flat 1: 12.77 TER Flat 1: 21.34 DER Flat 2: 13.82 TER Flat 2: 21.12 DER Flat 3: 14.60 TER Flat 3: 23.90

2.3.3 Comparison of the final design and the as built dwelling specifications

We compared the final design SAP worksheets and Building Regulations Compliance Checklists with the on-construction SAP results as well as the actual air pressure test results (see Table 2.5).

Generally, the as-built specification closely matches the final design. It is unclear why the differences occurred (e.g. the change of air tightness from 5 to 8 $m^3/m^2/hr$ @50Pa). We do note that the as-built SAP calculations do not appear to have been updated with the actual air pressure test results. However, as the test results were better than those assumed in SAP, the CO_2 emissions should be better than intended and the flats would still comply.

In terms of the dwelling emission rates (DER), these have remained broadly similar for Flats 1 and 3 (data not available for final design for Flat 2). The target emission rates (TER) have changed more significantly – a 20% reduction for both Flats 1 and 3 between the Final Design and As-built values. This change is likely a result of the implementation of Part L 2006 during the process, and the consequent change to the SAP software, which required a 20% improvement on Part L 2002.

2.3.4 Aspects of the design which could introduce performance issues

We have noted from the design some issues that we will particularly look at during this study.

- Balconies could introduce thermal bridging due to breaks in the thermal envelope where they are connected to the main building structure. Thermographic testing would be helpful in examining this.
- The living room and bedroom external walls incorporate a high percentage of glazing (greater than 50%). This could result in overheating and we would assess the environmental conditions during summer 2013 and part of summer 2014.
- The running of hot water pipes for the communal system through the two risers in Norfolk House could result in unwanted heat being delivered to the corridors and stairwells, resulting in overheating of these areas and heat loss. This in turn could lead to a poor efficiency of the communal heating system as considerable amounts of heat could be dissipated outside of the flats. We would again assess environmental conditions in the flats during the summer as well as determining the energy performance of the communal heating system.

2.4 Communal heating review

A review was carried out of the communal heating system. This review comprised the following activities.

- An interview with Galliards Mechanical and Electrical (M&E) Services Manager to gain an understanding of design, construction and operation of the communal heating system.
- A review of the initial design intent in the energy strategy proposal report – (Seager Energy Strategy Proposals, First Draft Issue, December 2006)
- A review of the final pre-construction design (Mechanical Specification for Shell & Core Works of Phase 1 of Seager Mixed Use Development at Brookmill Road, Deptford, London, SE8 for O’Shea Construction Ltd (March 2010)).
- A review of the Operation and Maintenance manuals (O&M’s).
- A walkthrough of the Energy Centre with the Galliards Mechanical and Electrical (M&E) Services Manager and an AECOM communal heating expert.

2.4.1 The design intent for the communal heating system

The design intent is similar from the concept design to the detailed pre-construction design specifications, although further detail was added to the pre-construction design specification. A dedicated district heating system (Energy Centre) provides heating and hot water throughout the development including the commercial buildings. Low temperature hot water is distributed from the central heating plant to heat interface units and heat emitters located within the apartments for heating and hot water generation.

The central heating plant comprises a biomass boiler, a Combined Heat and Power (CHP) plant and gas-fired boilers.

- A wood pellets fired biomass boiler provides low carbon heat and programmed as the lead boiler. It is noted that between the original and final design, the power output had increased from a 700kWth boiler to a 800kWth boiler (X1 Hoval, 800kWth STU wood pellet boiler) which reflects the size of the boilers available for procurement in the Hoval STU range rather than any recalculation of energy requirements.
- The CHP to be procured was an Ener-G 100 CHP plant with 165kWth and 100kWe, to increase the overall utilisation efficiency of the energy delivered to the development.
- The remaining heat load to be provided by high efficiency gas-fired central boilers: an 850 kW Hoval Cosmo boiler installed in Phase 1 construction, and an additional two 700 kW Hoval Cosmo boilers installed in Phase 2 construction.
- An 18,000 litres thermal store complete with thermal insulation to store CHP plant and biomass boiler's heat output, when the site thermal demand (space heating and domestic hot water demand) is less than the maximum heating output of both the CHP plant and biomass boiler.

2.4.2 Differences between design and construction

Prior to procurement, the Galliard's M&E services manager reviewed the procurement specification. There appeared to be no re-evaluation of the size of the heating systems from the conceptual to final design stages. In particular, it was decided at that point that instead of procuring three boilers, only two were necessary: a 1,000kW gas boiler for Phase 1 and a 1,500kW gas boiler for Phase 2.

It has not been possible to determine the final thermal store size from the documentation reviewed nor from the walkthrough. However, we have no reason to believe that the final thermal store is different to design.

2.4.3 Commissioning

We reviewed the commissioning documentation available from the electronic O&M manuals.

- CHP: the commissioning information supplied only applies to electricity requirements and not, for example, about heating-related set-points. There is no testing of the reliability of operation of the CHP (e.g. over a week period) as the commissioning document states that there was insufficient heat load to run the CHP. The CHP was only run for 7 hours for the purposes of commissioning. Galliard has made attempts to start the CHP during the course of this study but has been faced with technical issues and now intends it to be in operation shortly after the end of this study. The delay in operating the CHP was also due to the difficulty in finding a company to pay for the 'spill over' exported electricity. A contract has now been signed for this.
- Biomass boiler: A completed commissioning checklist was obtained which included checks that the boiler had been set up correctly. There does not appear to have been any confirmation of its heat output or efficiency.
- Gas boiler: The commissioning sheet for the Phase 1 1000kW gas boiler includes information about the performance of the boiler (e.g. efficiency, fuel). We assume that this is tested rather than the technical specifications of the boiler. We note that the customer's signature has not been included.
- LTHW pipe-work: The commissioning information consists of a one page document stating that the pipe-work has been tested to comply with relevant regulations by a visual inspection and by testing to a given pressure using a calibrated gauge.
- A Trend system has been installed to control the sequencing and delivery of the energy centre plant. However we could not find any information to confirm that the control system has been set up in line with design requirements.

2.4.4 Operation

This section is based on an interview with the Galliard's M&E Services manager. A number of problems have been identified which have been / are being rectified.

The CHP has not been run since it was commissioned. This is because there has not been sufficient electricity demand on the Seager site to use the electricity that would be generated by the CHP. It was previously decided not to export electricity as the price offered for the exported electricity meant that this would be uneconomical. However, when the Seager Distillery development is fully built, there may be sufficient electricity demand on the site to use all the electricity generated by the CHP. Furthermore, a better price has now been offered for the electricity exported by the CHP which may further make the use of the CHP more attractive.

There have been problems with the control of the communal system. This principally arises from the following causes

- A detailed and comprehensive control strategy was not provided by Mendick Waring. The result was that the controls company did not have adequate information to set up and commission the controls for the communal system. The controls company brought in one of their experienced Directors to fill in the gaps in the control strategy and implement the control system for the communal system.
- The controls company were directly appointed by the Main Contractor who did not have much experience of controls strategies and commissioning, which meant that they were not in a position to critically assess and audit the control system design, installation and commissioning.

As a result, the following problems have been identified.

- With the CHP not currently operating, it is not clear whether the gas boiler has been running in lead rather than the biomass boiler as intended.
- When the thermal store is unable to provide sufficient heat to the communal heat network, the control system switches to the gas boilers to provide all heat to the network. However, when the thermal store has been replenished by the biomass boiler, the system does not switch back to the thermal store to provide heat. This is suspected to be the result of a missing temperature sensor.

In October 2012, the communal heating system failed to provide heat to residents in Norfolk House and the Distillery Tower. This problem was traced to too many DPCV's (Differential Pressure Control Valves) resulting in too much restriction of the flow in the heat network. The heat network has provided heat reliably from November 2012 onwards. There was also a problem with the Differential Pressure Control Valves in Norfolk House riser which could lead to full flow rate of hot water always being supplied to Norfolk House and therefore no savings are made as variable speed pumps cannot ramp down.

There was a fault with one of the gas boiler burners – it was constantly cycling on and off and never exceeding 20% load. The boiler supplier traced the problem to a faulty delay timer device (this device is supposed to keep the burner operating at a lower rate for a few minutes after ignition before allowing the boiler to ramp up to its full output). The delay timer has been removed and the boiler can now reach its maximum output. The boiler supplier has planned to replace the faulty delay timer during the commissioning of the second gas boiler, which was underway at the time of the interview.

The biomass safety valve has been opening. The safety valve which releases water from the biomass boiler when the pressure exceeds a certain level has been opening during the winter months when the biomass boiler was in operation. The operation of this safety valve would not be expected in a system that has been well set up.

A mixing valve has been installed in the wrong position. While this may not lead to an overall loss in system efficiency, it is likely to lead to a shortened life of the valve.

While reactive maintenance is carried out (e.g. if a pump malfunctions, this is rectified), preventative maintenance does not appear to be carried out (e.g. checking of strainers, water quality checks, controls checks and other general tweaking of the system to keep it running at high an efficiency as possible).

For the Distillery Tower:

- The differential pressure control valves were not commissioned properly resulting in insufficient heat delivered during times of peak demand.
- There have been problems with pipe-work in the Distillery Tower risers and plant room which has resulted in leaks occurring when the pipe-work cooled down and contracted

In addition, AECOM noted from its walk-around that the valves and flanges were not insulated. These should be insulated to prevent unnecessary heat losses. We were informed by Galliard Homes that the completion of the insulation is to be addressed during the subsequent activities to complete the Energy Centre.

2.4.5 Initial recommendations

Some initial AECOM observations are as follows:

- There is the potential of claiming for the RHI (Renewable Heat Incentive) through the heat output of the biomass boiler. The eligibility of the installation would need to be checked.
- Currently there is a very large biomass boiler capacity (800kWth) in comparison to the current load on the heat network (estimated to be approximately 90kW diversified peak, assuming rule of thumb of 0.5 kWth per dwelling peak heat requirement), especially as the Seager site is still being built out. There is the potential to export heat from the biomass boiler to other users in the vicinity (e.g. Lewisham College) to maximise any potential returns from RHI.
- As a rule of thumb, thermal stores should be tall and narrow (e.g. height is 3 times diameter) to promote stratification. Furthermore, flow and return should be at top and bottom of thermal store respectively. Based on AECOM's walk-around, it was noted that the thermal store appears to have a similar diameter to its height and the return pipe is located halfway up the height of the store resulting in half the thermal store capacity not being used. See Figure 2.1.

In addition, we include some recommendations in terms of improvements for future communal heating systems based on the review.

- There should be more auditing of the design. This should ensure that there are sufficient details of the control system to support those installing and commissioning the system. Furthermore, there is a tendency at the design stage to overestimate the required capacity of plant and if this is not reviewed before construction, there is likely to be an overcapacity of plant, which would both increase cost and lead to a lower operating efficiency of the communal heating system. This could be a particular problem for CHP units and biomass boilers. If a CHP unit is oversized in terms of its heat or electricity output, it will tend to operate for far fewer hours or perhaps not at all. Over-sizing of biomass boilers can lead to boiler operating at low turndown and hence not only having lower efficiencies but also other operation and maintenance issues such as clinker and build up of explosive gases.
- The developer should directly appoint a commissioning company, rather than have it appointed by the main contractor. The commissioning company would then be more impartial and therefore flag up potential problems better than if they are appointed by the main contractor. This idea may be difficult in practice as the current way that building procurement operates is based on the main contractor taking full responsibility for delivering a construction project, including the appointment and management of the independent commissioning company.
- Where CHP is specified, it is important to check the cost that can be obtained for the export of electricity and it is economical to run.
- Given the relative novelty of community heating systems, it may be worth having a standardised design template. However, this may not be worthwhile as frequent changes in Building Regulations and planning requirements may mean that a particular design solution may quickly become non-compliant.

Thermal store	Flow and return thermal store connections
	

Figure 2.1: Photos of energy centre

2.5 Conclusions and key findings for this section

Seager Distillery site and Norfolk House

In terms of energy performance, the proposed Seager development committed to an 18% reduction in site-wide CO_2 emissions compared to Part L 2006 to comply with the London Plan.

The three flats monitored in detail are located in Norfolk House. They are reasonably representative of flats within Norfolk House as they comprise one of each of the predominant built forms, and a spread of orientation and locations within the apartment block.

Differences between design and construction

The constructed dwellings are similar to the conceptual design. Whilst the air tightness test results did not appear to be included in the on-construction SAP, the results were better than assumed in the SAP calculations and the dwellings would still comply.

Communal heating review

The original design intent was followed through into construction. The main difference is that the final design was for three gas boilers and this was modified by the Galliard's M&E services manager down to two gas boilers – a problem being that there appeared to be no re-evaluation of the size of the heating systems from the conceptual to final design stages.

Issues were highlighted with regards to the installation and commissioning of the energy plant, particularly with the system controls which have impacted on its operation. This is a combination of the design specifications for installation and commissioning not being sufficiently detailed and the inexperience of the mechanical and electrical installation company with evaluating such a system. Furthermore, the CHP has not run due to it being oversized for the current build out of the development and an uneconomical price offered for electricity exported to the grid.

Recommendations are provided for future improvement. In particular, there should be more auditing of the design to ensure that there are sufficient details to support those installing and commissioning the system and that the capacity of the plant has not been overestimated.

3 Fabric testing (methodology approach)

3.1 Introduction

To help assess the build quality of the flats, we commissioned BSRIA to undertake a series of performance tests of the building fabric. We summarise the methodology and results here – further details are provided in the BSRIA reports supplied as separate Annexes.

- The text initially describes air tightness testing and smoke tests for air leakage.
- We then describe in-situ U-value measurement through external walls of the dwelling fabric and thermographic inspection of the building fabric

3.2 Air tightness test methodology

The air tightness of the flats was determined through air pressurisation and depressurisation testing using a "Blower Door" system to generate a differential pressure across the building envelope. The pressurisation and depressurisation tests were averaged to provide the air pressure test result for each flat. The tests were carried out on the three flats which had detailed monitoring (Flats 1, 2 and 3) in accordance with the procedures described in the ATTMA technical standard, TSL1 October 2010. To carry out the tests, all external doors and windows in the flats were closed, whilst internal doors were open and all mechanical ventilation openings were temporarily sealed.

3.3 Smoke test methodology

Smoke tests were carried within each of the three flats to identify areas of air leakage whilst pressurising the flat. BSRIA used a smoke pencil which generated streams of white smoke. The white smoke provides a visual indication of air paths in its vicinity. The white smoke is entrained by the air flow when placed in the vicinity of a source of air leakage, rendering the air flow path and hence the indication of air leakage visible.

3.4 Results of air tightness and smoke tests

3.4.1 Initial air tightness tests

The initial air tightness tests were carried out in Flats 2 and 3 on 15th July 2013 and in Flat 1 on 22nd July 2013. The results are presented in Table 3.1. For comparison, we include the as-designed and as-constructed SAP air tightness values as well as the results from previous air tightness testing for the same flat type (not the actual flats monitored here) obtained from the test certificates provided by Galliard Homes.

The test results for all the three flats show significantly lower air leakage rates than assumed in SAP and measured by another contractor on the same flat types. It is perhaps understandable that the values would be better than in SAP, as the developer may have chosen conservative values to avoid non-compliance if the actual values were not as good as expected. It is perhaps more interesting that there are significant differences between the different contractors air tightness testing results. This may reflect differences between the flats, differences in the testing itself between contractors (calibration of the testing equipment, sealing of MVHR opening etc) as well as the fundamental accuracy of the measurement procedure itself.

Table 3.1: Air pressure test results for the three flats and comparison with other previous values

Air pressure measure	Air permeability at 50Pa ($m^3/h.m^2$)		
	Flat 1	**Flat 2**	**Flat 3**
Design air permeability (SAP)		8.0	
Measured on completion (original testing contractor)	4.5	4.2	5.6
Initial air pressure test results by BSRIA	2.4	3.2	3.6
Repeat air pressure test results by BSRIA	2.8	2.6	3.6

3.4.2 Repeat air tightness tests

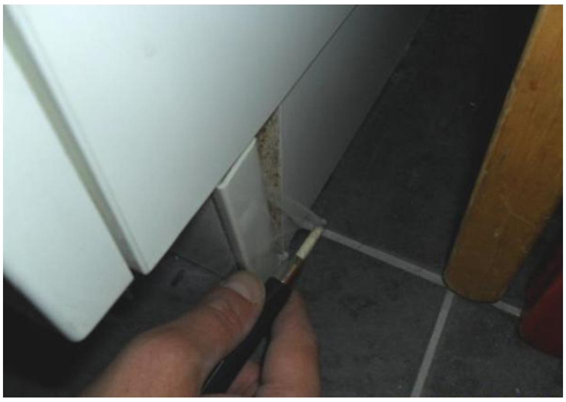
The air tightness tests were repeated in all three flats on the 11th August 2014 and are also presented in Table 3.1. The results showed no difference for Flat 3, an increase for Flat 1 and a reduction for Flat 2. We were unable to obtain from BSRIA the uncertainty in these measurements to determine if the change in results for two of the flats was due to a change in the fabric performance or could be associated with uncertainties associated with testing itself.

3.4.3 Smoke tests

The smoke tests were carried out around the three flats at the same time as the initial air tightness tests. They revealed some sources of air leakage (see Figure 3.1 for some examples). The most significant air penetrations identified were as follows.

- Pipe-work penetration in the airing cupboards
- Cut out under sinks in the kitchens and bathrooms
- Cracks around some window frames, particular in Flat 3
- Around window hinges
- Penetration at electrical sockets
- Some light fittings, particularly in Flat 2 where the occupant has installed new ceiling flushed lighting.

a) Penetration at water pipework in airing cupboard



b) Penetration under the sink in kitchen

c) Air leakage around light fitting in Flat 2 living room

d) Penetration at sink cut out in bathroom

	
e) Penetration at electrical sockets	f) Penetration at window frame cracks on landing

Figure 3.1: Photo evidence showing areas of air leakage penetrations around the Flats

3.5 In-situ U-value measurements

The intention was to undertake in-situ U-value measurements to compare the performance of the external fabric for the three detailed flats against the design specifications. The U-value measurement instruments were installed on site by BSRIA in the flats on 28th January 2014. The instruments were left in place for two weeks to record heat flux through a chosen external wall and the temperature difference between the outside and the room. Figure 3.2 shows the installations in the respective flats.

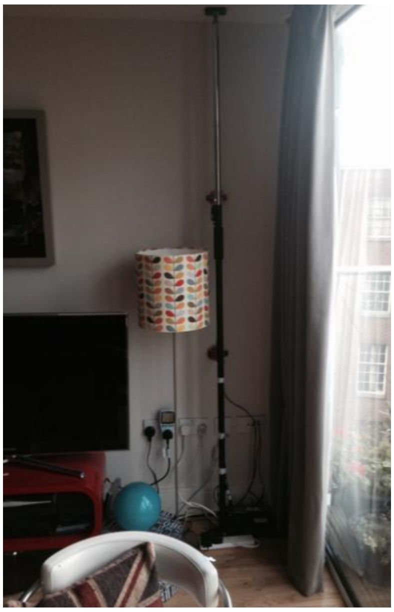
		
Flat 1	Flat 2	Flat 3

Figure 3.2: Photographs of the U-value measurement probe attachments in the respective flats

When removing the equipment after the tests, several key issues were found

- The data loggers in Flats 1 and 3 did not record any usable data. The data logger in Flat 2 operated for four days only which, whilst less accurate, produced an indicative U-value of the external wall of 0.23 W/m²K compared to a design value of 0.25 W/m²K.
- The heat flux probe installation left stains on the wall, due to thermal coupling paste leakage. The protective film, which functions to prevent direct contact with the wall, was compromised during installation.

3.5.1 Lessons learnt

The following learning points were identified:

- The data loggers were set up in the specialist contractor's offices. The installer sent on-site was not familiar with the loggers and had to liaise with others back in the office during installation. There should be better coordination and communication between the installer and personnel at base and the installer should have had better training in advance if non-standard instruments are being used.
- In AECOM's view the approach taken to avoid stains happening on walls was not sufficiently robust – there should be a more effective way to mitigate this work. However, we do note that the specialist contractor was not aware of this problem occurring and it could be a unique incident due to unexpected complications during the installation process.

3.6 Thermographic Imaging

A thermographic imaging survey was undertaken by BSRIA to support the investigation into the external fabric performance of the flats in Norfolk House. Internal and external surveys of the building elevations were carried out on two separate site visits on 20th January 2014 and 19th February 2014, in conjunction with site visits to carry out in-situ U-value measurements in the three detailed study flats.

The Thermal Index, TI, was used as a metric for fabric performance in the survey. It is the ratio of (surface temperature – external temperature) and (internal ambient temperature – external temperature). Thermal Index is related to the U-value as demonstrated by the following correlation in Table 3.2.

Table 3.2: Equivalence of Thermal Index and U-values

Thermal Index	0.5	0.75	0.8	0.85	0.9	0.95	0.97
U value	3.8	1.9	1.5	1.2	0.9	0.35	0.25

It should be highlighted that whilst thermographic imaging is a useful technique to determine building fabric performance, it becomes less effective on modern highly-glazed buildings as imaging of the external façade will tend to be predominated by the reflection of the sky and adjacent buildings; although some salient features will remain conspicuous.

3.6.1 Results

The term 'anomaly' is used as a proxy for wall areas that potentially exhibit performance issues (i.e. it visibly appears to be a cold-spot from the thermographic image). The survey validates these perceived anomalies through the calculation of the corresponding Thermal Index.

Internal

For areas with no perceived anomalies during the thermography survey, the reported Thermal Index generally suggested U-values that are in-line with design expectations. This was both the sub-contractor's view (they were provided with the design U-values by AECOM) and AECOM confirmed this as well.

Many of the internal images recorded were targeted at areas of perceived anomalies and these are recognised in the lower value of the Thermal Index (i.e. 'cold spots'). In particular, there are areas of confirmed anomalies relating to plain areas of wall, which exhibit much lower Thermal Index and hence significant reduction in performance against design intent. Examples are colder areas at the top of "Boxed-in" sections, perhaps covering pipe work with air leakage problems. Cold bridging from large dabs behind the plaster board may also be present. There are also some evidences of cold bridging due to penetration of stud-wall fixings. Examples of these anomalies are shown in Figure 3.3 to Figure 3.5.

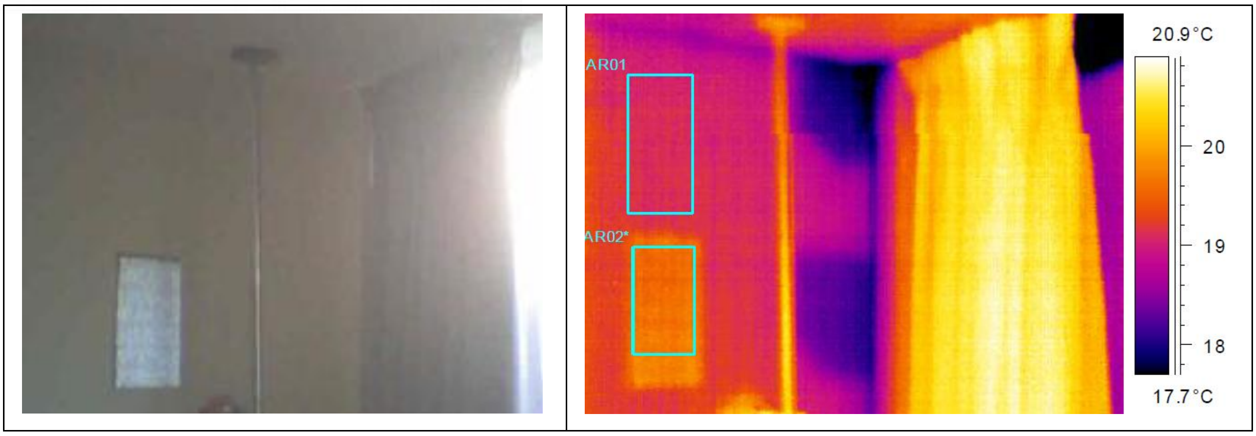


Figure 3.3: Thermography image of Flat 3 external wall indicating cold patches

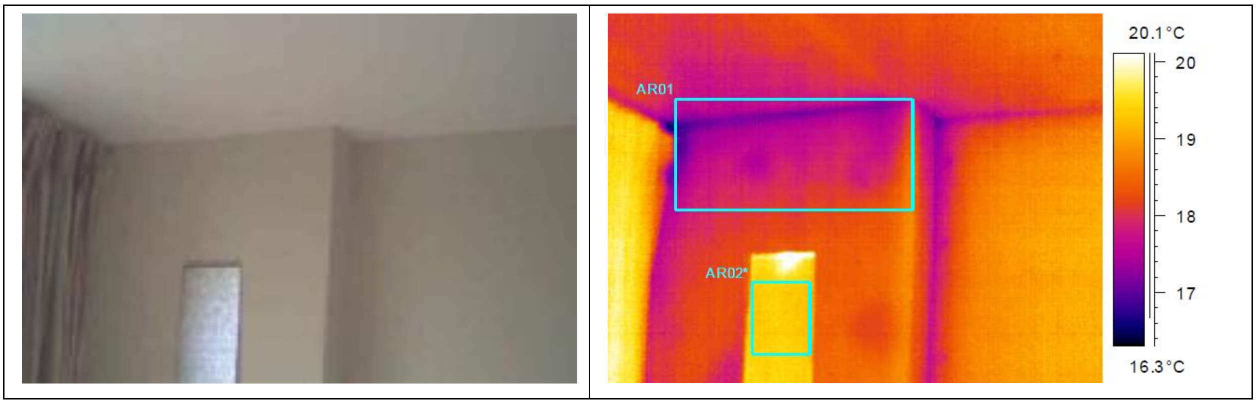


Figure 3.4: Thermography image of Flat 2 external wall indicating slight cold patch near wall roof interface

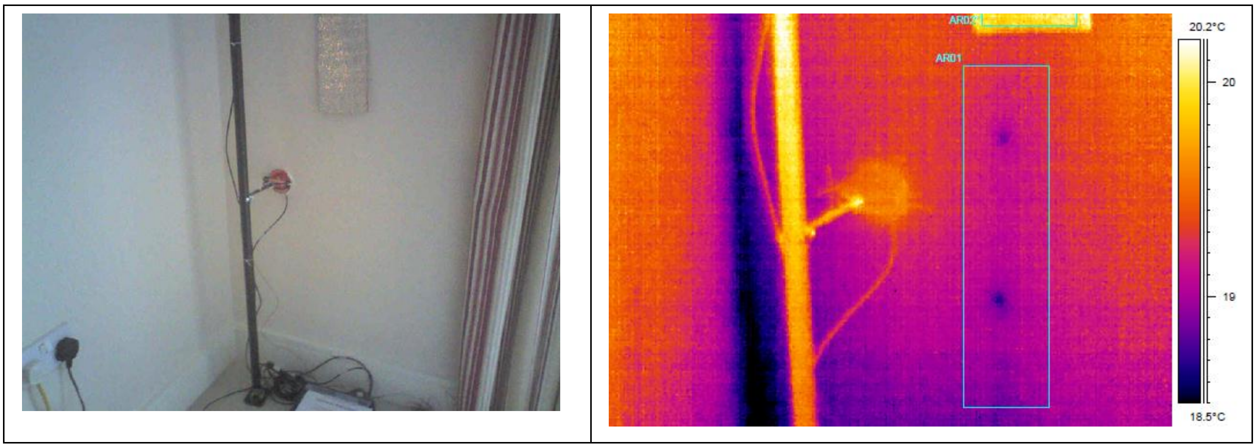


Figure 3.5: Thermography image of Flat showing potential cold bridging due to stud-wall fixings

External

No specific anomalies were identified on the external façade from the surveys carried out. As noted earlier, glazed sections provide some ambiguity when interpreting fabric performance, which is prevalent for Norfolk House. In addition, a high proportion of its opaque fabric consists of ventilated rain-screen cladding, which further renders the external survey ineffective.

However, salient features remain evident in the survey in the form of higher recorded temperatures related to MVHR outlet vents above windows and some “open” windows as demonstrated in Figure 3.6.

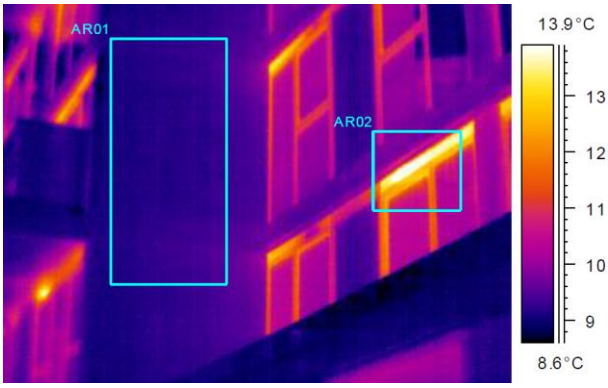


Figure 3.6: Thermography image showing heat loss (AR02) on the external façade of Norfolk House associated with the inlet/exhaust vents of the MVHR system

Figure 3.7 shows the thermography images of the underside of the Norfolk House flat balcony floor slabs. It can be seen that the surface temperature is higher at the interface with the external wall, indicating potential thermal bridging caused by the penetration of steel structure.

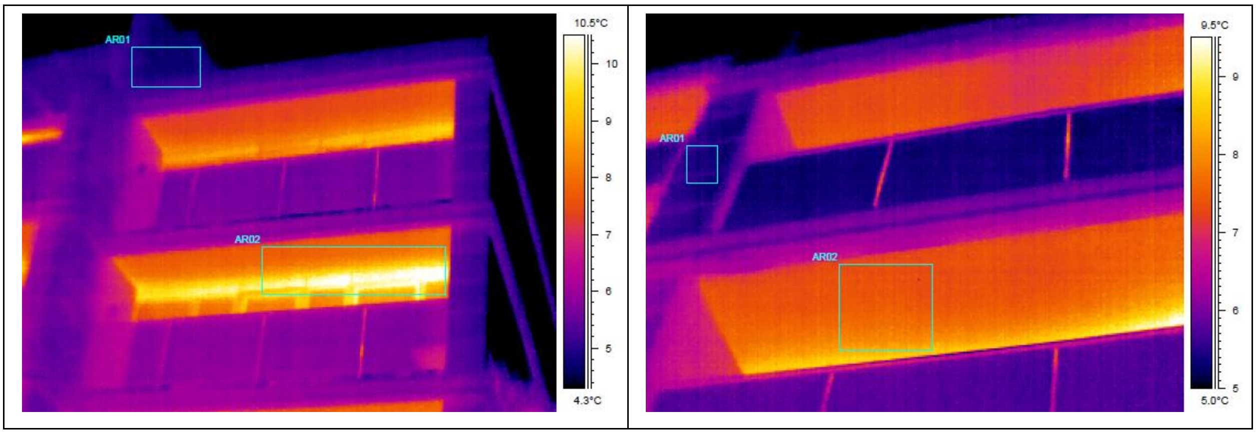


Figure 3.7: Thermography image showing heat loss (AR02) on the underside of the flat balcony floor slab of Norfolk House potentially by thermal bridging due to structural steel penetration at the façade.

3.7 Conclusions and key findings for this section

The key findings from this section can be summarised as follows.

- The initial and repeat air tightness tests undertaken as part of this study were 1-2 $m^3/(h.m^2)$ better than those undertaken for similar flats post construction. It would be interesting to compare the findings here across other TSB BPE studies. Potential causes of this difference include: (i) variations between flats (i.e. the flats tested previously were of the same type but different actual flats), (ii) different organisations undertook the two sets of air tightness tests and there may have been some differences in the methodology and the calibration of the equipment used and (iii) changes to the building fabric air tightness over time due to, for example, the building drying-out.
- Whilst the air tightness tests were all relatively low (<4 $m^3/h.m^2$), the smoke tests identified leakage paths and the potential for future improvement.
- The in-situ U-value tests were problematic with the data loggers recording limited or no data and stains left on the occupants' walls that needed to be rectified. We did receive one in-situ U-value measurement for a flat, although the data was only for four days instead of the intended two week

measurement and thus less accurate. It suggested that the actual performance is close to the design value (actual of 0.23 W/m²K versus design of 0.25 W/m²K)

- Infra-red thermography identified cold spots which highlighted potential areas of improvement for future construction. These were identified from internal measurements. Examples included: (i) colder areas at the top of “boxed-in” sections, perhaps covering pipe work with air leakage problems, (ii) cold bridging from large dabs behind the plaster board may be present, (iii) there is also some evidences of cold bridging due to penetration of stud-wall fixings.
- Gaining access to the properties takes careful organisation, particularly if wishing to visit multiple properties on the same date. It is dependent on the availability and willingness of the occupants. As such, it is important to be fully prepared before coming to site. Furthermore, sufficient time is needed for the setting up of domestic tests to ensure everything is working properly before leaving site. This is probably a greater issue in domestic than non-domestic studies. We particularly highlight the problems that the specialist contractor had issues with the data-logging equipment for the in-situ U-value testing which should not have occurred with sufficient advanced preparation and checking of the set-up on-site.

4 Key findings from the design and delivery team walkthrough

4.1 Introduction

A series of walkthroughs were carried out within the flats on 5th July 2013. These included walking through the flats with the occupants to discuss various features as well as additional time for inspection by the AECOM team. We did not include anyone from the design or delivery team both due to their accessibility and to avoid hassle to the occupants – but we have added some comments from Galliard Homes in response to their review of the report. Section 2 includes feedback from Galliard Homes regarding the design and construction of the development. Section 2 also includes information about the design intent, which provides useful context for the walkthrough.

The purpose of the walkthroughs was to explore and gain an understanding of the following key themes:

- How well does the occupant understand their flat? – How useful was the handover/training given to the occupant in the use of their flat?
- Are there any design and construction issues that are affecting the occupant's comfort and the energy performance of the flat?
- Aftercare - How easy is it for the occupant to resolve any problems with the flat that they may encounter?

Initially, one of the less detailed flats (Flat 21) was evaluated. Ian Mawditt, a specialist in Building Performance Evaluation, attended this visit to mentor the AECOM team. Following this, walkthroughs were undertaken within the 3 detailed flats by the AECOM team alone. Hence, the results below are based on the information on these four properties.

We are conscious that this is small sample of the flats. However, particularly issues common to the four flats are likely to be representative of all the flats in Norfolk House and potentially the Seager development in general.

Section 2 separately covers the walkthrough of the communal heating plant. Section 6 discusses in more detail installation, commissioning, maintenance and operation issues associated with the building services located in the flats. During the study, we were not able to engage with the design team. Ideally, it would have been useful both for us in gathering a further perspective of the findings from this project as well as helpful to the design team themselves to aid their learning for future developments.

4.2 Handover

A Home User Guide (HUG) and a Homeowner's Handbook (HH) were provided to occupants by Galliard Homes and Amicus Horizons (social housing provider) when they were handed the keys to the flats. They contain a comprehensive amount of information about the flat specifically and the development in general. Information is provided about the following:

- Access and security
- Acclimatisation (drying out of the home)
- Heating and hot water systems
- Electrical services
- Water services
- Health and safety
- Recycling and waste disposal
- Travel and the surrounding area
- Energy rating
- Aftercare
- Occupant rights
- Service charges

In general, no formal induction or training appears to have been provided to the occupants during the handover of the properties. Information provided was ad-hoc and inconsistent e.g. some reported that they were provided with an explanation of the heating controls whilst others reported that they were simply given the HUG and HH.

The occupants highlighted that they would have liked some more detailed face-to–face orientation of their flats and an explanation about how things work. While a large amount of useful information was provided in the HUG and HH, they did not provide some practical information – for example how to operate the MVHR unit (e.g. to activate the boost function), or the maintenance requirements of the MVHR unit and the Heat Interface Unit (HIU), including who actually maintains the equipment.

4.3 Design and Construction issues that may affect occupant comfort and energy performance

4.3.1 Ventilation

The following points were noted.

- The MVHR ventilation system installed was confirmed to be the same as the as-constructed SAP (Nuaire MRXBOX95).
- Occupants did not receive an explanation about the MVHR system and its function in the flats.
- Occupants were not told that the MVHR operates continuously and will draw electricity for operation, which the occupants will be paying for in their electricity bills.
- Occupants were not told about the boost function in the MVHR, its purpose and how to operate the boost function. It was found during the walkthroughs that the boost function for the whole flat could be activated in one of two ways – either via a switch located in the kitchen labelled “extract fan” or by switching on the bathroom light. Indeed, it was noted that in Flat 1, the MVHR was permanently left on boost as the occupant had not realised the purpose of the kitchen extract fan switch.
- The occupants were not advised on the importance of the maintenance of the MVHR filters or of the kitchen extract filter (cleaning of grease filter and changing of carbon filter) to ensure the performance and the lifespan of the unit.

4.3.2 Heating system

The following points were noted.

- All occupants found the space heating system effective in keeping their flats comfortable in the winter.
- The supply for hot water was found to be satisfactory by all occupants. They found the supply to be instantaneous and at adequate temperatures.
- All occupants found the heating controls to be confusing to setup and operate. The occupants found the instruction manual provided in the welcome pack to be confusing. Only occupants in Flats 2 and 21 attempted to interpret the instruction manual and adjust the heating settings on the control interface. The occupants in Flat 1 and 3 simply manually regulate the heating as they do not understand how to operate the control interface. [Feedback from Galliard Homes was that the selection of the heating controller is, in some cases, matched with the supply of the HIU and its controls. Galliard Homes do wish to keep the controller/thermostats as simple as possible. The old-fashioned ‘ACL’ type room thermostat controller is the one that people seem to understand most readily].
- All occupants raised the issue of being offered a heating tariff prior to moving in and subsequently subjected to a higher tariff after moving in. The occupants have all filed complaints to Amicus. After negotiation with Amicus, the tariff reverted back to the original tariff offered to the occupants.
- Occupants found that the tariff is still quite high due to the facility charge payable on top of the standing charge and the charge for heat consumed. For one occupant, the facility charge for the latest quarter is higher than the amount to be paid for the heat used.
- The occupant in Flat 21 felt residents should be allowed to physically see the heat meter installed within the HIU to better understand their heat consumption and how much they are spending on their heating bills. The current policy from Amicus is that residents are not allowed to access or otherwise

tamper with the HIU in any way. {Feedback from Galliard Homes was that they have heat meters installed on the wall adjacent to the HIU on other projects and it is simply a manufacturer design feature that the heat meter in this case is within in the HIU casing}.
- In general, there were no complaints regarding the reliability of the heat supply. There were several days when the communal heating system went down (in October 2012) and occupants went without heat (space heating and hot water). Galliard Homes/ Amicus were swift in resolving this and there have not been any problems reported since regarding the heat supply[1].

4.3.3 Lighting system

The following points were noted.

- The on-construction SAP showed 100% low energy lighting. This was typically borne out during the walkthroughs. In general, energy efficient lighting has been installed in the surveyed flats, with mainly compact fluorescent lamps used throughout, whilst LED lamps have been used in some parts of the flats, e.g. bathroom.
- In general, the occupants have not had any significant problems with the lighting installed in their flats. The occupant in Flat 1 had to contact Amicus to replace the faulty down-lighter in the bathroom. The occupant in Flat 2 replaced the original ceiling light fitting in the living room with ceiling flushed light fittings for aesthetic reasons.

4.3.4 Fabric and fenestration

The following points were noted.

- Feedback from the occupants is that the general construction quality is good. The occupant in Flat 1 has been particularly satisfied with the quality of both thermal and acoustic insulation in the flat.
- Minor issues were identified by AECOM during the walkthrough:
    - Some of the seals along the balcony door in Flat 1 and 21 have started to frail at the joining, example shown in Figure 4.1.
    - Significant cracks were found on Flat 3 between the window-wall interfaces as shown in Figure 4.2. Amicus Horizon has highlighted that cracks are likely to occur in some flats due to the building settling in post-construction.
    - All occupants complained about the windows and door being flush to the ceiling, as shown in Figure 4.3, making the fitting of blinds or curtains both difficult and expensive. In addition, AECOM noted the tight space at the top of windows would restrict air flow for ventilation when the windows are opened in a bottom-hung fashion. This could potentially affect both the amount of purge ventilation and means to control any overheating.

[1] Post the walkthrough, the gas boilers both failed over the Christmas holiday period in 2013. Due to the CHP and the biomass boiler being offline the residents had no heat or hot water for three 8-hour periods as temporary repairs were affected and then failed before being finally resolved. The problem was down to components on the boiler burners.

Figure 4.1: Balcony door seal, where the joints have started to fail, which would compromise the air-tightness of the property

Figure 4.2: Cracks found in Flat 3 at the wall interface with the windows

Figure 4.3: The narrow gap available between the windows/doors and the false ceiling, making the opening of fenestrations difficult and restricting ventilation

4.3.5 Other items

The following additional items were identified.

- In general, internal door undercuts were found to be around 4-5mm. This is less than the 10mm gap recommended by Approved Document F to allow air transfer between rooms. As the flats are mechanically ventilated such that the air is 'forced' around the home, this may be acceptable.
- All occupants surveyed were not aware of the location of the mains water stop-cock in their flats. Some were not even aware one existed. The occupant in Flat 2 highlighted a stop-cock was not initially installed in the flats by contractors, which led to the delay in handover to allow time for contractors to retrofit them.
- The survey found that the stop-cock is located in the ceiling void, accessible via a hatch in all the flats.
- A smart meter display console communicates with the corresponding fiscal meter located in the central cores. This can be used to inform occupants of their energy use as a basis for promoting energy use awareness and to stimulate behavioural change. Occupant in Flat 21 has been constantly monitoring the flat's energy use and attempting to adjust behaviour to save energy.
- There were no instructions for the entry phone. Hence occupants only learnt how to operate the basic function via trial and error.

4.3.6 Aftercare

Occupants interviewed during the walkthrough were all not aware of any maintenance contract relating to the MVHR unit. The user guide recommends that the unit is professionally inspected and filter replaced every 12-18 months and it claims to be 'fit and trouble free use'. From brief discussions with the occupants it appears they were unaware that filter replacement is required or whose responsibility it is to do this.

Responses by Amicus during the defects period have been reported by occupants to be generally swift; however, no occupants have had any experience to comment on yet for responses post-defects period, which all the flats surveyed have run into.

4.4 Conclusions and key findings for this section

The walkthroughs have enabled some aspects to be assessed in more detail to form a more comprehensive picture of the building construction, handover process, occupant comfort and system functions and usability. The key findings are summarised as follows

- There was no structured handover process. The usefulness of the Home User Guide has been somewhat limited.
- Some occupants have not been fully aware of the existence of some systems or technology in their dwelling, e.g. the MVHR, as well as what the systems do or how to operate them.
- The communal heating has been meeting the heat requirements of the occupants surveyed.
- The increase in heat tariff compared to that expected prior to moving into the flats was a contentious issue for the occupants, which has now been resolved. However, some occupants do find the facility charges high compared to the charge for the actual heat used. [Galliard Homes noted that they have investigated the Tariff calculations fully now and have established that the changes in rates were due to the 3rd Party Billing Agency using estimated gas bill values erroneously].
- The overall build quality of the flats is of acceptable standards apart from some shortfall found in Flat 3
- The narrow gap between the windows and the false ceiling of all flats makes the opening of fenestrations difficult and restricts ventilation
- The aftercare services have been generally very good by Amicus and Galliard Homes during the defects period
- Occupants were unclear and unaware of the maintenance regime for the MVHR as well as the kitchen extract.

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

5.1 Introduction

Two waves of surveys were conducted. In total, 27 responses were received which is just under 50% rate of return from of a total 58 flats.

- In the first wave, questionnaires were sent out on 2nd October 2013 to every flat in Norfolk House either directly from AECOM for flats already in the study or via Amicus Horizon for the others. This resulted in 16 responses.
- To increase the response, AECOM and Amicus Horizon staff approached residents in person on 26th November 2013 to conduct the survey. This resulted in an additional 11 responses.

In discussion with TSB, only the 11 surveys from the second wave of survey could be used to carry out the analysis as they were captured at the same time (guidance could have been clearer in advance). The results below are based on this data. Further detail is provided in separate documents supplied by Arup.

The respondents comprised a mixture of male and female occupants typically over the age of thirty. The flats are largely single occupancy or couples and a mixture of new and longer term residents who are usually at home in the evening and at weekends. It is important to note that these results represent a small proportion of the residents and this is a 'snap-shot' of views of resident perceptions.

5.2 Summary of environmental findings

The summary of the environmental results are illustrated in Figure 5.1. This is a summary chart distilling the analysis into 10 overall variables. The data collected is compared against a database of responses (benchmarks) and acceptable levels of performance resulting in the traffic light colour coding for each data point. It is noted that the colours are either green or amber (cautionary) ratings with no red ratings. The fact that amber rating is shown for 6 of the 10 variables suggests that there may be opportunities for improvement.

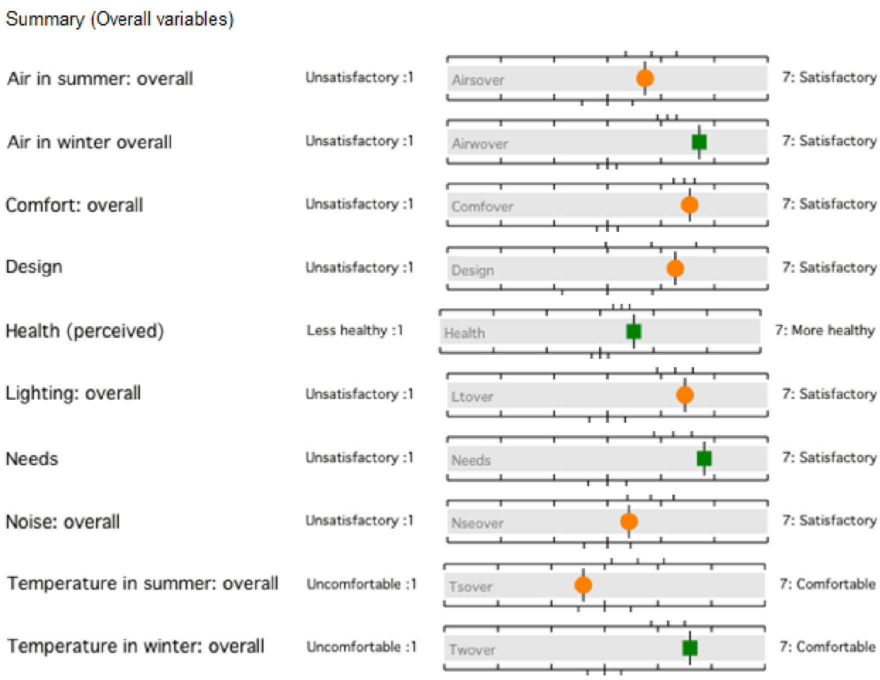


Figure 5.1: Overall variables summary

5.3 Further analysis of environmental findings

Many of these overall variables are a summary of multiple individual variables. We present this greater detail below, particularly where the overall rating is amber.

Figure 5.2 shows the more detailed results for the space temperature. Interestingly, whilst the overall temperature in summer was amber the individual space temperatures results in summer were red. The results suggest that the occupants perceived the flats to be too hot which aligns with the temperature measurements during the first summer in the three most detailed apartments. We note in Section 6 that the MVHR units do not appear to have a summer bypass capability and the ventilation rates were lower than designed. See also comments below regarding the control of cooling.

The variability in temperature was also red, although we do note that the results are still relatively close to the average of the scale and only just above both the upper range of benchmark data and what is judged to be acceptable. In contrast, space temperatures in winter appear to be relatively comfortable overall.

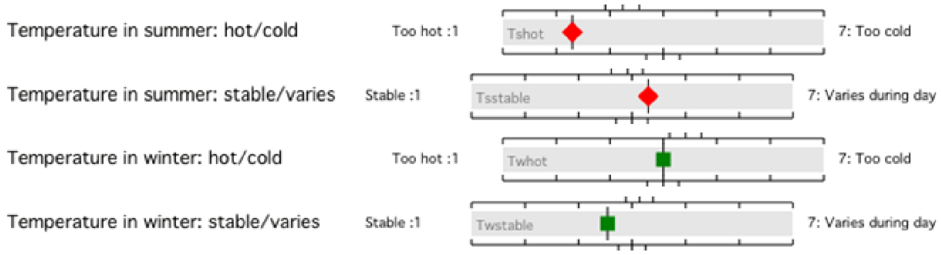


Figure 5.2: Temperature variables results summary

The survey of air conditions is shown in Figure 5.3. The occupants particularly rate their airflow as being still in summer and winter as well as the air being quite dry during the winter. We note in Section 6 that the mechanical ventilation systems in the flats tested delivered lower flow rates than recommended by Part F of the Building Regulations which may contribute to these ratings.

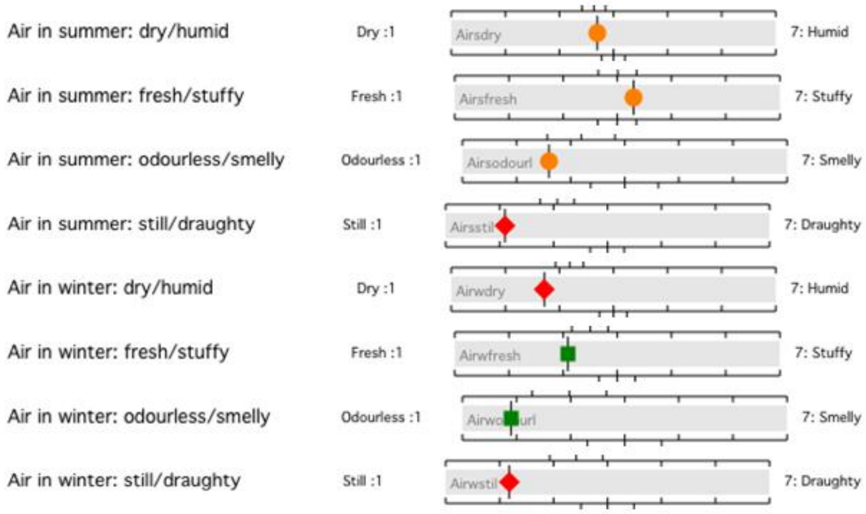


Figure 5.3: Air quality results summary

The graphs in Figure 5.4 show that residents tend to perceive that there is too much artificial lighting used in their flats. It is difficult to interpret these results as whilst the rating may be above the upper range of the benchmark data, the results are still fairly close to the average point on the range. It is unclear from the data returned by Arup why such a level should be considered as of concern.

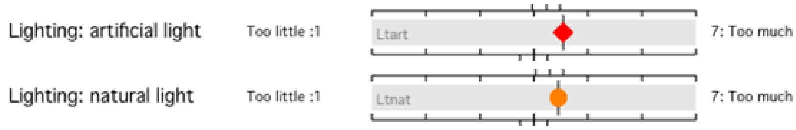


Figure 5.4: Lighting provision results summary

More detailed data with regards to the acoustics is given in Figure 5.5. In particular, the results suggest there is too little noise from neighbours and from other people. Again, it is important to take care in interpreting these results. It is unclear why such a score results in a red rating - the ratings are not excessively low. It is noted that in this study we have not measured the noise between properties, and minimum requirements are subject to Building Regulations. It is possible that the occupants' judgements were based on noise levels in previous homes which were less well acoustically insulated than currently.

The relatively high external noise rating may reflect previous feedback from several residents who have indicated that external sounds could be excessive at times, particularly for ones overlooking the busy Brookmill Road traffic and a nearby community centre, when their windows or balcony doors are open (the sound proofing has proven to be very effective otherwise). The noise originating from the construction of other phases around the site, which has ceased to be an issue at the time of reporting, may still affect current perception.

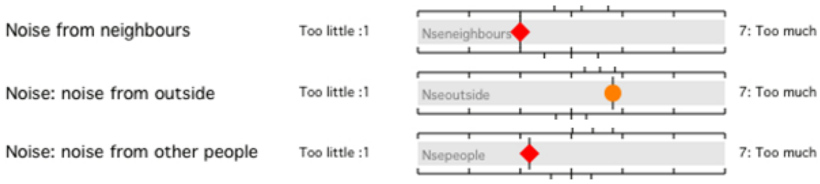


Figure 5.5: Noise results summary

Figure 5.6 shows occupant's perception of their control over the environment. In particular, it suggests that residents have insufficient control of cooling. This response may well link to the previous feedback on overheating during the summer. More so, it may link to issues raised on external noise and residents may be unwilling to leave windows open. It is not fully why the other responses are amber. In particular, there is an amber rating as a result of residents having a high-level of control over their ventilation.

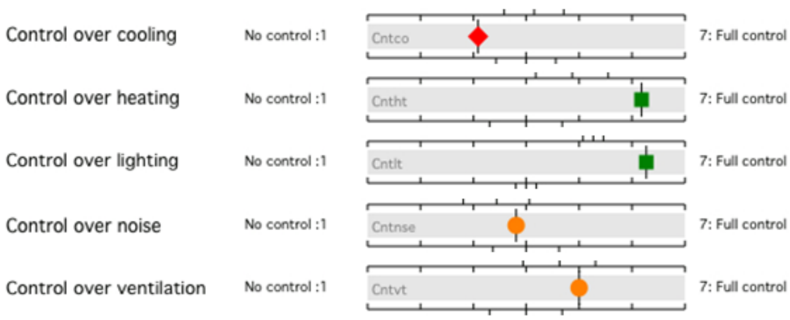


Figure 5.6 – Control levels results summary

Figure 5.7 summarises the survey of the overall the design of the dwelling itself and how this meets the residents' requirements. It suggests that residents are reasonably content.

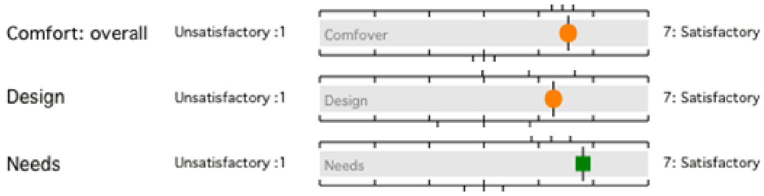


Figure 5.7 – Summary of design/needs

5.4 Summary of utility costs

Figure 5.8 showed that residents felt they are paying much more for their heating compared to their previous homes/suppliers. Comments received from residents included “Cost for hot water very high, cannot change supplier”, “Now have to switch off heating completely for fear of being sent a bill which can’t be explained” and “Communal heating rather than individual boilers is not good - very expensive and unreliable”. This aligns with issues of high heat tariff identified in the walkthrough of flats.

Whilst not shown there, the costs for electricity and water were rated as being similar to what the residents paid previously.

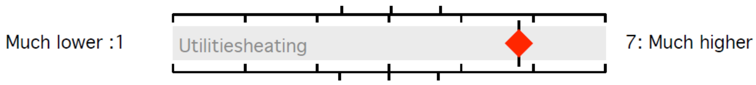


Figure 5.8 – Heating costs chart

5.5 Conclusions and key findings for this section

The BUS survey is based on a small sample of 11 surveys. A further 16 responses had to be excluded. Better guidance by TSB would have helped here. A summary of the key points identified are given below.

- The different overall aspects of the environment were rated as acceptable or cautionary. The latter suggests that there may be opportunities for improvement.
- The space temperatures in summer were perceived as being too hot. This aligns with temperature measurements during the first summer of the study in the three most detailed apartments. We note in later that the MVHR units do not appear to have a summer bypass capability and the MVHR units had a lower ventilation rate than designed.
- Residents perceive that they have insufficient control of cooling. This may relate to issues of external noise and potentially unwillingness to open windows to reduce the temperature.
- Residents rate their airflow as being still as well as the air being quite dry during the winter. This may be partly explained by tests which showed that the mechanical ventilation systems in the 3 detailed flats delivered lower flow rates than recommended by Part F of the Building Regulations.
- Residents tend to perceive that there is too much artificial lighting used in their flats.
- The results suggest there is too little noise from neighbours and from other people. The occupants’ judgements may be based on noise levels in previous homes which were less acoustically insulated.
- The results suggest relatively high external noise levels. Thus may reflect previous feedback from several residents who have indicated that external sounds could be excessive at times, particularly for those overlooking the busy Brookmill Road traffic and a nearby community centre, when their windows or balcony doors are open. The noise originating from the construction of other phases around the site, which has ceased to be an issue at the time of the survey, may still affect current perception.
- Residents felt that they are paying much more for their heating compared to their previous homes/suppliers. This aligns with feedback by residents during the walkthroughs of high heat tariffs.

Overall, we suggest care needs to be taken in interpreting the amber and red ratings. In particular the range of acceptable levels to achieve a green rating appears quite narrow in some cases. Furthermore, the implications of the ratings are unclear e.g. an amber rating was achieved as a result of a high level of control over the ventilation system – it is unclear why such a high level of control is a bad thing for residents.

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

6.1 Introduction

Installation and commissioning checks were carried out in the three detailed flats (Flats 1 to 3) and one of the less detailed monitored flats (Flat 21). The purpose was to assess the installed systems on aspects relating to their installation, operation, maintenance, performance and energy use. These systems are:

- Mechanical supply and extract ventilation system with heat recovery (MVHR)
- Heating system for space heating and hot water provision
- Lighting system

In general, the information was collected during the walkthroughs described in Section 4. In addition the performance of the ventilation system was tested for Flat 2 and 3 on 15th July 2013 and for Flat 1 on 22nd July 2013.

6.2 MVHR

The MVHR unit installed in the flats is the mrxbox95 model by Nuaire as shown in Figure 6.1. The MVHR is used to provide fresh air supply into the living room and the bedrooms, tempered via heat recovered from return air extracted from the kitchen and bathroom. The MVHR unit is capable of a normal and boost operation with a manufacturer specified heat recovery effective of up to 95% (not tested in this project). Both the supply and extract air are filtered.

Figure 6.1: The installed MVHR unit in one of the Flats

Installation/workmanship

- All MVHR boxes were installed too high into the false ceiling to allow the full use of rigid ducting. Flexible ducts were required for ease of installation between the four spigots on the MVHR box and the rigid ducting in the false ceiling. This is shown in Figure 6.2 and is consistent with as-installed drawings for all the flats surveyed. Flexible ducting was also used to connect to the supply and extract terminals. Whilst the use of flexible ducting in these cases is acceptable, we were not able to view the ceiling voids to confirm that rigid ducting was used throughout the rest of the system (although we could see that the flexible ducting from the spigots did connect into rigid ducting in the ceiling void).
- All MVHR units sit on a mounting bracket, which allows the units to be reasonably supported. However, one unit was found not permanently secured, which may lead to it coming off the wall if severely knocked off its bracket. This could damage the connection with the flexible ducting and potentially cause injury to occupants.

- Installing on the side wall of the airing cupboard makes operational adjustments more difficult to carry out on the unit as the view of the adjustment screws and LED indicators is at a slightly obscured angle.
- There is generally acceptable fall from the MVHR condensate outlet to the tundish.
- All MVHR units were installed in the airing cupboard located in the centre of the flats leading to the need for long ducts from the inlet and outlet grilles on the external wall façade to the MVHR box.
- The cap on most supply and extract ceiling terminals was not locked in place or sufficiently tightened. The cap is rotated to achieve the desire flow during commissioning. Potentially the occupant could rotate the cap and affect the commissioned flow settings.
- The location of all of the supply and extract ceiling terminals were found to be consistent with the as-installed drawings provided apart from the extract terminal in the kitchen, which appear to all been fitted slightly further away from the cooker hob than suggested on the drawings.

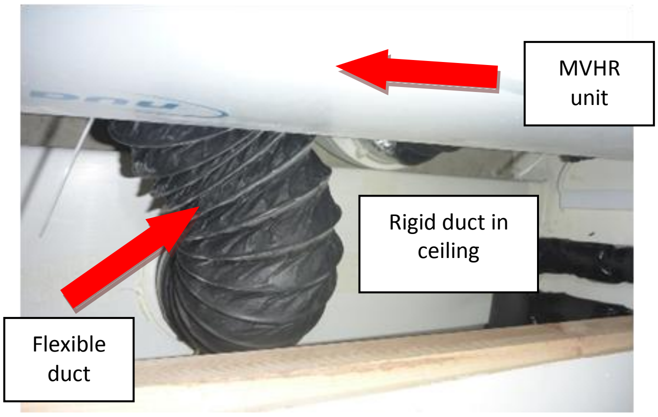


Figure 6.2: Flexible duct used to connect the MVHR spigots to the rigid ducts in the false ceiling (the photo was taken looking upwards)

Operation

- The MVHR unit has three screw-adjustable potentiometers to regulate its normal and boost operation ventilate rates and the duration for the boost mode respectively. Prior to the handover of the flats to its occupants, the MVHR unit is commissioned by contractors to settings suitable for the respective flats. Thereafter, these settings should not be changed. In order to prevent this, caps over these potentiometers (screw caps) should be provided to prevent tamper. However, most of the commissioning screws were found exposed, and not covered with screw caps.
- There were generally no reports of noise issues with the MVHR units during normal and boost operation. However, the MVHR unit in Flat 21 was found to be excessively noisy during normal operation with air rushing out of the supply terminal and subsequently the issue of cold draught. This could, for example, have been due to a dislodged filter or worn bearing. The cause has not been confirmed by AECOM due to restriction to getting into the unit for inspection. The noise has prompted the occupant to intervene by using a screwdriver to turn down the MVHR speed, which would have affected the commissioned setting as a result.
- There is a power switch to turn off the MVHR unit located next to the consumer unit in the airing cupboard, which will be useful when maintenance of the unit is being carried out. However, it was found that the power switch did not seem to work for Flat 1, which may have been by-passed.
- The boost operation can be operated via a switch amongst the kitchen switch bank labelled 'extract fan' or via turning on the bathroom light. This will keep the MVHR on the boost mode as long as the switch is turned on. This may lead to energy waste if the occupant is unaware of the purpose of the switch. This was actually the case with occupant in Flat 1, who has left the switch permanently turned on. We note that perhaps a rocker switch would be a better alternative and/or better instruction or labelling of the switch. Figure 6.3 shows the boost switch in the kitchen, left permanently 'on' prior to intervention during the survey.
- There does not appear to be any summer bypass facility incorporated into the MVHR system, which could potentially contribute to summertime overheating.

- The boost capability in Flat 2 has only been operating via the kitchen extract fan switch and not the bathroom switch. This is despite an engineer visiting to repair the MVHR, during which the filters were also changed. This may have contributed to the occupant's complaints of condensation (e.g. not using boost during bathing).

Figure 6.3: The switch gang in the kitchen where the switch for MVHR boost is located, labelled as 'extract fan'

Maintenance

- The placement of the MVHR unit part way into the false ceiling may make accessibility for repairs, maintenance and cleaning difficult. In some flats, it also requires the removal of false ceiling when the opening of the MVHR front panel is required for filter change (see Figure 6.4).
- We reviewed the filter in Flat 1 and this does not appear to have been changed or cleaned since the start of occupancy as the filters were quite dirty (see Figure 6.5). We do note that Flat 2 has had its filter changed as they reported problems with their ventilation system.
- Inlet and outlet grilles on the external side wall were observed to be generally clogged up with dust. The location of the grilles does not appear to allow easy access for cleaning. For some flats, the grilles are placed on the side of the flat where access is only through the use of a cherry picker, whilst others have the grilles on the balcony side, which will facilitate access to the grilles. Furthermore, it appears difficult to remove the insect grille mesh for cleaning. Please see Figure 6.6.
- The MVHR unit works in conjunction with a recirculating extract hood in the kitchen, which is fitted with a grease filter and fan cover integrated carbon filter. The extract hood extracts air through the filters and re-introduces the air back into the kitchen space through its vents near the ceiling. There is a risk of the MVHR extract cooking air into its filter when the extract hood is not used or its filters are not effectively maintained. This will tend to require more frequent maintenance and filter change/clean of the MVHR unit itself. From observation during the survey, none of the cooker hood filters appeared to be regularly maintained (i.e. they were dirty). Occupants were unaware when told about the need for regular maintenance of the grease filters.

Figure 6.4: The constraints with opening the MVHR front panel due to placement of the unit part way into the false ceiling

Figure 6.5: The MVHR extract side filter showing the difference between before and after cleaning, illustrating the extent of dust clogging up the MVHR at the time of the survey.

Figure 6.6: The MVHR inlet grille insect mesh heavily clogged up with dust. There is no clear way to remove the mesh for cleaning apart from via vacuum cleaning

Performance and energy use

- BSRIA tested the air flow of the MVHR units. AECOM supplied energy use data during the tests to determine the specific fan power. This is discussed further below.
- The air quality in the flats has been reported by the occupants to be generally good, with very little need to have the windows open for added ventilation. However, the occupant in Flat 2 regularly opens windows for more fresh air as a personal preference. The occupant also reported that the ventilation felt inadequate at times with humidity from the bathroom taking considerable amount of time to be removed. Flat 2 and 21 reported having condensation issues during the winter period on the large windows and glazed balcony door. We note above that the boost function for Flat 2 does not appear to operate via the bathroom switch as intended.
- Further details of the MVHR energy use from sub-metering is given in Section 7.

BSRIA MVHR test

The BSRIA MVHR test results are presented here and the BSRIA report provided in a separate Annex. We include additional interpretation by ourselves here.

Measurements of the MVHR supply and extract rates were carried out on both the normal and boost ventilation modes. This was done at the terminals on the ceiling in the flats. Measurements to verify the volume air flow through the system in each dwelling were carried out in accordance with the guidance in BSRIA Guide BG46/2013, Domestic Ventilation Systems, A Guide to Measuring Air Flow Rates.

An *Observator DIFF* air capture hood was used to measure the air volume from the supply and extract terminals in the flats, by fully enclosing the terminals with the inlet hood of the instrument. This instrument has a built-in fan and pressure compensation facility, with an accuracy of ±3% of reading ±1m^3/h.

In Flat 1, measurements were carried out for the “as-found”, “clean” and simulated “50% blocked” filter conditions. Due to accessibility, measurements in Flat 2 and 3 were for only an “as-found” filter condition.

Results from Flat 1

This test took place on 22nd July 2013. Figure 6.7 shows the "as-found" condition of the two filters. The filter on the right filters the extract air from the flat, where it was heavily clogged up with dust. The cleaner filter on the left filters the intake air from outside. Figure 6.8 shows the impact of partially cleaning the extract filter using a vacuum cleaner on-site. The extract filter was fully cleaned with the vacuum cleaner for the "clean" test. To carry out a simulated blocked filter, tape was wrapped around half of each of the filters to achieve a "50% blocked filter" test (see Figure 6.9).

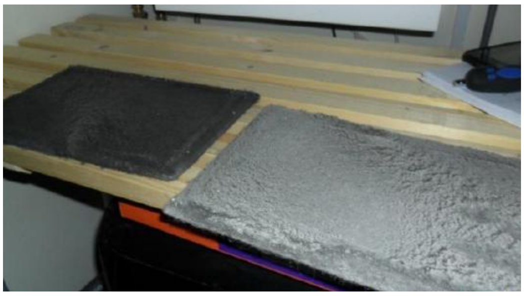


Figure 6.7: The filters for the supply and extract side of the MVHR unit in Flat 1

Figure 6.8: The extract side filter partially cleaned to illustrate the before-after change

Figure 6.9: Tape being placed across 50% of the filter to simulate a 50% blocked filter

Table 6.1 summarises the test results under the three different test conditions. The extract flow rates, in particular, significantly increase with the extract filter cleaned. There is a smaller reduction with 50% of the filter blocked. Given the significant difference between the "50% blocked filter" and the "as-found" results, it does question how well the "50% blocked filter" test represents a dirty filter. The normal supply rate approximately achieves the commissioning data for all three tests. The clean and 50% block filter extract overall achieve the commissioning data results and the clean filter approached the boost commissioning results. This does suggest that with new filters, the results may well achieve the commissioning test data.

Approved Document F 2006 recommends that the minimum normal ventilation rate of a dwelling with one bedroom should:

- Not be less than 13 l/s
- Not be less than 0.3 l/s per m^2 of internal floor area. The floor area of this flat is 45 m^2 and thus this equates to 13.5l/s

The commissioned test data delivers 13 l/s which appear to account for the first recommendation but not the second (although both recommendations are close).

Note that Approved Document F 2006 allows the designer to take account of the air leakage of the property in determining the normal ventilation rate for MVHR systems. Using the formula in Approved Document F, it can be assumed that 4l/s of the normal ventilation rate arises from air leakage. However, this allowance is not appropriate for such an airtight property which was measured by BSRIA to be 2.4 $m^3/hr/m^2$ @ 50 Pa.

Approved Document F 2006 recommends a boost rate for MVHR of 13l/s in the kitchen and 8l/s in bathroom and 6 l/s in toilets. This concurs with the commissioned data.

Table 6.1: Flat 1 measured MVHR flow rates compared against commissioning data

	Flat 1							
	BSRIA measured (l/s)						Commissioning data (l/s)	
	"As-found"		"Clean"		"50% blocked filter"			
Location	**Normal**	**Boost**	**Normal**	**Boost**	**Normal**	**Boost**	**Normal**	**Boost**
Living room	7.2	10.3	7.8	10.5	7.3	10.0	7	No data
Bedroom	5.5	7.5	5.5	7.7	5.3	7.0	6	No data
TOTAL SUPPLY	12.7	17.8	13.3	18.2	12.6	17	13	No data
Bathroom	-7.7	-9.8	-8.9	-13	-8.4	-12.3	-7	-13
Kitchen	-2.8	-4.8	-4.5	-6.0	-4.7	-5.5	-6	-8
TOTAL EXTRACT	-10.5	-14.6	-13.4	-19	-13.1	-17.8	-13	-21

Results from Flat 2

This test took place on 15th July 2013. No access into the MVHR and its filters was possible, hence only "as-found" filter condition was tested, under normal and boost mode. Table 6.2 shows the air flow rates measured, which are all below the commissioning data. It is not possible from this data to determine whether clean filters would have achieved the commissioned test results.

Table 6.2: Flat 2 measured MVHR flow rates compared against commissioning data

	Flat 2			
	BSRIA measured (l/s)		Commissioning data (l/s)	
Location	**Normal**	**Boost**	**Normal**	**Boost**
Living room	1.9	2	7	No data provided
Master bedroom	2.4	3.8	6	No data provided
Bedroom	3.3	4.4	-	No data provided
TOTAL SUPPLY	**7.6**	**10.2**	**13**	**No data provided**
Bathroom	-3.6	-4.6	-7	-13
Kitchen	-5.2	-6.4	-6	-8
TOTAL EXTRACT	**-8.8**	**-11**	**-13**	**-21**

Approved Document F 2006 recommends that the minimum normal ventilation rate of a dwelling with two bedrooms (Flat 2) should:

- Not be less than 17 l/s
- Not be less than 0.3 l/s per m^2 of internal floor area. The floor area of this flat is 74 m^2 and thus this equates to 22.1l/s

The commissioned test data shows the system delivers 13 l/s, which is below both recommendations.

Note that Approved Document F 2006 allows the designer to take account of the air leakage of the property in determining the normal ventilation rate for MVHR systems. Using the formula in Approved Document F, it can be assumed that 7l/s of the normal ventilation rate arises from air leakage. However, it is questionable whether this allowance is appropriate for such an airtight property which was measured by BSRIA to be 3.2 $m^3/hr/m^2$ @ 50 Pa.

Approved Document F 2006 recommends a boost rate for MVHR of 13l/s in the kitchen and 8l/s in bathroom and 6 l/s in toilets. This concurs with the commissioned data.

Results from Flat 3

This test took place on 15th July 2013. No access into the MVHR and its filters were possible, hence only "as-found" filter condition was tested, under normal and boost mode. Table 6.3 shows the air flow rates measured, which are all below the commissioning data. It is not possible from this data to determine whether clean filters would have achieved the commissioned test results.

Table 6.3: Flat 3 MVHR flow rates measured against commissioning data

	Flat 3			
	BSRIA measured (l/s)		Commissioning data (l/s)	
Location	**Normal**	**Boost**	**Normal**	**Boost**
Living room	4.6	10	7	No data provided
Bedroom	4.9	10.9	6	No data provided
TOTAL SUPPLY	**9.5**	**20.9**	**13**	**No data provided**
Bathroom	-3.7	-7.6	-6	-8
Toilet	-3.2	-9.9	-4	-6
Kitchen	-3.7	-6.8	-7	-13
TOTAL EXTRACT	**-10.6**	**-24.3**	**-17**	**-27**

Approved Document F 2006 recommends that the minimum normal ventilation rate of a dwelling with one bedroom (Flat 3) should:

- Not be less than 13 l/s
- Not be less than 0.3 l/s per m^2 of internal floor area. The floor area of this flat is 63 m^2 and thus this equates to 18.9l/s

The commissioned test data shows the system delivers somewhere between 13 and 17l/s which appear to account for the first recommendation but not the second.

Note that Approved Document F 2006 allows the designer to take account of the air leakage of the property in determining the normal ventilation rate for MVHR systems. Using the formula in Approved Document F, it can be assumed that 6l/s of the normal ventilation rate arises from air leakage. However, it is questionable whether this allowance is appropriate for such an airtight property which was measured by BSRIA to be 3.6 $m^3/hr/m^2$ @ 50 Pa.

Approved Document F 2006 recommends a boost rate for MVHR of 13l/s in the kitchen and 8l/s in bathroom and 6 l/s in toilets. This concurs with the commissioned data.

Specific Fan Power (SFP)

The MVHR fan SFPs for each flat are tabulated in Table 6.4. The SFP can be determined by taking the metered fan power consumption (W) and dividing by the corresponding flow rate (l/s) (maximum between the supply and extract rate) for the different operating conditions. This was calculated by taken the air flow rates measured by BSRIA during the tests with the energy use measured by AECOM at the same time. AECOM measured the time taken between three pulses on the MVHR sub-circuit, with each pulse being 0.5Wh.

Table 6.4: The MVHR measured SFPs for the Flats under the normal and boost operating mode

	"As-found" SFP		"Clean" SFP		"50% blocked filter" SFP	
	Normal (W/l/s)	**Boost (W/l/s)**	**Normal (W/l/s)**	**Boost (W/l/s)**	**Normal (W/l/s)**	**Boost (W/l/s)**
Flat 1	1.34	2.08	1.27	1.95	1.30	2.08
Flat 2	1.31	2.32	-	-	-	-
Flat 3	1.51	2.03	-	-	-	-

The results are fairly consistent. Based on results for Flat 1, the condition of the extract filter did not affect the MVHR SFP significant although it can be seen from Table 6.1 that the clean filter resulted in significant increase in extract flow rates. This was due to the much higher flow rate on the supply side, which predominantly determines the overall system SFP.

By comparison, Table 6.5 summarises the data used in the as-build SAP assessment for the flats. The measured MVHR SFP for all of the flats are higher than assumed in SAP by 120-130%. It is noted that the MVHR performance is tested in a laboratory using, for example, specific lengths and types of ducting. This may not be fully representative of what was actually installed in the flats. Some allowance is already made in SAP for differences between the laboratory and installation with a 40% uplift for rigid ducting and 70% uplift for flexible ducting but even this does not account for the difference in performance observed.

Table 6.5: Parameters used for the MVHR in the as-build SAP calculation for Flats 1, 2 and 3

	Mechanical ventilation type	**Normal mode SFP (W/l/s)**	**Heat recovery effectiveness**	**Ductwork type**
Flat 1	Balanced with heat recovery	0.59	92%	Rigid ductwork
Flat 2	Balanced with heat recovery	0.59	91%	Rigid ductwork
Flat 3	Balanced with heat recovery	0.68	91%	Rigid ductwork

Summary of results

- The air flow rates measured on the supply and extract terminal in Flats 1, 2 and 3 are below the figures reported in the commissioning certificates obtained from the Seager Distillery development O&M.
- The extract filter in MVHR unit of Flat 1 was very dirty and with this filter cleaned, the air flow rates approached those from the commissioning data. The (unseen) inlet and/or extract filters in the other two flats may also be dirty and, if cleaned, the commissioning test results may also be achieved.
- The commissioning of the MVHR and the certificate provided appears suspicious due to the identical results and errors in room details provided. Furthermore, the ventilation rate at normal conditions does not appear to achieve Part F recommended ventilation rates, at least for Flats 2 and 3.

6.3 Heating system

The heating in the flats is provided via a Hydraulic Interface Unit (HIU) installed in the airing cupboard, which regulates the supply of heat from the communal heating system on site to provide space heating and hot water (see Figure 6.10). The hot water is supplied through a circa 40kW heat exchanger, circulated on mains water pressure. Space heating is circulated around the flats to radiators using a rated 9-35W circulation pump. It is a closed pressurised system via an expansion tank in the HIU. The heat is regulated via an actuator controlled by the remote heating control panel located in the living room. In most cases the radiator heaters in the flats have been fitted with a TRV apart from one near the control panel.

Figure 6.10 An HIU with the metal encasement removed to show the internal pipework and components.

Installation/workmanship

- Flexible host union pipes on the HIU building side supply manifolds have been removed in most cases apart from one flat where whilst still attached, the isolation valves are engaged to close off the circuit. Whilst this did not pose an operational issue, the union pipe should have been removed as good practice.
- Not all pipes leading from the HIU have been insulated. Whilst insulated, some of the cold water feeds were not tightly insulated leading to a risk of condensation between the pipe and the insulation sheet.
- In Flat 21, where there are two radiators in the living room, the further one from the control panel has no TRV whilst the one nearer has been fitted with a TRV.
- There is no drain-cock, therefore when works are to be carried out on the HIU, a bucket will be needed to catch any water draining from the heat plates.

Operations

- Occupants generally found no issues with the heating system, although they found the control panel not user-friendly and the instruction manual confusing.
- The supply of heat has been consistent and meets instantaneous demands, apart from the several occasions of short disruptions.
- Temperature of hot water generated has been adequate and as expected.
- There are no noise issues associated with the operation of the circulation pump.
- No leakages from the HIU have been reported in the flats surveyed.

Maintenance

- There is a contract in place with Galliard Homes for periodic maintenance and servicing of the HIU to ensure good operation, for which residents pay a fee towards.
- There were several instances where supply of heat was disrupted; however, this was swiftly addressed and dealt with by Amicus Horizon and Galliard Homes and the supply was quickly restored

Performance and energy use

- The performance of the community heating system is assessed in Section 7.

6.4 Lighting system

Efficient lighting has been installed in the surveyed flats, with compact fluorescent and LED lamps used throughout. The kitchens are fitted the ceiling flushed light fittings, whilst corridors use pendant fittings. The lights are on two separate lighting circuits in the flats, arrangement of which differs slightly between the surveyed flats. There are also other standalone lights in the flats which use electricity from wall sockets.

Installation/workmanship

- In general, lights were flushed and tightly installed but there are some minor gaps in some installations which may lead to air leakage.

Operations

- All lights were working in the flats when surveyed; however, some issues were reported about bathroom mirror down-lighter by the Flat 1 occupant, which were swiftly replaced by Galliard Homes.
- In general, the positioning of light switches is ergonomical and allows intuitive and easy access to operate the lights in the flats.

Maintenance

- Minimal to no maintenance has been reported for the lighting in the flats surveyed; however, Flat 1 did have some minor issue with the bathroom down-lighter, which was swiftly dealt with by Amicus
- During the survey, it was found that dedicated LEL lamps were installed in the kitchen, which may be an issue for occupant, in terms of the replacement lamps may not be widely available and comparatively more expensive. So far, no occupants have had to replace these.

Performance and energy use

- Some occupants prefer to use standalone lighting in the living space, powered via wall sockets. Hence, these occupants did not necessarily use the provided ceiling lighting. Therefore, it will not be possible to accurately monitor the energy use from lighting in the flats and hence the associated energy consumption.

6.5 Conclusions and key findings for this section

Several issues were highlighted around the installation, maintenance and operation of the MVHR systems. In particular, we note the following here.

- One MVHR unit was not sufficiently secured to its mounting bracket which could lead to the MVHR unit coming off the wall if severely knocked off its bracket, damaging the connection with the ducting and potentially causing injury to occupants.
- The MVHR unit in one flat was found by the occupant to be excessively noisy during normal operation. The noise prompted the occupant to intervene by using a screwdriver to turn down the MVHR speed, which would have affected the ventilation rate achieved.
- The placement of the MVHR unit part way into the false ceiling may make accessibility for maintenance difficult. In some flats, it also requires the removal of false ceiling when the opening of the MVHR front panel is required for filter change. False ceilings were added retrospectively to conceal the ducting, which were perceived to be untidy and hence potentially an undesirable sight to residents. This then compromised accessibility to the MVHR for maintenance.
- We reviewed the filter in Flat 1 and this does not appear to have been changed or cleaned since the start of occupancy as the filters were quite dirty. As discussed elsewhere, the residents were not aware of the need to clean the filters and the process for doing so. Furthermore, inlet and outlet grilles on the external side wall were observed to be generally clogged up with dust - the location of the grilles does not appear to allow easy access for cleaning.

The MVHR systems at the commencement of our assessment all delivered lower flow rates than recommended by Approved Document F. The actual air flow rates based on the as-found conditions for Flat 2 and Flat 3 were 34% and 18% respectively below the Part F recommended ventilation rates, taking into account infiltration allowances which are likely overly generous given the high level of air tightness of the properties.. Furthermore, the commissioned rates in at least Flat 2 is lower than recommended by Approved Document F. Flat 1 achieved the commissioned rate, which was also approximately the air flow rate recommended by Approved Document F, upon cleaning the filters. Furthermore, the measured MVHR SFPs for all of the flats were higher than assumed in SAP by 120-130%. Finally, issues were also identified in terms of ease of access to the MVHR system to undergo maintenance. There are potential implications of these results as discussed in Section 7 including higher electricity usage and lower heat consumption. This may also impact on the BUS results as discussed in Section 5.

The heating system appears to have been well installed in the flats, which has been providing satisfactory supply of heat for both space heating and hot water. However, the controls were reported to not be user-friendly and two of the four occupants surveyed have resorted to manual operations.

The provision of artificial lighting in the surveyed flats is generally good, with good quality installation and use of low energy lighting throughout.

7 Monitoring methods and findings

7.1 Monitoring methods

7.1.1 Introduction

Our monitoring strategy was as follows.

- We selected three homes for the most detailed evaluation.
- We selected twelve homes, including the three detailed study homes, to provide further information on appliance energy use. This included one home in Distillery Tower.
- We selected twenty homes, including the three detailed study homes, to assess how representative the three homes were. All of these homes were in Norfolk House.
- We have assessed the efficiency of the communal heating system.

Details of the flat numbers used in the study and how they fit into the monitoring strategy are as below. These flat numbers are used for the purpose of this study and are no relation to the actual flat numbers.

Table 7.1: Flats taking part in each study

Study	**Flat numbers**
Detailed evaluation	1,2,3
Appliance energy use	1,2,3,6,9,20,21,22,23,24,25,26
Representative Analysis	1 to 20

7.1.2 Three Detailed Study Homes

Electricity metering

We sub-metered each electricity circuit with each flat. For each circuit we used a PRO1DE from Eltek, which is a Rayleigh direct connection DIN rail mounting secondary meter with pulsed output. We used a battery powered GD-68 transmitter from Eltek, which provided 8 x pulse inputs (for the different electrical circuits). Readings were wirelessly received and recorded at 5 minute intervals by a central RX250AL data logger from Eltek. Resolution of each circuit was 0.5 Wh (i.e. 1 pulse per 0.5Wh). In each apartment, there were 8 active circuits within each consumer unit, which were each monitored (see Table 7.2). Note that all components of the cooker were electric.

Table 7.2: a breakdown of sub-meter electrical circuits monitored based on the end-use categories in the Flats

End-use category	**Number of circuits**
Cooker in kitchen	1
Mechanical Ventilation with Heat Recovery (MVHR) unit	1
Heating controls (actuator and space heating circulation pump within the HIU)	1
Wall sockets, oven and extract hood	2
Ceiling and fixed lighting	2
Smoke alarm	1

There was insufficient space to install the sub-metering equipment within the existing consumer unit. This resulted in the need to install an additional consumer unit box in each apartment as shown in Figure 7.1.

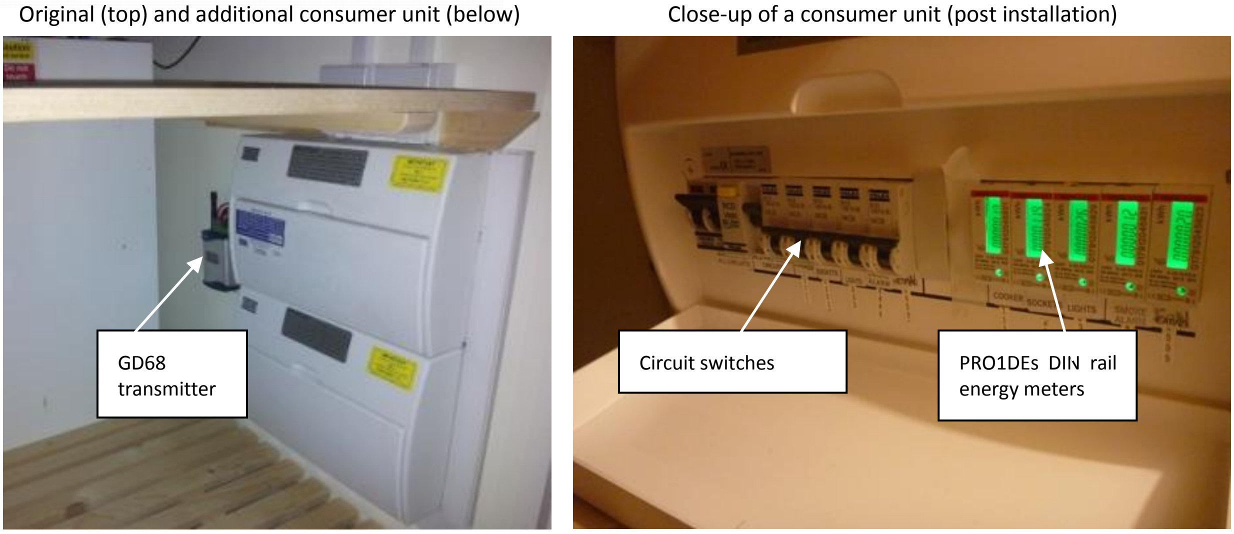


Figure 7.1: Photos of consumer units post-installation

The electricity provider did not allow us to connect to the main fiscal electricity meters and read the pulse outputs. We summated all the sub-metered circuits within the consumer unit to determine the total electricity consumption. For validation purposes, we periodically compared the manual readings from the main electricity meters with the accumulated total from the sub-meter readings.

Heat metering

For this study, we replaced the original heat meter, which gave a radio signal, with the same model but with a pulsed output. The heat meter is one component in the heat interface unit (HIU) – see Figure 7.2.

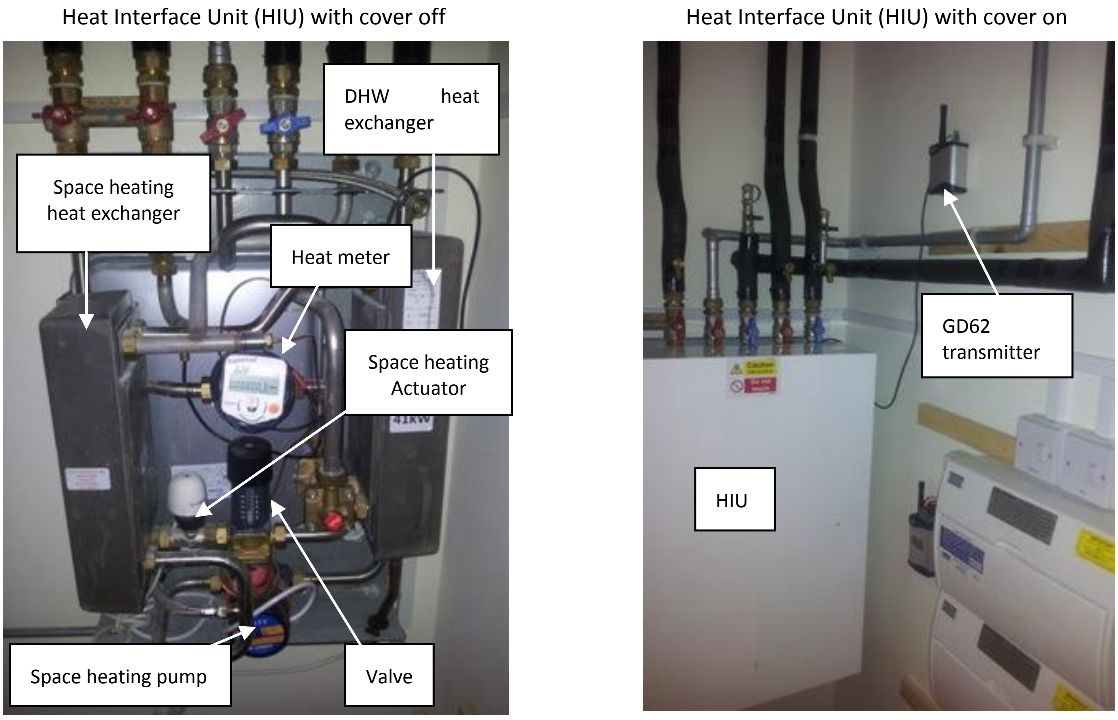


Figure 7.2: Photo of heat meter and HIU

The heat meter model was a Supercal 539. We improved the resolution from the original heat meter which had one pulse per kWh to one pulse per 0.1 kWh for the replacement meter. The heat meter was located within each property. We used a battery powered GD-62 transmitter from Eltek, which provided 2 x pulse inputs, only one of which was used. Readings were recorded at 5 minute intervals by the central RX250AL data logger.

Water metering

The water meters were located outside the properties within the central core risers. The water meters did not provide a pulsed output. An optical reader (Eltek PR6) was fixed to the front of the existing meter which 'watches' the rotation of the meter dials and converts this information into pulse outputs. We used a battery powered GC-62 transmitter from Eltek to each meter which provided 2 x pulse inputs, only one of which is used. Readings were recorded at 5 minute intervals by the central RX250AL data logger. The resolution of the equipment was 1 pulse per litre.

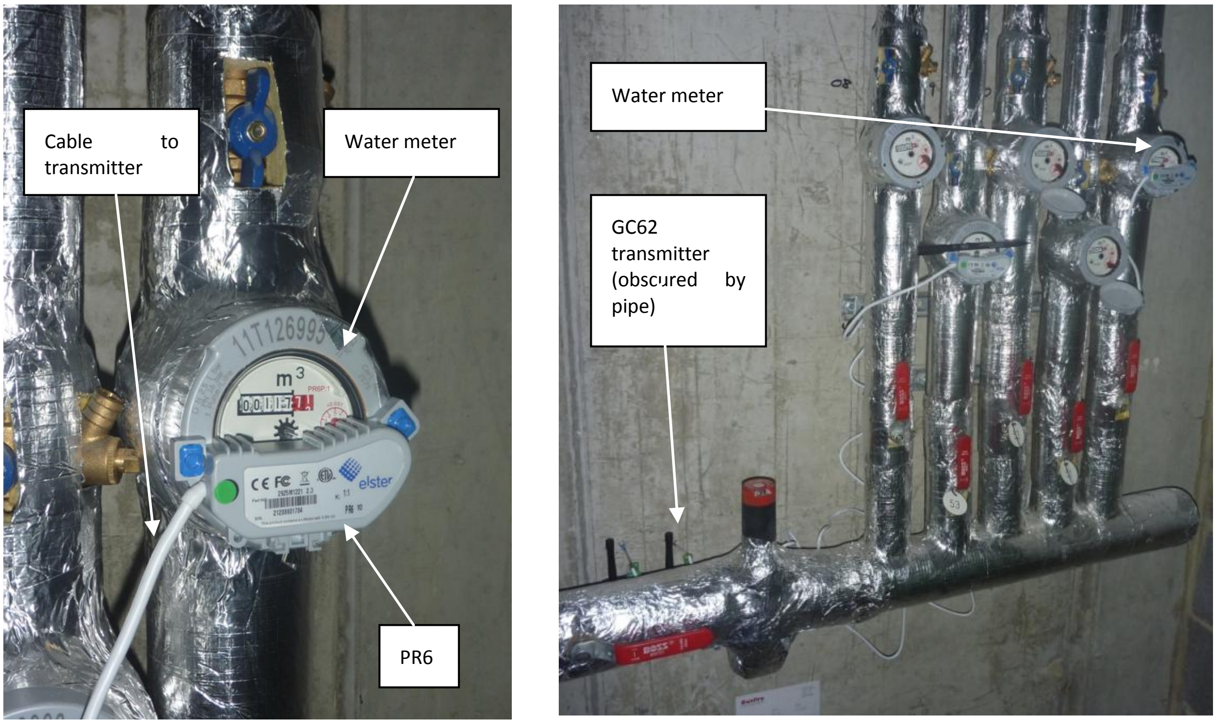


Figure 7.3: Photo of installed water meter and transmitter

Temperature, Relative Humidity and CO_2 monitoring

Within each home, we monitored temperature and relative humidity (RH) in the bedroom, bathroom and living room and we monitored CO_2 in the living room. We monitored temperature and relative humidity externally at one location on-site. Details of the equipment are below, all of the equipment supplied by Eltek.

- The internal temperature and RH in the bedroom and bathroom were measured with a battery powered GC-10 transmitter with temperature and RH sensors. The accuracies of the two sensors were ±0.4°C and ±2%RH respectively. The resolutions of the outputs of the two sensors were 0.1°C and 0.1%RH respectively.
- The internal temperature, RH and CO_2 in the living room were measured with a mains powered GD-47 transmitter with temperature, RH and CO_2 sensors. The accuracy and resolution of the temperature and RH sensors were the same as for the GC-10, with the exception of the accuracy of the temperature sensor now being ±0.5°C. The accuracy and resolution of the CO_2 sensor were ±(50ppm+3% of measured value) and 1ppm respectively.
- The external temperature and RH were measured with a battery powered OD-13J outdoor RH and temperature transmitter with integral Stevenson screen. The accuracy and resolution of the temperature and RH sensors were the same as for the GC-10, with the exception of the accuracy of the temperature sensor now being ±0.2°C.

Readings were received and recorded at 5 minute intervals by the central RX250AL data logger.

Outdoor unit (OD-13J)

Squirrel data logger (RX250AL)

Figure 7.4: The outdoor unit (temp/RH) and central data logger

Eltek GC10 (T and RH) transmitter in bathroom

Eltek GD47 (T, RH and CO_2) transmitter in living room

Figure 7.5: The temp/RH/CO_2 sensors installed in dwelling

7.1.3 Twelve Homes Monitoring Appliance Energy Use

We evaluated the energy use from four individual appliances in each of 12 homes, including the three detailed study homes. Four Energenie Plug-In Power Meters were placed in each home in series between the socket and each appliance. The monitors provide cumulative energy consumption for each appliance. The householder provided details of the current reading each quarter.

We aimed to install the monitors on those appliances that have the greatest energy use. We initially drew up a matrix of domestic unregulated appliances, their energy loads and the potential to change through purchase and/or change in use. The benchmarked energy load was taken from DomEarm. The matrix is shown in Table 7.3 with the largest energy users highlighted in red.

Table 7.4 shows the appliances that we are monitoring within the homes. It was not possible to monitor all the appliances with the highest energy use. This is because some of these appliances (for example the oven, some fridges) did not have removable 3 pin plugs but were hard-wired into the electricity supply. In other cases, there either was not enough space to install the monitors or it was not practical to place the monitor to measure the consumption of some appliances, for example where a 3 pin plug does not have enough clearance above it to accomodate the plug in monitor or where 3 pin plugs are difficult to access and the use of an extension lead resulted in health and safety risks (e.g 3 plug located behind a washing machine and use of an extension cable would result in a trip hazard).

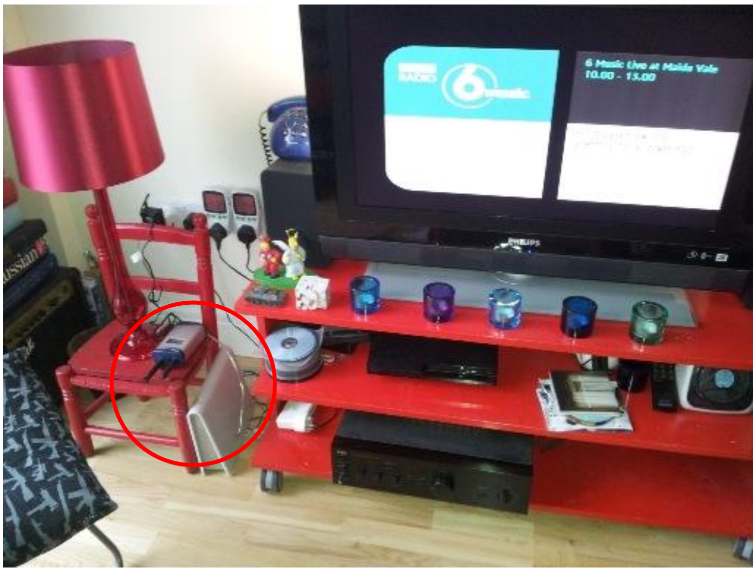


Figure 7.6: Plug in monitors installed to measure consumption of TV and games console in Flat 1.

Table 7.3: A matrix of domestic appliances, their energy loads and the potential to change through purchase and/or change in use (from DomEarm)

Appliance	Typical energy use (kWh/yr)	Potential to change through purchase or use
Electronics		
DVD/Video/Blu-ray player	30-160	There is potential to reduce energy consumption for all items through less frequent use. There is potential to use less stand-by power. According to DomEarm, typical values are: • DVD/Video/Blu-ray player: 20-140 kWh/yr • TV: 16-25 kWh/yr • Set-top box: 15-55 kWh/yr Purchasing smaller televisions consume significantly less energy which is the main factor for the range of consumption values shown for televisions.
TV primary	370-1840	
TV secondary	150-730	
Set-top box	60-160	
Digital radio	20	
Games console	120	
Phone charge	2-14	
Power adaptor	1-4	
Computer		
Desktop	300	This is potential to reduce energy consumption for all items through less frequent use. For these products, there is 'sleep' mode and 'off mode' which both demand energy. According to DomEarm the combined values range from 5 to 30 kWh/yr depending on the product. The type of monitor significantly impacts energy use e.g. 100 kWh/yr for LCD and 1260 kWh/yr for plasma.
laptop	50	
Printer	11-60	
Monitor	100-1260	
Power supply - modem/router	80	
Kitchen appliances – Refrigeration		

Upright freezer (A++ to C band)	175-350	There is no potential to reduce energy consumption through less frequent use or using less stand-by power. The range of values shows the benefit of purchasing a more efficient appliance or replacing an existing less efficient one.
Upright freezer (>12 years old)	445	
Fridge (A++ to C band)	90-245	
Fridge (>12 years old)	265	
Fridge/freezer (A++ to C band)	200-610	
Fridge/freezer (>12 years old)	590	
Chest freezer (A++ to D band)	175-450	
Chest freezer (>12 years old)	445	
Kitchen appliances – Cooking		
Induction hob	215	There is some potential to reduce energy consumption for all of the items through less frequent use. However, people need to eat cooked food. Interestingly, the results suggest that a microwave is more efficient than other products. However, this is not true. The default DomEarm data assumes that the microwave is purely on stand-by for 24/7 and not actively used. There is the potential to use less stand-by power. According to DomEarm typical values are: • Electric hob: 2-3 kWh/yr • Electric oven/microwave: 20-30 kWh/yr
Electric resistance hob	300	
Electric oven	150-210	
Microwave	20	
Gas hob	380	
Kettle	170	
Toaster	22	
Washing Machines / Dryer		
Washing machine (A+ to B band)	110-120	There is some potential to reduce energy consumption for all items through less frequent use. However, people need to wash their clothes. The DomEarm results suggest 40% less energy use if washing at 40C instead of 60C. Potentially washing could be carried out during off-peak energy tariffs. There is the potential to use less stand-by power. The DomEarm results show approx 5 kWh/yr for all washing machines and washer dryers. The results suggest that there is no stand-by energy use for a standard tumble dryer. There may be a benefit of replacing an existing appliance with a more efficient one (details not provided with DomEarm). Based on the information provided, there is limited difference in energy use between the different energy band washing machines and washer dryers. There is a wider range of available energy bands in practice.
Washer dryer (A+ to B band)	290-300	
Standard Dryer	185	
Dishwashers		
Dishwasher (Band A to C)	160-210	There is some potential to reduce energy consumption through less frequent use. However, it is necessary for people to clean dishes. There is no comparative information on washing by hand. Potentially washing could be carried out during off-peak energy tariffs. There is the potential to use less stand-by power. The DomEarm results show approx 2 kWh/yr for all dishwashers.
Other electrical appliances		
Shower	15	There is some potential to reduce energy consumption for all items through less frequent use. However, they tend to be essential activities. In particular, energy could be saved through shorter showers. It is noted that, particularly for electric car charging, it would be beneficial to charge at off-peak tariff.
Iron	52	
Vacuum cleaner	37	
Electric car charging	1365	
Misc appliances	37	
Cooling appliances		
Air conditioning	225	There is considerable potential to reduce energy consumption through less frequent use. Furthermore, the building can be adapted (solar shading) or behaviour adapted (opening windows during cooler periods) to improve occupant thermal comfort.

Table 7.4: The appliances monitored

Appliances		Flat Numbers
Consumer electronics	DVD/Video/Blu-ray/CD player	Flat 22
	TV	Flat 1, Flat 3, Flat 6, Flat 9, Flat 21, Flat 24
	Audio HiFi system (not on DomEarm List)	Flat 6, Flat 25, Flat 26
	Set-top box	Flat 9, Flat 20
	Internet router	Flat 2, Flat 20, Flat 23
	Games console	Flat 1, Flat 21, Flat 25
	Microwave (whilst DomEarm suggested low energy use, we believe it is an underestimate)	Flat 2, Flat 3, Flat 21, Flat 24,
Computer	Desktop	Flat 6
	Monitor	Flat 22
	Laptop	Flat 9, Flat 22, Flat 25
Food, Cooking	**Fridge-freezer**	Flat 6, Flat 23, Flat 26
	Freezer	Flat 24
	Electric hob	
	Electric oven	
	Kettle	Flat 1, Flat 20, Flat 23, Flat 24, Flat 25, Flat 26
	Toaster (whilst expected to be a low energy user, this was checked in one home)	Flat 20
Washing	Washing machine	Flat 1, Flat 21, Flat 23, Flat 26
	Washer dryer	Flat 22
	Tumble dryer	
Dishwasher		
Lamp/lighting (not included in DomEarm list – so have monitored)		Flat 2
Eltek GD47 transmitter (requires AC power supply to operate – so assessing energy consumption of equipment installed in flats)		Flat 2, Flat 3

7.1.4 Twenty Homes

To provide an assessment of how representative the three homes are in terms of energy consumption, we also collected data for another 17 homes for comparison. AECOM or Galliard Homes manually read the main electricity meters approximately at monthly intervals. Galliard Homes measured the heat meter readings at weekly intervals for billing purposes and provided AECOM with these readings.

7.1.5 District Heating Performance

An analysis of the efficiency of the communal heating system has been carried out by comparing the energy used by the energy centre to the heat consumed by all of the apartments connected to the system.

7.2 Analysis Plan

7.2.1 Three Detailed Study Homes

Utility metering (electricity, heat and water)

We have analysed the recorded data as follows.

- We have shown graphically the monthly total consumption in each property.
- We have compared the energy and water usage between the three properties.
- We have determined the split between the different electricity energy uses in each property and presented as a horizontal bar charts

- We have compared the actual energy use against the predicted annual energy use from the SAP calculation (regulated energy).

Temperature, Relative Humidity and CO_2 monitoring

We have analysed the recorded data as follows.

- We have shown graphically the daily average temperature, RH and CO_2 reading in each location within each property, as well as provided a basic statistical summary of the readings.
- We have evaluated whether the dwellings overheat. CIBSE Guide A recommends that for living areas, less than 1 per cent of occupied hours should be over an operative temperature of 28˚C and for bedrooms, less than 1 per cent of occupied hours should be over 26˚C. We have not measured operative temperature – only air temperature. We have assumed that ambient temperature equals operative temperature (i.e. air temperature equals radiant temperature). We have analysed this on a monthly basis. Furthermore, as the dwellings could potentially be occupied for much of the time depending on the activities of the occupants, we have assumed that the bedrooms are occupied from the hours of 10pm to 8am, and the living room is occupied from 8am to 10pm. As an alternative, we could have looked to base this analysis on the actual occupancy periods but this would not assess the risk of overheating of the building, only of the building with its current occupants.
- We have evaluated the risk of mould growth. Part F of the Building Regulations recommends that the relative humidity should meet each of the following three criteria.
    - Below 65%, as a rolling monthly average
    - Below 75%, as a rolling weekly average
    - Below 85%, as a rolling daily average

  For each room monitored in the property, we have assessed the recorded RH data against each of these three criteria.
- CO_2 is produced as part of the metabolic process. The concentration of metabolically produced CO_2 correlates with metabolic odour intensity. It can then act as a marker to provide an indication of the adequacy of ventilation when occupants themselves represent the dominant source.

  The rate of CO_2 production is well defined and is a function of the level of activity. We have assumed that on average, activity within the dwelling is fairly sedentary and the heat generation of a person is 125 W (see CIBSE Guide A, Table 1.4). BS 5925, Table 1, suggests a production rate of carbon dioxide per person (l/s) of 0.00004 x heat generation. Hence this amounts to a CO_2 production rate 0.005 l/s per person.

  Part F of the Building Regulations recommends that to control metabolic odour for adapted individuals (reduction in perception due to being exposed to the environment for a period of time – which is appropriate for a residential situation), it will be achieved by an air supply rate of 3.5 l/s/person. For steady-state equilibrium, assuming an external CO_2 concentration of 400ppm and the metabolic production rate of CO_2 given above, that equates to a CO_2 equilibrium level of 1830ppm.

  For the purposes of this work, it is unclear over what averaging period to apply this criterion. We have chosen for this evaluation to apply this over a rolling eight hour period.

  Care needs to be taken in interpretation of the findings. Other sources of pollutants may dominate which are not assessed by this calculation (hence, for example, we are separately assessing RH levels). Secondly, if the CO_2 level is below the criterion, the ventilation rate may not be sufficient since it is possible that equilibrium has not yet been achieved.

7.2.2 Twelve Homes Monitoring Appliance Energy Use

We have compared the actual electricity use against the benchmarked energy used shown in DomEarm.

7.2.3 Twenty Homes

We have compared the average electricity consumption of the 17 homes against the individual consumption of the three detailed homes. We have also ranked the consumption from highest to lowest for all 20 homes to assess where the three detailed flats occur in the ranking. More sophisticated statistical analysis could be used but the analysis proposed was judged sufficient for this study.

7.3 Study period

7.3.1 Introduction

Table 7.5 to Table 7.7 show the start dates for the various parameters measured in each home.

- For the detailed house study, initial installation occurred prior to these dates and reflects the time necessary to resolve problems. Information on the commissioning of the equipment is provided separately in Appendix A.
- The initial plan for the Appliance Study was to monitor three homes at a time, moving the monitors between homes each quarter. This would allow 12 homes to be monitored each year. This would be repeated within the same homes for the second year. It was decided during the study that it would be more cost-effective to install monitors in all homes and leave them there through the duration of the study – this saved having to organise visits to the occupants to remove and install the equipment. The spread of commencement dates partly reflects this change in strategy after installation in the first three homes and difficulties in recruitment which required two rounds of engagement.

In general, the study finished on 30th June 2014, with the exception of the environmental monitoring (temperature, RH and CO_2) which continued to 15th July 2014 in order to assess summer comfort conditions.

Table 7.5: Commencement Date for 3 Detailed House Study

	Flat 1	Flat 2	Flat 3
Electricity (sub-metering)	13 March 2013	13 March 2013	13 March 2013
Heat	13 February 2013	28 February 2013	26 February 2013
Water	5 April 2013	5 April 2013	5 April 2013
Temperature, RH, CO_2	13 February 2013	28 February 2013	26 February 2013
External Temperature and RH	13 February 2013		

Table 7.6: Commencement Date for Appliance Study

House	Commencement Date	House	Commencement Date/Time
Flat 1	13 February 2013	Flat 14	-
Flat 2	28 February 2013	Flat 15	-
Flat 3	26 February 2013	Flat 16	-
Flat 4	-	Flat 17	-
Flat 5	-	Flat 18	-
Flat 6	13 March 2013	Flat 19	-
Flat 7	-	Flat 20	28 May 2013
Flat 8	-	Flat 21	13 March 2013
Flat 9	30 August 2013	Flat 22	14 February 2013
Flat 10	-	Flat 23	30 August 2013
Flat 11	-	Flat 24	30 August 2013
Flat 12		Flat 25	30 August 2013
Flat 13		Flat 26	30 August 2013

Table 7.7: Commencement Dates/Times for Monthly Heat and Electricity Monitoring of 20 homes

Parameter	Commencement Date/Time
Heat	November 2012[2]
Electricity	12 March 2013

7.4 Results

7.4.1 Three Detailed Study Homes – Total electricity, heat and water consumption

We describe here the results from the study. Appendix B discusses how we have addressed any data loss in our analysis.

Total electricity, heat and water consumption

We provide a series of figures to provide easier comparison of consumption between flats and months, and provide commentary. The monthly data is also provided in tabular form in Appendix C.

Figure 7.7 shows the monthly total electricity consumption in each of the three flats. Data collection started 13th March 2013, so the consumption is only for part of March. The electricity usage is similar throughout the monitoring period. More detailed analysis is provided with the sub-metering results.

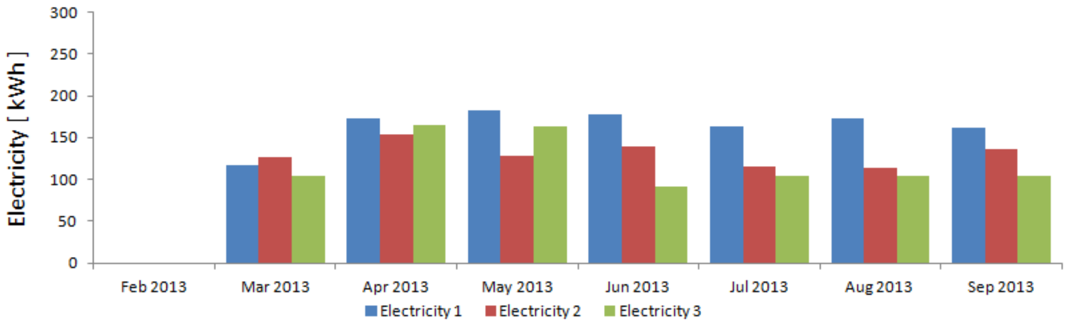


Figure 7.7a: Monthly electricity consumption (kWh) March 2013 to 30th September 2013

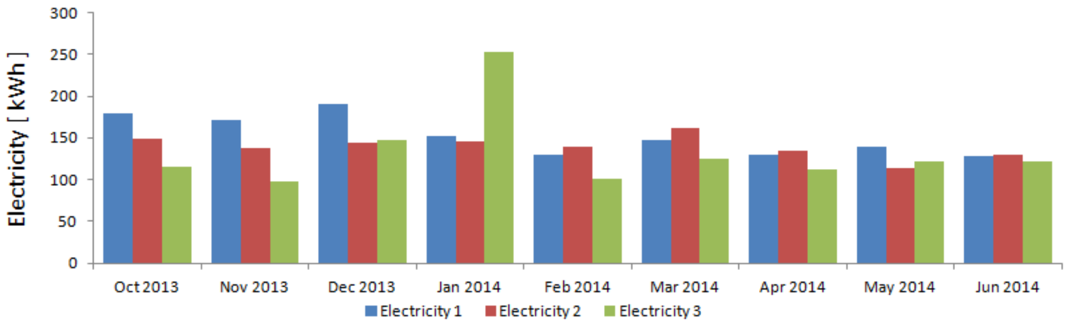


Figure 7.7b: Monthly electricity consumption (kWh) 1st October 2013 to 30th June 2014

Figure 7.8 shows the monthly total heat consumption in each of the three flats. Note that data collection for each flat started on different dates in February 2013. As expected, the heat consumption shows higher consumption in the winter period and lower demand in the summer period.

Flat 1 tends to show the lowest heating consumption, particularly during the winter period. This is consistent with it being a mid-floor flat whereas the other two are top-floor flats with greater heat loss through the roof.

[2] We obtained weekly heat meter data for these apartments over the 2012/13 heating season from Galliards.

Flat 2 tends to show a larger heating consumption than Flat 3. This is at least partly explainable by the fact for much of the study Flat 3 only had a single occupant whilst Flat 2 had two occupants which would have increased the hot water usage e.g. for showers and washing clothes. Additionally, feedback at the mid-point of the study from Flat 2 was that a lodger was frequently having longer showers which may be a further causal factor for higher heat consumption.

We note from the occupant feedback that Flat 3 had elevated heating for a period around December 2013 as their was a roof leak and windows were opened to remove moisture.

Note that as shown further in this report, the overall heating consumption was below that predicted by on-construction SAP.

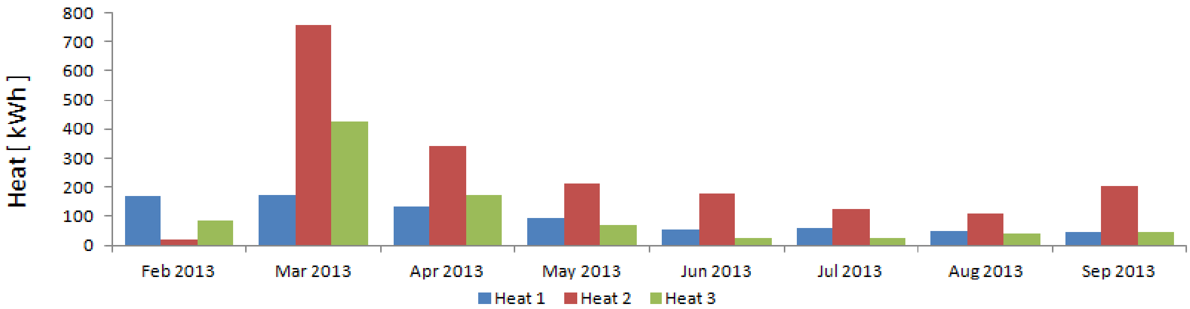


Figure 7.8a: Monthly heat consumption (kWh) February 2013 to 30th September 2013

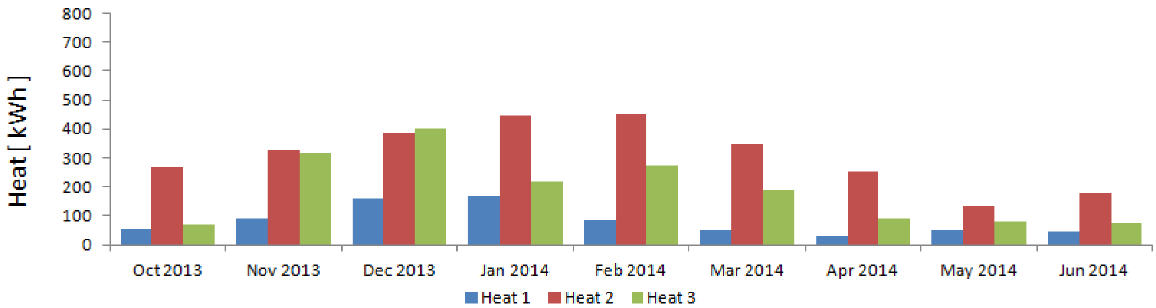


Figure 7.8b: Monthly heat consumption (kWh) 1st October 2013 to 30th June 2014

Figure 7.9 shows the monthly total water consumption in each of the three flats. Data collection started 5th April 2013. The water consumption of the three flats also showed significantly higher results for Flat 2 and is possibly explained by the frequent and long use of showers by the lodger as included in the heat consumption discussion above. It is also noted that there was only one occupant in Flat 3 during much of the study and it is plausible that the results from Flat 1 are relatively low to make Flat 2 appear high. To provide a wider comparison, the average consumption in Flat 2 was determined as 183 litres per person per day. By comparison, Part G 2010 of the Building Regulations subsequently set a requirement of 125 litres per day per person determined using the Government's water calculator.

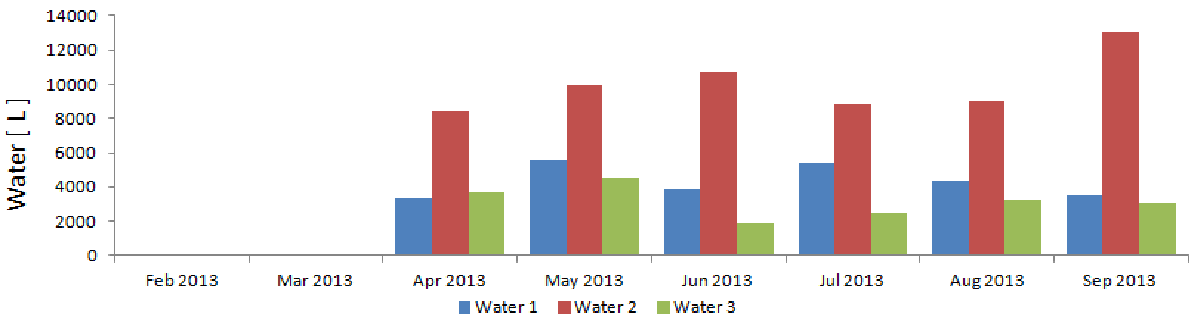


Figure 7.9a: Monthly water consumption (L) April 2013 to 30th September 2013

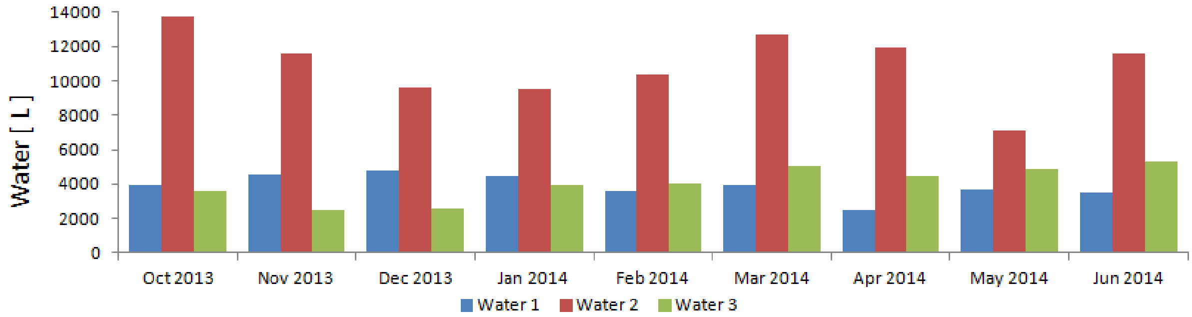


Figure 7.9b: Monthly water consumption (L) 1st October 2013 to 30th June 2014

7.4.2 Three Detailed Study Homes – Sub-metered electricity consumption

Introduction

Figure 7.10 shows the total electricity consumption for the three flats and their breakdown of the percentage energy use between each end-use category. Overall, Flat 1 consumed the most and Flat 3 the least during the study. Consistently, the sockets use the most energy followed by the MVHR unit.

The rest of this section focuses on the largest electricity usages. It also provides explanations for differences in the consumption between the flats.

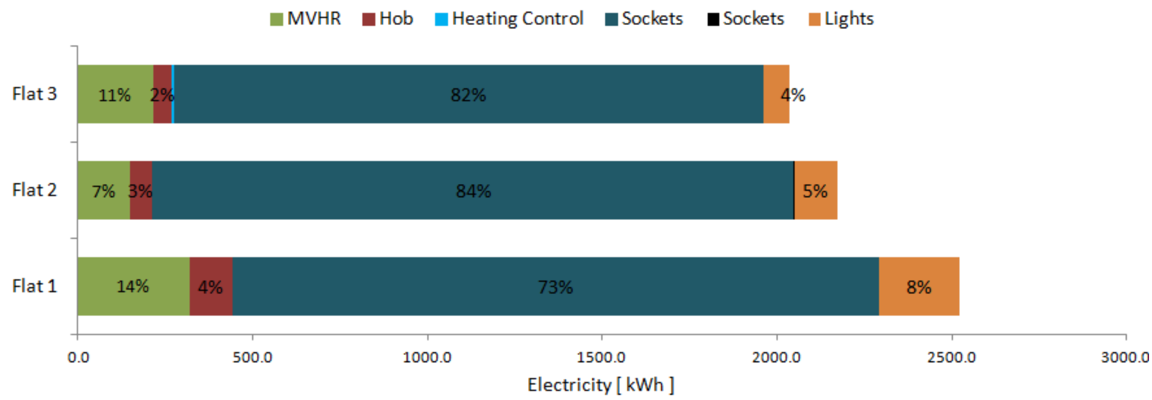


Figure 7.10: The comparison of total electricity consumption between the three Flats and their respective split in sub-metered uses for 13th March 2013 to 30th June 2014

MVHR

Figure 7.11 shows the monthly MVHR electricity consumption for the flats. Flat 1 exhibits the highest MVHR energy use.

Figure 7.12 shows the daily total electricity use on the MVHR circuit for the three flats for 13th March 2013 to 30th June 2014. It shows a relatively constant, but higher electricity use by the MVHR unit in Flat 1 compared to Flat 2 and Flat 3 during 2013. Furthermore, the results from Section 6 suggest under boost Flat 1 should use 0.87 kWh per day which is approximately that shown in the figure.

During a site visit on 22 July 2013, it was established that the occupant in Flat 1 has unknowingly had the MVHR set to boost continuously. The boost was set back to normal rate. However, the collected data does suggest that the MVHR was left continuously at boost rate for much of the period until towards the end of December 2013, at which point the boost rate was used intermittently.

Flats 2 and 3 do show variations over time. Based on the results in Section 6, the normal flow rates should result in a daily energy use of 0.28 kWh and 038 kWh respectively which is approximately what is shown here. The fluctuations can reasonably be expected to reflect the use of boost intermittently.

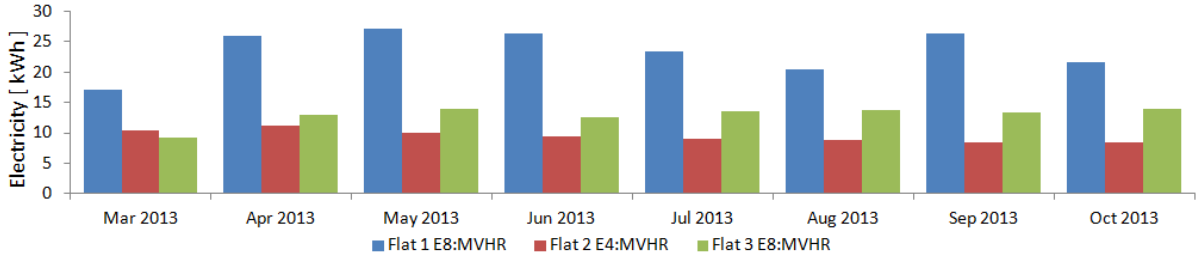


Figure 7.11a: Monthly MVHR electricity use for the three Flats for 13th March to 30th September 2013

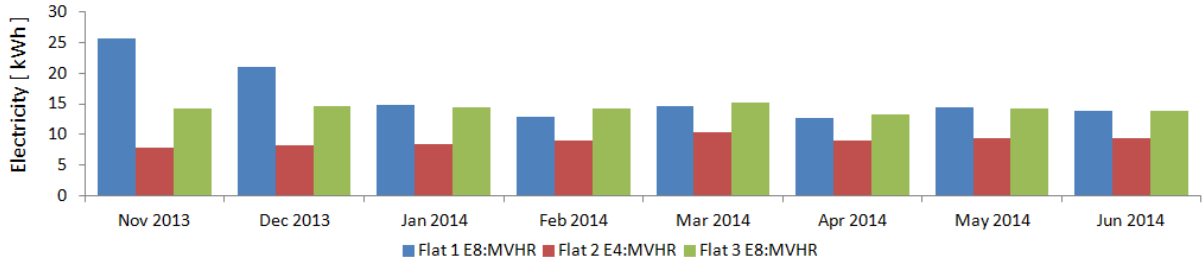


Figure 7.11b: Monthly MVHR electricity use for the three Flats for 1st October 2013 to 30th June 2014

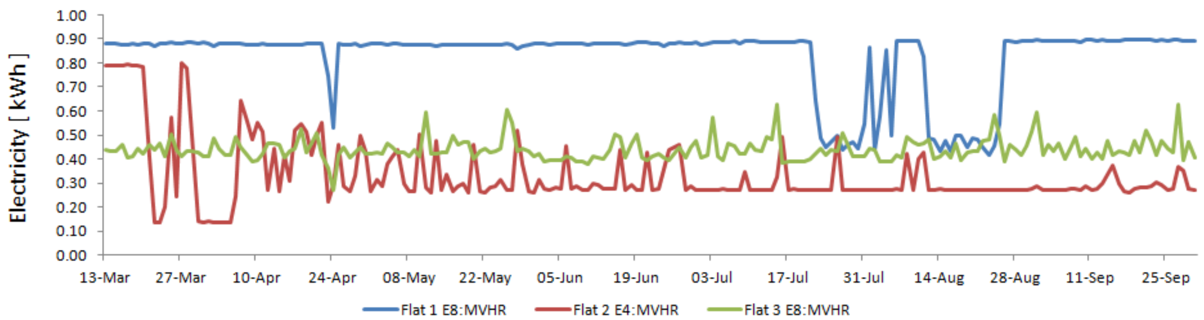


Figure 7.12a: MVHR daily electricity use for the three Flats for 13th March to 30th September 2013

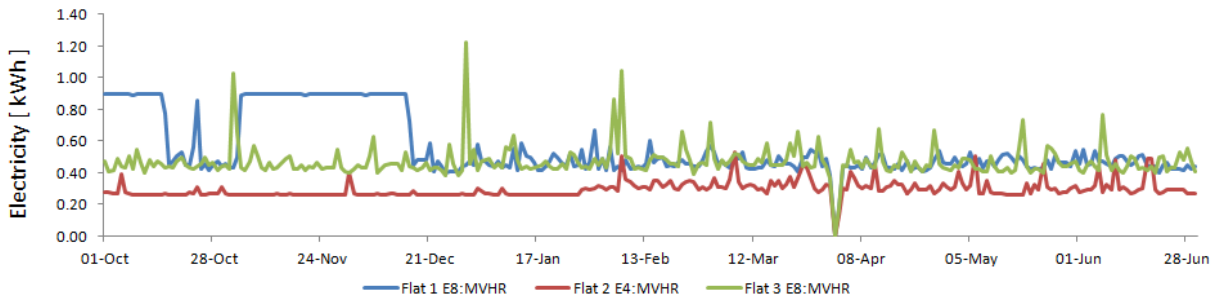


Figure 7.12b: MVHR daily electricity use for the three Flats for 1st October 2013 to 30th June 2014

Wall sockets, lighting and electric cooker use

Figure 7.13, Figure 7.14 and Figure 7.15a show the monthly socket, lighting and cooker electricity use respectively for the three flats.

- All flats had similar monthly consumption via sockets. As part of the mid-point discussions, Flat 3 noted the subsequent use of two electric de-humidifiers to remove moisture after a leak through the roof in December 2013. This may explain the particularly elevated socket consumption in January 2014.
- Flat 1 consistently consumed the most electricity amongst the three flats for lighting, with Flat 3 typically the least. This may be explained by feedback during the walkthrough and interview with the occupants of Flats 2 and 3. The occupants expressed preference for standalone lighting, which uses

power from the wall sockets. This reduces the need, and thus energy consumption, for ceiling lights which are on the lighting circuit.

- Flat 1 tended to use the larger amount of electricity for cooking. This could be explained by the shift working patterns of one of the occupants in this flat and hence the occupants having meals at different times resulting in more frequent and potentially greater use of the cooker.

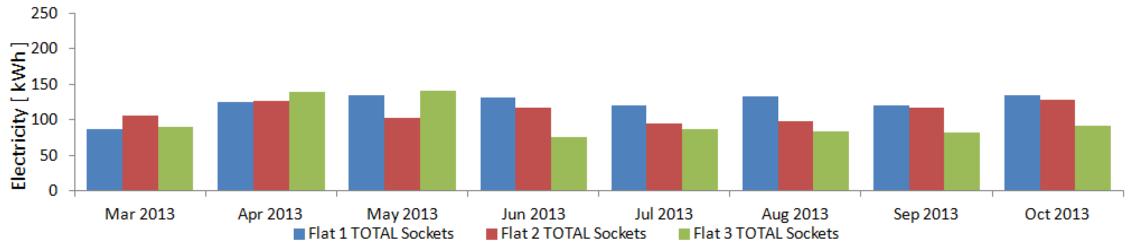


Figure 7.13a: Monthly socket electricity use for the three Flats for 13th March to 30th September 2013

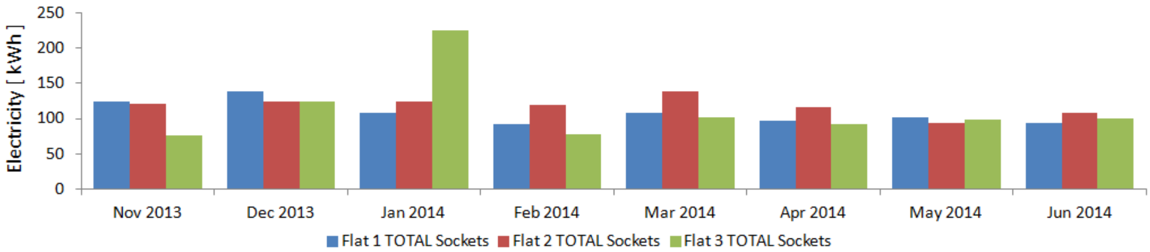


Figure 7.13b: Monthly socket electricity use for the three Flats for 1st October 2013 to 30th June 2014

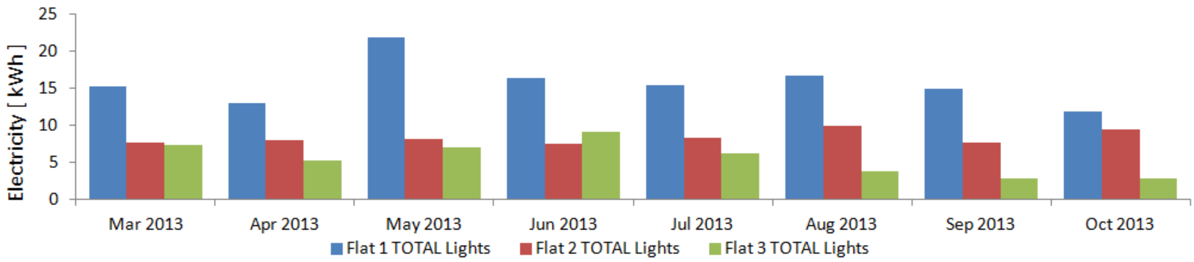


Figure 7.14a: Monthly lighting electricity use for the three Flats for 13th March to 30th September 2013

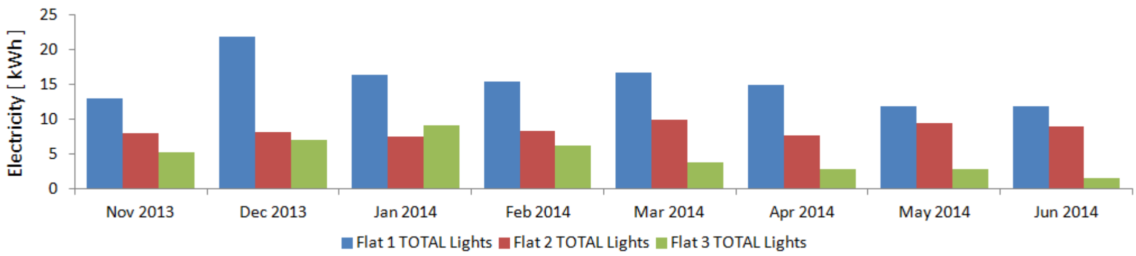


Figure 7.14b: Monthly lighting electricity use for the three Flats for 1st October 2013 to 30th June 2014

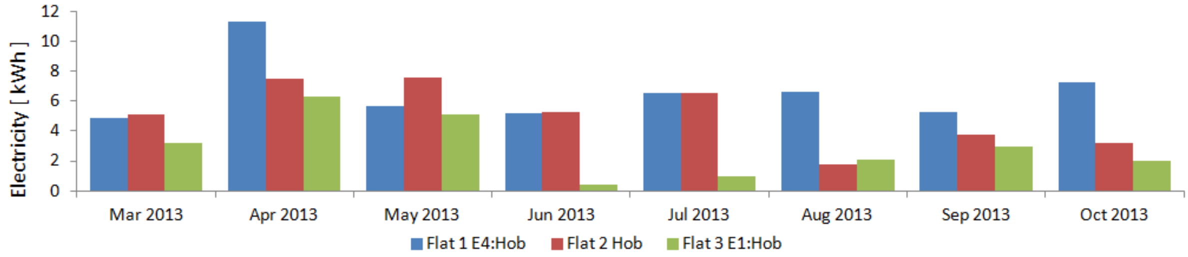


Figure 7.15a: Monthly cooker electricity use for the three Flats for 13th March to 30th September 2013

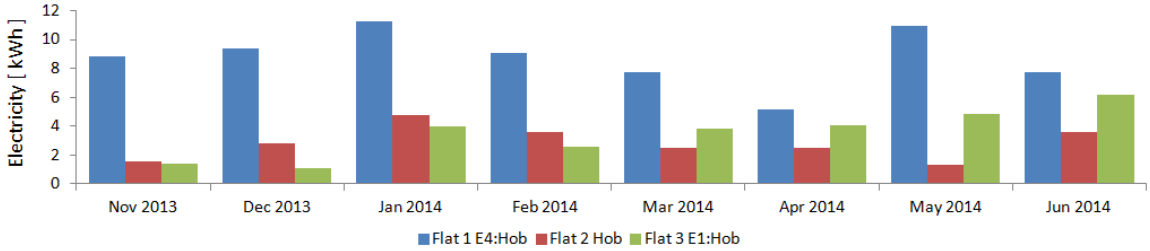


Figure 7.15b: Monthly cooker electricity use for the three Flats for 1st October 2013 to 30th June 2014

7.4.3 Three Detailed Study Homes – Environmental monitoring

Temperature monitoring and overheating assessment

Table 7.8 summarises the monthly temperature readings. Appendix D provides figures which show the daily-averaged temperature data measured both externally and in each of the three flats during the study. The temperatures show the expected seasonal variations, with higher temperatures in summer and lower temperatures in winter.

Table 7.8: Summary of the temperature data

	External	Flat 1					Flat 2					Flat 3				
		Bedroom		Bathroom	Living room		Bedroom		Bathroom	Living room		Bedroom		Bathroom	Living room	
		Average °C	% time OH	Average °C	Average °C	% time OH	Average °C	% time OH	Average °C	Average °C	% time OH	Average °C	% time OH	Average °C	Average °C	% time OH
Feb-13	3.6	19.6	0.0%	21.4	20.2	0.5%	17.6	0.0%	20.1	18.3	0.0%	19.3	0.0%	19.5	20.3	0.0%
Mar-13	3.7	18.5	0.0%	20.4	19.0	0.5%	18.6	0.0%	20.4	17.5	0.0%	18.2	0.0%	18.5	19.1	0.0%
Apr-13	7.9	20.5	0.0%	21.7	21.1	0.0%	19.0	0.0%	20.0	19.0	0.0%	21.1	0.0%	20.4	21.3	0.0%
May-13	11.3	22.2	0.0%	22.9	23.3	0.7%	20.3	0.0%	20.7	20.3	0.0%	22.4	0.0%	22.2	22.4	0.0%
Jun-13	14.7	23.9	0.0%	24.3	25.3	14.9%	22.0	0.0%	22.2	22.1	0.8%	23.3	0.7%	23.5	23.9	0.0%
Jul-13	20.3	26.3	26.1%	26.9	27.1	50.4%	26.3	38.7%	25.9	25.7	27.3%	27.6	58.1%	27.5	27.2	55.2%
Aug-13	19.4	24.6	1.0%	25.5	25.6	21.1%	24.7	1.3%	24.7	24.6	2.2%	26.0	11.0%	25.9	25.2	15.2%
Sep-13	14.7	22.7	1.7%	23.7	23.7	5.1%	22.1	0.0%	23.0	22.3	0.5%	22.3	0.7%	22.7	21.6	0.0%
Oct-13	13.2	21.4	0.0%	22.4	22.8	0.0%	20.5	0.0%	21.1	20.3	0.0%	20.7	0.0%	21.1	21.0	0.0%
Nov-13	8.5	20.0	0.0%	21.3	21.6	0.0%	17.9	0.0%	18.6	17.2	0.0%	18.8	0.0%	19.2	19.6	0.0%
Dec-13	7.2	19.2	0.0%	20.8	20.8	0.0%	18.0	0.0%	18.5	16.6	0.0%	18.6	0.0%	18.9	19.4	0.0%
Jan-14	6.9	19.1	0.0%	20.8	21.0	0.0%	18.1	0.0%	18.8	16.6	0.0%	18.4	0.0%	18.1	19.3	0.0%
Feb-14	7.2	18.9	0.0%	20.4	20.3	0.0%	18.3	0.0%	19.1	16.8	0.0%	17.8	0.0%	18.3	19.0	0.0%
Mar-14	9.0	20.1	0.0%	21.2	21.6	0.0%	19.1	0.0%	19.8	18.2	0.0%	19.8	0.0%	19.9	20.4	0.0%
Apr-14	11.5	21.1	0.0%	22.1	22.2	0.0%	20.5	0.0%	20.9	19.7	0.0%	22.1	0.0%	21.7	21.7	0.0%
May-14	13.5	22.0	0.0%	22.9	23.0	0.0%	22.0	0.0%	22.1	21.3	0.0%	22.9	0.0%	22.8	22.5	0.0%
Jun-14	16.8	23.7	0.0%	24.7	24.8	0.0%	24.5	0.0%	24.8	24.0	0.0%	25.2	0.0%	25.0	24.3	0.0%
Jul-14	17.9	23.5	0.0%	24.8	24.6	0.0%	24.6	0.0%	24.8	24.0	0.0%	25.1	0.0%	25.3	24.6	0.0%

Note: % time OH: percentage time space overheat above criteria limits in bedroom and living room respectively (overheating criteria specified in Section 7.2)

The average temperatures for the winter and summer months for each apartment is shown in Table 7.9. For the purposes of this analysis, we have assumed winter is November to February and summer in June to September.

- Winter: Flat 1 is the warmest flat, followed by Flat 3 and then Flat 2. It is noted that Flat 1 is mid-floor whilst the other two flats are top-floor – hence heat loss should be less. However, this may simply represent occupants chosen thermostat settings.
- Summer: There is a less clear trend during the summer months with the order depending on the room, particularly noting the sensor accuracy of ±0.4°C in the bedroom and bathroom and ±0.5°C in the living room.

As a comparison benchmark, it is noted that SAP assumes for the three properties

- Flat 1: 20.1°C in the living room, 18.4°C in the other rooms
- Flat 2 and Flat 3: 19.6°C in the living room, 17.7°C in the other rooms

The measured results show that the actual living room temperatures were higher for Flat 1 and lower for Flat 2 than predicted, with Flat 3 being close to that predicted. The measured results also show that all flats had higher temperatures in the other rooms than predicted (4°C to 5°C) which is particularly important as such areas account for 60-70% of the three flats. It is unclear how good SAP is as a benchmark for new energy-efficient homes given its long history and its use for both new and existing homes.

Table 7.9: Average temperatures for the winter and summer months.

	Flat 1			Flat 2			Flat 3		
	Bedroom	Bathroom	Living rooom	Bedroom	Bathroom	Living rooom	Bedroom	Bathroom	Living rooom
Winter	19.4	20.9	20.8	18.0	19.0	17.1	18.6	18.8	19.5
Summer	22.2	22.9	23.1	22.0	22.2	21.8	22.8	22.9	22.4

Table 7.8 also shows that all flats experienced periods of overheating during the summer of 2013 despite the SAP assessment expressing a 'slight' overheating risk in Flat 3 and 'medium' overheating risk in Flat 1 and Flat 2 and being assessed as passing Criteria 3 of Part L of the Building Regulations by the SAP software. This occurred in both the living room and bedrooms. In particular, all of the rooms in the three flats exceeded the overheating criteria in July and August 2013, with the exception of the bedroom in Flat 1 in August. The instantaneous peak temperatures recorded are given in Table 7.10. The highest temperatures were recorded in the Flat 1.

Table 7.10: Peak temperatures for July and August 2013

	Flat 1		Flat 2		Flat 3	
	Bedroom	Living room	Bedroom	Living room	Bedroom	Living room
July	34.9°C	38.0°C	30.6°C	32.5°C	34.0°C	33.5°C
August	33.1°C	32.8°C	28.4°C	29.7°C	30.6°C	30.3°C

The overheating could be due to the high amount of glazing rendering the flats susceptible to excessive solar gain, coupled with insufficient ventilation through the mechanical ventilation in some of the flats, which also appears not to feature the capability for a summer by-pass. The lack of sufficient natural ventilated through the openable windows due to restricted effective open area, an issue pointed out during the flat walkthrough exercise, may have further exacerbated the overheating problem. Finally the BUS noted issues with external noise which could have limited opening of windows.

There were periods of high temperatures in the Flat 1 living room in February and March. Further investigation showed that these periods were around 2 to 3pm in the afternoon. The temperature sensor in the living room is mains operated. For practical reasons, it was located on the floor of Flat 1. On visiting the flat, it was found that the occupant had moved the temperature sensor to be in the direct path of sunlight. The meter was subsequently moved to a more satisfactory location.

Relative Humidity (RH) monitoring and mould growth assessment

Table 7.11 summarises the monthly RH readings. Appendix D provides figures which show the daily-averaged RH data measured both externally and in each of the three flats during the study.

The results can be summarised as follows.

- Flat 1 was within the RH criteria in all rooms throughout the study.
- Flat 2 exceeded the RH criteria on a number of occasions from August 2013 onwards. This particularly occurred in the bathroom but also the other rooms monitored. This may be explained by the fact that during the walkthrough we noted that the ventilation boost operation was not operating via the bathroom light switch. Hence, high levels of moisture could have occurred in the bathroom and spread throughout the home.
- Flat 3 exceeded the RH criteria in December 2013 to February 2014. On initial analysis it was unclear why the RH levels are particularly high during that period. RH levels should be lower as during the winter the internal air has a higher capacity for moisture as it is at a much higher temperature than outside. This suggested either a high internal source of moisture or issues with the ventilation system or its use. Subsequent discussions with the resident highlighted a leak in the room in December 2013 which was repaired and need the use of de-humidifiers to remove the moisture from the property.

Table 7.11: Summary of the RH data

		Flat 1											
		Bedroom				Bathroom				Living room			
	External RH	Average RH	rda >85%	rwa >75%	rma >65%	Average RH	rda >85%	rwa >75%	rma >65%	Average RH	rda >85%	rwa >75%	rma >65%
Feb-13	75.2	38.3	0%	0%	0%	39.4	0%	0%	0%	40.7	0%	0%	0%
Mar-13	76.2	38.8	0%	0%	0%	38.5	0%	0%	0%	41.1	0%	0%	0%
Apr-13	69.2	38.7	0%	0%	0%	39.4	0%	0%	0%	39.8	0%	0%	0%
May-13	67.8	40.3	0%	0%	0%	42.3	0%	0%	0%	40.0	0%	0%	0%
Jun-13	69.2	43.8	0%	0%	0%	46.3	0%	0%	0%	42.1	0%	0%	0%
Jul-13	62.1	46.1	0%	0%	0%	47.5	0%	0%	0%	45.9	0%	0%	0%
Aug-13	62.9	48.7	0%	0%	0%	49.8	0%	0%	0%	47.8	0%	0%	0%
Sep-13	77.3	50.7	0%	0%	0%	51.5	0%	0%	0%	49.8	0%	0%	0%
Oct-13	82.5	56.1	0%	0%	0%	57.6	0%	0%	0%	53.4	0%	0%	0%
Nov-13	82.5	51.3	0%	0%	0%	53.1	0%	0%	0%	48.0	0%	0%	0%
Dec-13	84.3	49.9	0%	0%	0%	51.3	0%	0%	0%	46.5	0%	0%	0%
Jan-14	86.0	52.9	0%	0%	0%	53.1	0%	0%	0%	48.4	0%	0%	0%
Feb-14	79.2	50.3	0%	0%	0%	50.9	0%	0%	0%	47.5	0%	0%	0%
Mar-14	73.8	45.8	0%	0%	0%	46.8	0%	0%	0%	43.1	0%	0%	0%
Apr-14	72.6	45.9	0%	0%	0%	47.1	0%	0%	0%	44.5	0%	0%	0%
May-14	70.4	46.2	0%	0%	0%	47.7	0%	0%	0%	45.3	0%	0%	0%
Jun-14	65.4	45.2	0%	0%	0%	45.8	0%	0%	0%	44.3	0%	0%	0%
Jul-14	67.3	48.9	0%	0%	0%	48.5	0%	0%	0%	48.6	0%	0%	0%

	External RH	Flat 2											
		Bedroom				Bathroom				Living room			
		Average RH	rda >85%	rwa >75%	rma >65%	Average RH	rda >85%	rwa >75%	rma >65%	Average RH	rda >85%	rwa >75%	rma >65%
Feb-13	75.2	42.4	0%	0%	0%	47.1	0%	0%	0%	47.1	0%	0%	0%
Mar-13	76.2	46.7	0%	0%	0%	54.4	0%	0%	0%	54.4	0%	0%	0%
Apr-13	69.2	47.8	0%	0%	0%	59.1	0%	0%	0%	59.1	0%	0%	0%
May-13	67.8	47.0	0%	0%	0%	59.9	0%	0%	0%	59.9	0%	0%	0%
Jun-13	69.2	49.8	0%	0%	0%	64.1	0%	0%	0%	64.1	0%	0%	0%
Jul-13	62.1	46.1	0%	0%	0%	58.4	0%	0%	0%	51.0	0%	0%	0%
Aug-13	62.9	49.2	0%	0%	0%	60.5	0%	0%	7.7%	51.8	0%	0%	0%
Sep-13	77.3	55.5	0%	0%	0%	66.0	0%	0%	100.0%	57.4	0%	0%	12.7%
Oct-13	82.5	62.0	0%	0%	0%	75.2	0.2%	52.6%	100.0%	65.5	0%	0%	100.0%
Nov-13	81.7	60.0	0%	0%	0%	74.4	0%	32.5%	100.0%	67.0	0%	0%	100.0%
Dec-13	84.3	60.5	0%	0%	0%	70.5	0%	0%	100.0%	67.7	0%	0%	100.0%
Jan-14	86.0	60.0	0%	0%	0%	69.0	0%	0%	100.0%	67.8	0%	0%	92.5%
Feb-14	79.2	56.7	0%	0%	0.0%	67.0	0%	0%	100.0%	64.0	0%	0%	0%
Mar-14	73.8	53.2	0%	0%	0%	65.7	0%	0%	58.1%	59.0	0%	0%	0%
Apr-14	72.6	51.7	0%	0%	0%	64.9	0%	0%	0%	57.4	0%	0%	0%
May-14	70.4	48.6	0%	0.1%	0.2%	56.1	0%	0%	0%	52.4	0%	0%	0%
Jun-14	65.4	45.6	0%	0%	0%	56.7	0%	0%	0%	50.1	0%	0%	0%
Jul-14	67.3	47.2	0%	0%	0%	57.4	0%	0%	18.9%	50.7	0%	0%	0%

	External RH	Flat 3											
		Bedroom				Bathroom				Living room			
		Average RH	rda >85%	rwa >75%	rma >65%	Average RH	rda >85%	rwa >75%	rma >65%	Average RH	rda >85%	rwa >75%	rma >65%
Feb-13	75.2	43.6	0%	0%	0%	48.1	0%	0%	0%	42.5	0%	0%	0%
Mar-13	76.2	44.0	0%	0%	0%	48.8	0%	0%	0%	41.3	0%	0%	0%
Apr-13	69.2	41.4	0%	0%	0%	48.1	0%	0%	0%	40.0	0%	0%	0%
May-13	67.8	41.6	0%	0%	0%	47.6	0%	0%	0%	40.9	0%	0%	0%
Jun-13	69.2	44.9	0%	0%	0%	47.2	0%	0%	0%	43.5	0%	0%	0%
Jul-13	62.1	42.6	0%	0%	0%	46.3	0%	0%	0%	44.2	0%	0%	0%
Aug-13	62.9	45.6	0%	0%	0%	49.9	0%	0%	0%	47.8	0%	0%	0%
Sep-13	77.3	52.5	0%	0%	0%	55.4	0%	0%	0%	54.5	0%	0%	0%
Oct-13	82.5	60.2	0%	0%	0%	62.5	0%	0%	0%	57.5	0%	0%	0%
Nov-13	81.7	52.0	0%	0%	0%	54.8	0%	0%	0%	48.7	0%	0%	0%
Dec-13	84.3	54.4	0%	0%	0%	58.2	0%	0%	65.7%	52.4	0%	0%	0%
Jan-14	86.0	61.9	0%	0%	27.7%	75.4	3.4%	60.1%	100.0%	58.6	0%	0%	0%
Feb-14	79.2	60.7	0%	0%	0%	67.9	0%	0%	26.7%	52.9	0%	0%	0%
Mar-14	73.8	50.7	0%	0%	0%	57.6	0%	0%	0%	46.2	0%	0%	0%
Apr-14	72.6	48.0	0%	0%	0%	54.2	0%	0%	0%	45.8	0%	0%	0%
May-14	70.4	46.3	0%	0%	0%	51.9	0%	0%	0%	45.7	0%	0%	0%
Jun-14	65.4	44.0	0%	0%	0%	50.1	0%	0%	0%	45.5	0%	0%	0%
Jul-14	67.3	46.4	0%	0%	0%	50.3	0%	0%	0%	47.3	0%	0%	0%

Note:
rda > 85% rolling daily average > 85%
rwa > 75% rolling weekly average > 75%
Rma > 65% rolling monthly average > 65%

CO_2 monitoring

Table 7.12 summarises the monthly CO_2 readings. Appendix D provides figures which show the daily-averaged CO_2 data measured in the living rooms of each of the three flats during the study.

The results can be summarised as follows.

- There is a general trend of lower CO_2 levels during the warmer months and higher levels during the winter months. The lower levels of CO2 during the warmer months may be a consequence of two factors: (i) being out of the flat more during warmer weather and, (ii) use of windows and balcony doors for additional ventilation during the warmer summer months to help alleviate high internal temperatures noted previously.
- For Flats 1 and 2, there were periods of time where in the living room the average 8-hour CO_2 level exceeded the guideline of 1830ppm. Reviewing the data, the exceedances all occurred during afternoon and/or evenings at either at weekends or bank holidays. The slow build up and decay suggests a real occurrence (i.e. not someone breathing on sensor or lighting a cigarette close by) and we presume caused by visitors coming around. The large percentage for Flat 2 during December reflects several exceedances during that month. During one prolonged period from 30th Nov 2013 to 1st Dec 2013, the sensor went out of range (>5000ppm) on two occasions for 20 minutes each time. It is noted that the MVHR flow rates recommended in Part F are for a standard occupancy with the potential to open windows during periods of occasional high pollutant events (e.g. visitors). Designing the MVHR system for such rare events would result it in it being over-sized for the majority of the period of the time and potentially less energy efficient. It is also noted in Section 6 that the MVHR rates measured in July 2013 were lower than both the commissioned rates and those recommended in Approved Document F (it is possible that the air flow rates in March would have been greater e.g. due to cleaner filters). Whilst there may have been some dissatisfaction from occupants from the high levels of metabolic odour, it was unlikely to be a health concern.
- It is interesting to note that the high levels for Flat 2 occurred during the winter 2013/2014. This coincides with the period that RH levels were also high in the bathroom (see earlier). It is unclear whether there is any causal relationship or coincidence given that the former could be explained by occupancy and the latter by the boost switch not operating in the bathroom.

Table 7.12: Summary of the CO_2 data

	Living room					
	Flat 1		Flat 2		Flat 3	
	Monthly average ppm CO_2	% 8-hour rolling average CO_2 >1830ppm	Monthly average ppm CO_2	% 8-hour rolling average CO_2 >1830ppm	Monthly average ppm CO_2	% 8-hour rolling average CO_2 >1830ppm
Feb-13	923	0.0%	664	0.0%	731	0.0%
Mar-13	819	0.4%	926	1.2%	745	0.0%
Apr-13	776	0.0%	829	0.0%	747	0.0%
May-13	747	0.0%	760	0.0%	708	0.0%
Jun-13	686	0.0%	642	0.0%	564	0.0%
Jul-13	600	0.0%	503	0.0%	580	0.0%
Aug-13	587	0.0%	531	0.0%	608	0.0%
Sep-13	632	0.0%	700	0.0%	627	0.0%
Oct-13	764	0.0%	781	0.0%	732	0.0%
Nov-13	868	0.0%	953	1.2%	748	0.0%
Dec-13	855	0.0%	961	4.8%	746	0.0%
Jan-14	952	0.0%	907	0.1%	807	0.0%
Feb-14	864	0.0%	888	0.7%	772	0.0%
Mar-14	878	0.0%	879	0.0%	783	0.0%
Apr-14	747	0.0%	810	0.0%	739	0.0%
May-14	716	0.0%	652	0.0%	702	0.0%
Jun-14	611	0.0%	644	0.0%	659	0.0%
Jul-14	579	0.0%	571	0.0%	639	0.0%

7.4.4 Twelve Homes Monitoring Appliance Energy Use

The total energy consumption for each appliance is shown in Table 7.13 for the study period. This shows both the total and annual consumption of each appliance. The DomEarm data is shown as a comparable benchmark. We have not been able to obtain any readings from Flat 6, despite many attempts to contact the resident. Furthermore, 7 of the 44 monitors (16%) became faulty during the monitoring period which questions the long-term reliability of such lower-cost devices. For these devices, where necessary, annual energy consumption was determined by pro-rata of the data (e.g. if we only received 6 months of data, the consumption was doubled to estimate the annual consumption). Faulty monitors are highlighted in light red in Table 7.13.

Table 7.13: Average annual appliance energy use with corresponding DOMEARM benchmark

Appliance	Energy use since monitoring start, kWh	Average energy use per year, kWh	Benchmark yearly DomEarm data, kWh/yr
TV	517	380	370-1840
TV (bedroom)	143	108	150-730
TV (lounge)	142	104	370-1840
TV	-	-	370-1840
TV	855	652	370-1840
TV	24	29	370-1840
TV	51	61	370-1840
TV	57	69	370-1840
Surround sound amplifier	-	-	n/a
Audio Hifi	59	69	n/a
Set-top box	9	8	60-160
Set-top box	120	144	60-160
Wireless Router	59	44	80
Wireless router	58	52	80
Wireless router	20	18	80
Internet router	31	38	80
Games console	95	70	120
Games console	37	28	120
Games console	18	53	120
Microwave	49	36	20
Microwave	68	50	20
Microwave	52	92	20
Microwave	13	15	20
Desktop computer	-	-	300
Monitor	69	50	100-1260
Laptop	110	79	50
Laptop	42	51	50
Laptop (Mac)	14	17	50
Kettle	73	54	170
Kettle	21	19	170
Kettle	29	35	170
Kettle	21	25	170
Kettle	29	34	170
Kettle	29	35	170
Grill/ toaster	10	9	22
Washing machine	90	66	110-120
Washing machine	47	85	110-120
Washing machine	101	286	110-120
Washing machine	24	28	110-120
Washer-dryer	14	22	290-300
Bedside lamp	45	33	n/a
GD47	11	8	n/a
GD47	11	8	n/a
Fridge	-	-	90-245
Fridge-freezer	21	59	90-245
Fridge-freezer	119	141	90-245
Freezer	298	357	90-245

Some key conclusions are provided below.

- The top two energy readings were from the use of televisions. However, there was a significant spread in results between all homes where a television was monitored which will reflect the type of television and its hours of use. The measurements were all within or below the DomEarm benchmarks.
- Freezers and fridge-freezers were the second highest category of energy use. In particular, the freezer consumption was higher than the DomEarm benchmark. The location of the freezer in the living room, which may have been warmer than the kitchen and being surrounded by general storage of items may have impeded adequate ventilation to the condenser, may have led to increased energy use.
- The kettle was most commonly monitored. In all cases, the results showed much lower consumption than the DomEarm benchmark. Whilst this may be linked to usage pattern of the sample, it may also suggest a revised figure is required for the benchmark.
- In general, the results were within or below the DomEarm benchmarks. As noted above, the Freezer consumption was a notable exception. We also note that microwave consumption tended to be above the DomEarm benchmark (3 of the 4 cases) which could reflect assumptions of microwave usage compared to the volunteers within the study.

7.4.5 Twenty Homes

Electricity

Monthly electricity consumptions based on fiscal meter readings are shown in Table 7.14. The readings have not been taken exactly monthly as it depends on the availability of AECOM and Galliard Homes staff to undertake visual readings on site. For the purpose of this work, it is not important to have exactly monthly intervals.

We have compared the consumption for the three detailed flats against the average consumption for the other 17 flats for each month period. We have also ranked the energy consumption for all 20 flats – where ‘1’ represents the highest electricity consumption and ‘20’ represents the lowest electricity consumption.

We first undertook an analysis as to whether the average electricity consumption for the 17 comparator flats is typical. The average annual consumption is 1560kWh (May 2013 to May 2014). For comparison, we used the Ofgem domestic energy consumption factsheet (“Typical domestic energy consumption figures”, Factsheet 96, 18.01.11). Given the relatively small size of the homes, we used the “Typical low annual electricity consumption” which is stated as 2,100 kWh. A potential reason that the recorded electricity consumption is lower than the Ofgem value is that newer more efficient appliances could be expected in these homes, whereas the Ofgem figures are based on dwellings of a range of ages, many of which would have less efficient appliances. Another potential reason is that the most appropriate Ofgem benchmark was the ‘low’ value which is based on a typical household with a low energy consumption. Whilst the flats, due to lower occupancy, would also likely have lower level of consumption that the typical household with medium level of energy consumption, the benchmark is not tailored to lower than average households which is the situation expected for the flats.

In summary, the results of the three flats are as follows. Overall, no particular outliers have been identified compared to the wider population of flats in Norfolk House.

- Flat 1 had an annual consumption of 2020kWh which is 30% above the average consumption (albeit only the fifth highest of the 20 flats). Flat 1 was continually one of the highest consumers during 2013. However, 2014 consumption is consistently around the median which aligns with the period that the MVHR boost switch was set to intermittent.
- Flat 2 had an annual consumption of 1704kWh which is 9% above the average consumption. With the exception of the first month, Flat 2 tends to be around the median level throughout the study
- Flat 3 had an annual consumption of 1565kWh which is approximately the average consumption. Apart from the first three months, the flat tended to have consumption around or below the median.

Table 7.14: Monthly fiscal meter electricity readings (kWh)

Flat Number	5th April 2013	2nd May 2013	28th May 2013	5th July 2013	1st Aug 2013	29th Aug 2013	1st Oct 2013	30th Oct 2013	29th Nov 2013	2nd Jan 2014	31st Jan 2014	28th Feb 2014	31st Mar 2014	1st May 2014	3rd June 2014	30th June 2014
Flat 1	153	165	156	239	137	158	192	173	177	212	146	134	148	148	154	119
Flat 2	180	116	116	172	107	145	117	140	144	162	143	145	162	151	130	120
Flat 3	136	154	143	128	93	99	119	112	103	175	237	106	127	123	132	114
Other 17 flats	43	71	73	67	68	70	94	87	81	99	82	77	89	85	92	69
	94	101	92	125	71	97	105	117	120	107	124	115	125	125	130	94
	151	185	151	251	155	180	136	224	210	166	188	151	207	211	216	187
	120	115	111	174	125	134	167	140	132	151	128	120	145	158	155	121
	105	102	104	145	120	106	125	92	113	192	144	144	154	138	165	123
	123	126	126	179	135	132	132	154	156	255	153	149	145	160	164	142
	70	97	84	137	102	65	124	106	107	119	289	79	111	99	95	81
	93	93	86	127	94	100	112	100	94	112	101	103	108	102	104	87
	103	102	73	130	211	235	178	130	168	197	379	121	178	177	210	196
	136	147	142	157	137	120	149	150	147	284	187	177	190	232	161	113
	124	120	116	157	109	136	130	98	145	130	130	131	153	141	140	113
	121	138	122	216	155	152	191	158	152	190	157	146	172	182	185	157
	133	124	129	187	571	123	162	156	167	228	160	147	162	124	179	182
	79	83	74	110	679	120	151	137	139	136	170	131	138	130	153	120
	44	53	48	81	58	67	65	55	66	66	61	71	62	55	67	56
	74	70	88	145	99	103	128	108	113	112	115	113	100	100	114	68
	54	62	48	99	54	60	78	73	76	81	68	70	76	73	78	69
Average consumption for 17 other flats	98	105	98	146	173	118	131	123	129	154	155	120	136	135	142	116
Flat 1 consumption (and ranking)	153 (2)	165 (2)	156 (1)	239 (2)	137 (6)	158 (3)	192 (1)	173 (2)	177 (2)	212 (4)	146 (10)	134 (8)	148 (9)	148 (8)	154 (9)	119 (10)
Flat 2 consumption (and ranking)	180 (1)	116 (9)	116 (8)	172 (7)	107 (12)	145 (5)	117 (15)	140 (7)	144 (9)	162 (10)	143 (12)	145 (6)	162 (5)	151 (7)	130 (13)	120 (8)
Flat 3 consumption (and ranking)	136 (4)	154 (3)	143 (3)	128 (14)	93 (16)	99 (15)	119 (14)	112 (12)	103 (16)	175 (8)	237 (3)	106 (15)	127 (13)	123 (14)	132 (12)	114 (11)

Heat

Monthly heat meter consumption data is shown inTable 7.15. Similar analysis was undertaken to that described above for electricity consumption. For comparison, the average annual heat consumption of the 17 comparator flats was 2283kWh.

In summary, the results of the three flats are as follows. Overall, no particular outliers have been identified compared to the wider population of flats in Norfolk House.

- Flat 1 had an annual consumption of 898kWh which is 60% lower than the average consumption (the third lowest of the 20 flats). Flat 1 was particularly one of the lowest energy consumers during the final year of the study. It is noted that Flat 1 is a relatively small mid-floor flat and would thus tend to have a lower heat consumption. This was recognised by the resident who said that they did not need to use much heat and, in any case, wished to limit heat use due to the heat tariff.
- Flat 2 had an annual consumption of 3271kWh which is 43% above the average consumption (the fourth highest of the 20 flats). This is highlighted by the frequent high ranking during the study. The Flat 2 resident particularly noted frequent and lengthy showers by the lodger and as noted previously the water usage does appear relatively high.
- Flat 3 had an annual consumption of 1565kWh which is approximately the average consumption. The ranking is around the medium although possibly with consistently lower consumption than the median during warmer months.

Table 7.15: Monthly heat consumption (kWh)

	Q2			Q3			Q4		Q5			Q6			Q7			Q8		
Flat number	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14
Flat 1	312	173	251	218	181	134	107	53	59	52	44	54	88	153	165	86	48	29	49	42
Flat 2	466	250	454	482	748	347	227	175	126	115	209	264	330	381	460	455	330	257	146	181
Flat 3	216	297	450	300	433	162	66	32	28	39	42	71	279	384	233	284	168	94	74	80
Other 17 flats	76	160	244	192	134	83	50	21	13	8	13	17	51	149	119	79	78	15	19	13
	328	590	628	462	545	239	92	75	55	59	49	65	135	446	497	405	146	74	75	56
	122	133	168	126	114	123	104	99	75	62	35	96	86	109	128	83	109	110	95	66
	86	171	235	102	154	113	81	66	44	58	59	90	69	114	131	94	96	126	85	59
	1,116	1,002	1,003	744	1,035	726	517	466	410	405	393	426	636	1,136	1,121	820	667	332	399	190
	746	540	659	375	467	230	137	115	97	100	51	127	231	487	396	333	140	126	129	126
	65	464	472	440	612	309	92	87	86	57	93	147	496	1,314	289	366	471	196	238	123
	-	80	314	186	228	113	405	416	386	382	317	188	267	289	473	331	403	365	283	54
	218	154	285	267	349	186	69	129	143	110	86	114	111	152	72	93	168	136	129	96
	771	758	823	609	660	320	148	88	102	103	149	133	248	446	403	321	285	362	119	86
	167	125	155	173	297	208	120	100	99	95	96	99	120	198	288	275	145	103	105	85
	85	126	128	77	145	85	64	70	47	53	59	64	95	138	129	118	94	85	82	63
	263	190	293	269	318	252	130	134	99	69	104	166	223	267	248	231	203	164	128	140
	543	706	731	438	476	143	37	26	23	21	33	40	121	539	504	347	272	177	144	39
	31	145	216	118	112	44	22	21	10	11	13	16	46	135	174	104	54	23	15	13
	319	202	378	230	261	131	69	70	41	48	50	59	147	260	293	225	107	59	55	31
	144	167	223	242	468	241	110	108	85	74	75	126	225	497	488	410	219	120	137	98
Avg for 17 other flats	299	336	409	297	375	208	132	123	107	101	99	116	195	393	338	273	215	151	132	79
Flat 1 ranking (1 is highest user)	8	11	13	13	15	13	9	16	12	15	15	17	16	14	15	18	20	18	18	16
Flat 2 ranking (1 is highest user)	5	8	7	3	2	2	3	3	4	3	3	2	3	9	6	2	4	4	4	2
Flat 3 ranking (1 is highest user)	11	7	8	8	9	11	16	17	17	17	16	13	4	8	13	10	10	14	16	10

7.5 Benchmarking against SAP calculation

7.5.1 Introduction

We obtained the SAP 2005 assessment documents for Flats 1, 2 and 3. The annual energy demands were extracted for space heating, hot water, fans and pumps and lighting. These were compared against corresponding data collected via the monitoring equipment.

7.5.2 Data adjustment

In order to carry out a fair comparison, adjustments have been made to both the SAP calculation data as well as the data collected from the monitoring equipment.

SAP calculation data

The monthly heating energy use is a summation of the predicted energy for space heating and hot water use. They were determined as follows.

- The monthly energy use from space heating was determined by taking the annual space heating energy use and apportioning it monthly by pro-rating based on the actual heating degree-day data determined from the monitored external temperature at the site.
- The monthly energy use from hot water use was determined by simply dividing the annual use by 12.

Data from monitoring equipment

Monthly summated metered data has been used. The data for fans and pumps was a summation of data from two sub-meters: MVHR and heating controls (which principally comprises the energy use for the space heating circulation pump).

7.5.3 SAP vs. measured

Space heating and hot water consumption

Figure 7.16 shows the comparison of heat energy consumption for space heating and hot water in the three flats.

- The results show the significant lower heat usage of the mid-floor Flat 1 vs the top-floor Flat 2 and Flat 3.
- The adjusted SAP data tends to over-predict actual consumption. Key explanations could be that both the actual air tightness and observed ventilation rates are less than assumed by the SAP assessment and this would tend to reduce the heat load in the flats. A further contribution is that there were additional heat gains arising from the distribution system heat losses from the district heating system (see Section 7.6).

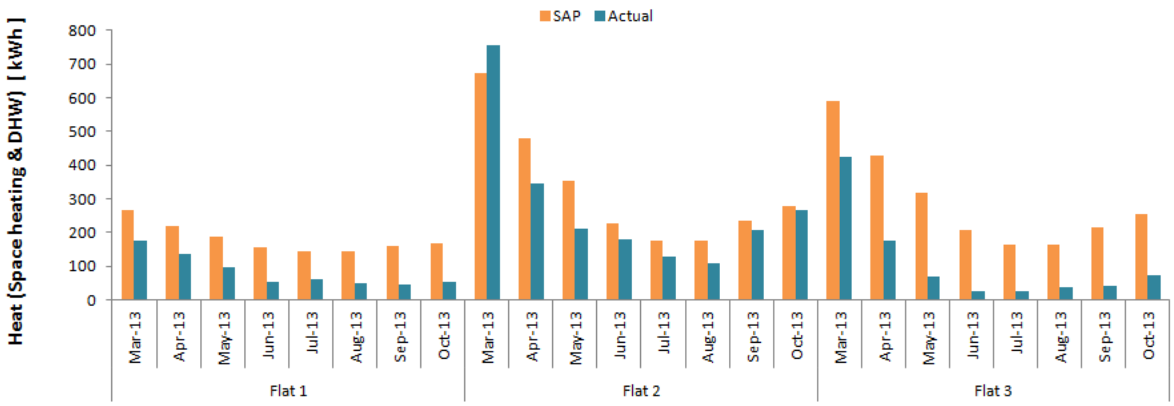


Figure 7.16a: SAP and actual heating energy use for the three flats for March to September 2013

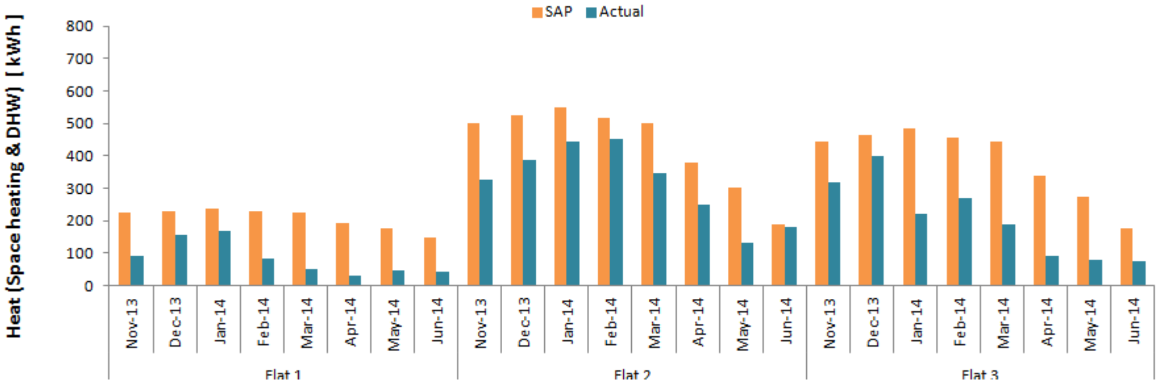


Figure 7.16b: SAP and actual heating energy use for the three flats for October 2013 to the end of June 2014

Fans and pumps electricity consumption

Figure 7.17 shows the energy use for fans and pumps in the flats. The actual consumption is consistently higher than predicted by SAP.

- In particular the results for Flat 1 are significantly higher than the SAP prediction. One key reason is the use of MVHR on boost setting (impact estimated of around 9 kWh per month from data in Section 6) and hence the difference reduces at the start of 2014. Another key reason is that even at normal use the MVHR energy use is higher than predicted as the actual flow rate is similar to that recommended in Part F whilst the SFP is over 100% higher than that included in SAP.
- Given that all actual SFPs were 120-130% higher than assumed in SAP, it may be expected that the actual energy use would be significantly higher than predicted by SAP. It may well be that the higher SFP are balanced at least to some degree by the fact that the ventilation rates were lower for Flat 2 and Flat 3 than recommended by Part F.

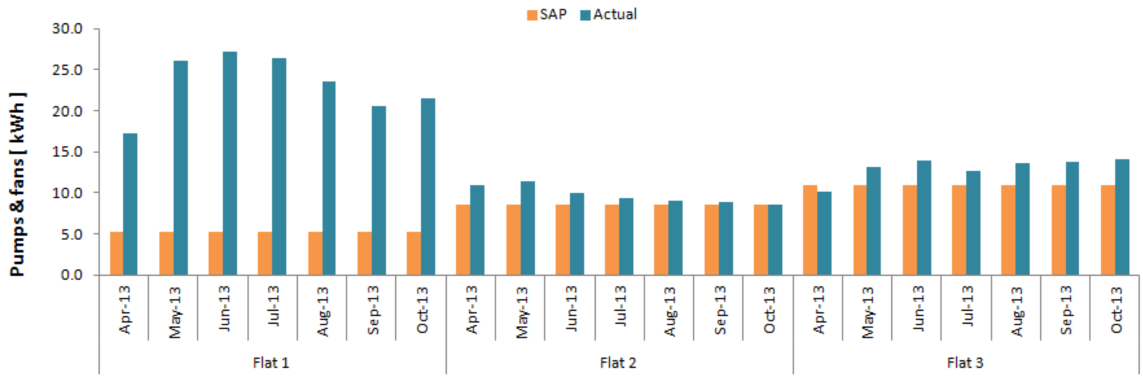


Figure 7.17a: SAP and actual fans and pumps energy use for the three Flats for March to September 2013

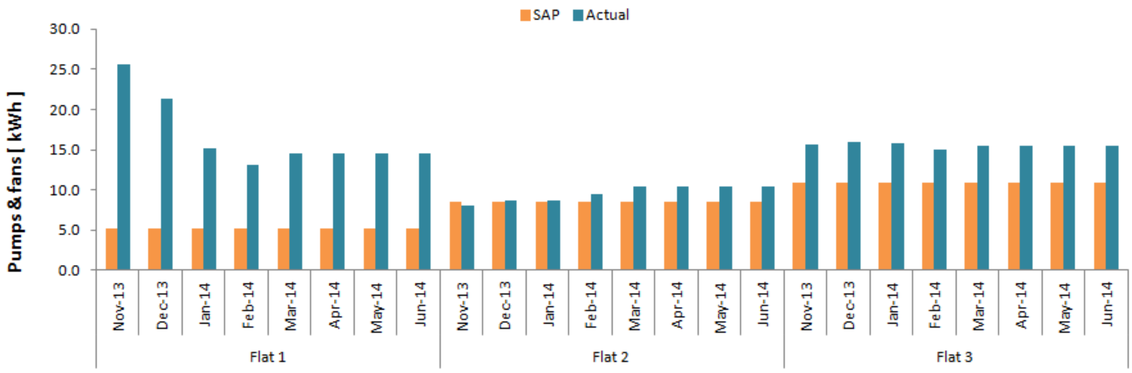


Figure 7.17b: SAP and actual fans and pumps energy use for the three Flats for October 2013 to the end of June 2014

Lighting electricity consumption

Figure 7.18 shows the lighting for the flats. Flat 1 demonstrated a more comparable usage with SAP prediction However, Flat 2 and Flat 3 used significant less lighting than predicted by SAP. This may be explained by feedback during the walkthrough and interview with the occupants of Flats 2 and 3. The occupants expressed preference for standalone lighting, which uses power from the wall sockets. This reduces the need, and thus energy consumption, for ceiling lights which are on the lighting circuit. It was also noted during the final meeting with Galliard Homes that 100% low energy lighting was installed which is greater than that assumed in SAP.

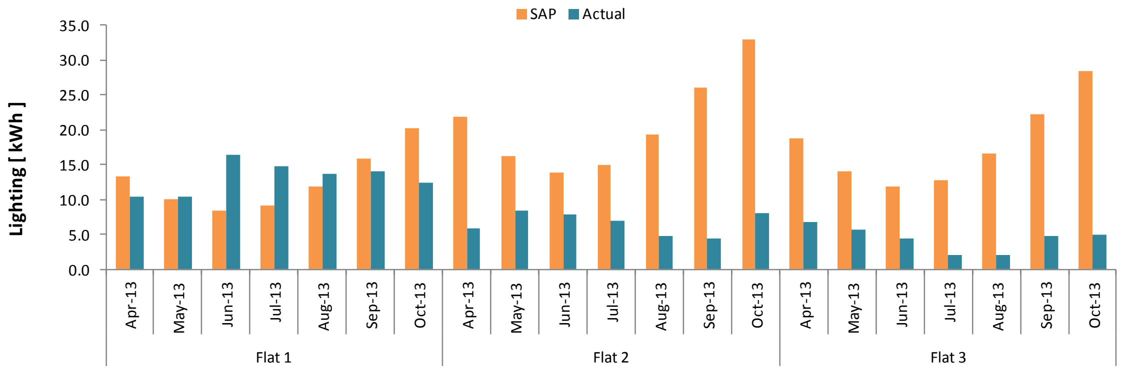


Figure 7.18a: SAP and actual Lighting energy use for the three Flats for March to September 2013

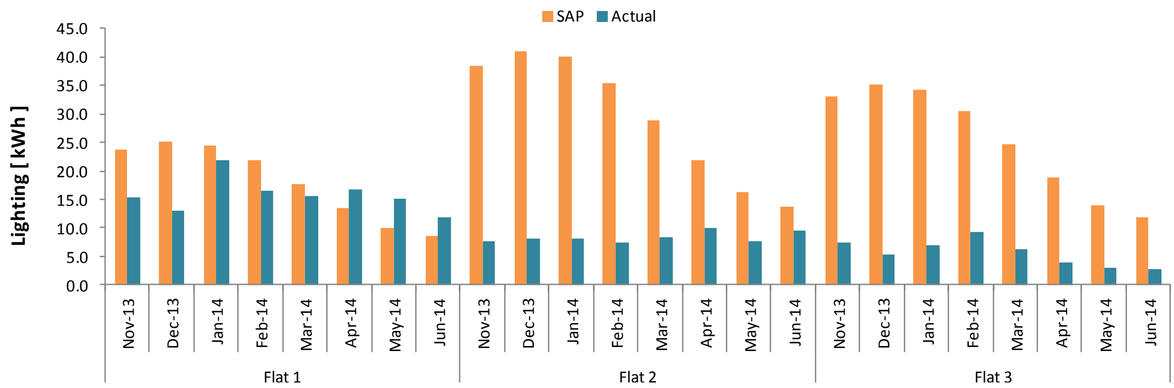


Figure 7.18b: SAP and actual Lighting energy use for the three Flats for October 2013 to the end of June 2014

Overall consumption

Table 7.16 provides an overall summary of the annual energy consumption. The results clearly summarise the discussion above.

- The actual space heating and hot water are 40-65% less than that predicted by SAP.
- For Flat 1 the electricity energy use is 67% greater than predicted likely due to high energy consumption by the MVHR system. For Flat 2 and Flat 3, the electricity consumption is around 50% less than predicted due to significantly less usage of fixed lighting than predicted by SAP (which would have been at least partly off-set by the use of individual lamps powered by wall sockets).

Table 7.16: Comparison of annual energy consumption between actual monitored and SAP predictions for the three detailed study flats

	Space heating + DHW		Electricity - fan, pump, lighting	
	SAP	Actual	SAP	Actual
	kWh/m²/yr	kWh/m²/yr	kWh/m²/yr	kWh/m²/yr
Flat 1	66.84	22.97	5.86	9.77
Flat 2	75.16	46.22	5.86	2.73
Flat 3	78.76	29.21	6.54	3.72

7.6 Performance of the District Heating System

7.6.1 Analysis

An analysis of the efficiency of the communal heating system has been carried out by comparing the fuel used by the energy centre to the heat consumed by all of the apartments connected to the system for the following time periods:

- 2012 winter (1st of October 2012 to 28th February 2013)
- 2013 summer (1st May 2013 to 31st August 2013)
- One year period (1st October 2012 to 30th September 2013)
- 2013 winter (1st of October 2013 and 28th February 2014)

We determined two measures of efficiency

- The delivery efficiency of the community heating system was calculated as the heat delivered to occupants divided by the heat generated in the energy centre.
- The overall efficiency of the community heating system was calculated as the heat delivered to occupants divided by the fuel consumed in the energy centre.

During these time periods only the gas boilers were used (the biomass boiler was used until August 2012). The fuel consumption at the energy centre is based on billing information provided by Galliard Homes which were either based on actual or estimated meter readings. Based on the commissioning report, it is assumed that the gas boiler efficiency is 85%.

Heat consumption of all flats has been assessed based on remote readings collected on-site. It should be noted that the heat use measured by the dwelling heat meters does not take into account the heat loss from distribution pipes within the apartment blocks external to the actual flats.

During the second winter period, the final phase of the site, the Crescent block, has come online as occupants started moving in. The supply of heat to the dwelling units in this block has resulted in an increase in the overall site gas consumption.

Furthermore, a review carried out has established that the heat meter installation in the HIUs was not in accordance with best practice recommendation, whereby a heat meter should be installed at a specified distance away from bends in pipes. The compact nature of the HIUs meant that it is not possible to meet this recommendation, which could lead to issues of accuracy.

7.6.2 Results

The results for the four periods are shown in Table 7.17. The results can be summarised as follows.

- Winter 2012/2013. Based on the heat delivered to the flats within the two constructed apartment blocks (Norfolk House and Distillery Tower), it is estimated that the delivery efficiency of the community heating system was 38%, whilst the overall efficiency of the community heating system was 32%.
- Summer 2013. The efficiency was lower than during the winter period – now with an estimated delivery efficiency of 22% and an overall efficiency of 19%. This reduction is assumed to be as a result of the reduced heat consumed by the flats in the development in the warmer period but the continual circulation of heat through the distribution pipes with consequent distribution losses. Furthermore, additional heat has been generated as part of commissioning and testing of new flats being constructed which were as yet un-metered (Galliard Homes reported this testing started taking place around the end of July 2013). The energy used for construction has been allowed for in the calculation of the residents heating bills by Galliard Homes.
- Annual 2012/2013. A performance somewhere between that of the winter and summer periods.
- Winter 2013/2014. The delivery efficiency was 40%, whilst the overall efficiency was 33%. This is very similar to the performance during the first winter period.

This is a very low level of performance. Some issues were highlighted previously in Section 2. However it is expected that a key cause of this performance is the relatively high distribution losses compared to the heat load. It is noted that as part of this study we have not evaluated whether any such distribution losses are as a result of the pipework installation and/or the standards of insulation on heating pipework are below what is required to achieve a reasonable system distribution loss and to limit overheating in dwellings. It can be expected that the delivery efficiency will improved somewhat as increased number of buildings come on-line and greater overall efficiencies can be gained from the communal heating system with the ability to also use the CHP and benefit from the additional generation of electricity.

Table 7.17: Analysis of the energy centre performance based on data from 1st October 2012 to 28th February 2014

	2012 winter	2013 summer	One year period	2013 winter
	1th Oct 2012 to 28th Feb 2013	1st May 2013 to 31st Aug 2013	1st Oct 2012 to 30th Sept 2013	30th Sept 2013 to 28th Feb 2014
Energy centre fuel use	**kWh**	**kWh**	**kWh**	**kWh**
Gas boiler	945,667	496,748	2,141,993	1,383,281
Biomass boiler	-	-	-	-
CHP	-	-	-	-
TOTAL heat generated	803,817	422,236	1,820,694	1,175,789
Heat delivered to occupants	**kWh**	**kWh**	**kWh**	**kWh**
Norfolk House	100,312	25,817	172,928	85,637
Distillery Tower	205,618	66,553	394,081	214,164
Crescent (online around Autumn 2013)	-	-	-	171,713
TOTAL	305,930	92,370	567,009	471,513
Estimated delivery efficiency	38%	22%	31%	40%
Energy plant overall efficiency	32%	19%	26%	34%

7.7 SAP calculation review

Changes have been made to the as-built SAP calculation based on information found about the actual performance of the three detailed flats. Table 7.18 shows a summary of the modifications made to as-built SAPs.

- Air permeability tests (reported in Section 3) which show significantly better performance compared to both that previously assumed in SAP and that measured at building completion.
- MVHR specific fan performance tests (reported in Section 6). We include here the actual performance for SFP which is significantly below that assumed previously in SAP. We do not have information on the actual heat exchange efficiency.

Table 7.18: Summary of modifications made to as-built SAPs based on findings from site visits and tests

		Flat 1	Flat 2	Flat 3
Air permeability	As-built: value entered into SAP	8	8	8
	After modification: value entered into SAP	2.4	3.2	3.6
MVHR	As-built	SFP: 0.59 W/l/s; Heat ex efficiency: 92%	SFP: 0.59 W/l/s; Heat ex efficiency: 92%	SFP: 0.68 W/l/s; Heat ex efficiency: 91%
	After modifications	SFP: 1.34 W/l/s; Heat ex efficiency: 92%	SFP: 1.31 W/l/s; Heat ex efficiency: 92%	SFP: 1.51 W/l/s; Heat ex efficiency: 92%
DER	As-built	12.77	13.82	14.60
	After modifications	13.41	15.27	18.65
TER	TER	21.34	21.12	23.90
% reduction of DER over TER	As-built	40.2%	34.6%	38.9%
	After modifications	37.2%	27.7%	22.0%

Despite the inclusion of better air permeability, the poorer specific fan power resulted in an increase in the DER. It is noted that the results still meet Part L of the Building Regulations. Furthermore, the measured low ventilation rates compared to Part F, particularly for Flat 2 and Flat 3, actually result in a significant reduction in space heating loss in practice compared to that predicted.

7.8 Dwelling CO_2 emissions compared to SAP

The monitored heat and electricity energy use in the dwellings have been converted into CO_2 emission rates and compared against that predicted for the dwellings via the as-built SAP calculation outputs provided by Mendick Waring. Whilst we have shown earlier that the actual energy consumption is significantly less than predicted, the actual CO_2 consumption is much higher than predicted as can be seen from Table 7.19 with Flat 2 almost tripling its SAP prediction.

There are two key reasons for the higher CO_2 emissions.

- The low efficiency of the community heating system during the course of this study. As shown earlier in this section, the heating system is currently operating at an annual efficiency of approximately 26% (see Section 7.6).
- The sole use of the centralised gas boiler for heating during this study. The design intent is based on the use of both the gas CHP and biomass boilers which results in a significantly lower prediction of CO_2 emissions in the corresponding SAP assessments.

Table 7.19: Comparison of monitored dwelling CO_2 against as-built SAP predictions for the three detailed study flats

	Actual	SAP	% difference
	kgCO2/yr	kgCO2/yr	kgCO2/yr
Flat 1	962.5	521.5	85%
Flat 2	2625.8	931.6	182%
Flat 3	1479.2	849.4	74%

7.9 Conclusions and key findings for this section

The key conclusions from the three flats studied in most detail:

- The results of comparing the three flats with the full sample showed that the total electricity and heat consumption were typical of the apartments within the apartment block.
- The combined space heating and hot water energy use for the three apartments is 40 to 65% less than predicted by SAP. Key reasons include: (i) the actual air permeability being less than 50% assumed in SAP and (ii) the actual ventilation rates significantly less than recommended by Part F of the Building Regulations.
- The regulated electricity use for the three apartments is more variable in comparison with SAP. For Flat 1 the electricity energy use is 67% greater than predicted, a key contribution being that the MVHR system was constantly on boost for much of the project duration. For Flat 2 and Flat 3, the electricity consumption is around 50% less than predicted due to significantly less usage of lighting than predicted by SAP with both sets of occupants expressing their preference for standalone lighting, which uses power from the wall sockets. We were not able to determine separately the electricity use for stand-alone lighting to compare against this lower than predicted consumption of fixed lighting.
- All three flats experienced periods of overheating during the summer of 2013 as evaluated against the CIBSE Guide A criteria. This occurred in both the living room and bedroom monitored. This could be due to the high amount of glazing rendering the flats susceptible to excessive solar gain, coupled with insufficient ventilation through the mechanical ventilation in some of the flats, which also appears not to feature the capability for a summer by-pass. The BUS noted issues with external noise which could have limited opening of windows. It should be noted that the SAP assessments showed a 'slight' overheating risk in Flat 3 and 'medium' overheating risk in Flat 1 and 2 with all assessed as passing Criteria 3 of Part L of the Building Regulations by the SAP software. None of the flats were rated as having a 'high' overheating risk.

- Flat 2 exceeded the RH criteria recommended by Part F of the Building Regulations on a number of occasions, particularly in the bathroom. This may be explained by the fact that we identified that the ventilation boost operation was not operating via the bathroom light switch.
- For Flats 1 and 2, there were periods of time where in the living room the average 8-hour CO_2 level exceeded the guideline of 1830ppm. Reviewing the data, the exceedances all occurred during afternoon and/or evenings at either at weekends or bank holidays. It is presumed that these levels are caused by visitors coming around. It is noted that the MVHR flow rates recommended in Part F are for a standard occupancy with the potential to open windows during periods of occasional high pollutant events (e.g. visitors). It is also noted that the MVHR rates measured were lower than those recommended in Approved Document F. Whilst there may have been some dissatisfaction from occupants from the high levels of metabolic odour, it was unlikely to be a health concern.

The key conclusions from the 12 home study of unregulated electricity use:

- The top two energy readings were from the use of televisions. However, there was a significant spread in results between all homes where a television was monitored which may reflect the type of television and its hours of use. The measurements were all within or below the DomEarm benchmarks.
- Freezers and fridge-freezers were the second highest category of energy use. In particular, the freezer consumption was higher than the DomEarm benchmark. The location of the freezer in the living room, which may have been warmer than the kitchen and being surrounded by general storage of items may have impeded adequate ventilation to the condenser, may have led to increased energy use.
- In general, the results were within or below the DomEarm benchmarks.

The key conclusion from the evaluation of the performance of the district heating was the low actual overall communal heating system annual efficiency of 26%. It is expected that a key cause of this performance is the relatively high distribution losses compared to the heat load – albeit some of this would be useful heat during the winter period where the heat loss occurred within the apartment building. It is noted that as part of this study we have not evaluated whether any such distribution losses are as a result of installation and/or the standards of insulation on heating pipework are below what is required to achieve a reasonable system distribution loss and to limit overheating in dwellings. It can be expected that the efficiency will improved somewhat as increased number of buildings come on-line and greater efficiencies can be gained from the use of the CHP. As a result of the low plant efficiency, the CO_2 emission rates are significantly higher than predicted (nearly three times in the case of one of the apartments) even allowing for the fact that the actual energy consumption is significantly less than predicted.

8 Key messages for the client, owner and occupier

8.1 Introduction

We present here feedback from both the occupants and developer during the course of this study.

8.2 Occupier feedback

Written feedback and face-to-face meetings were held with occupants from the 3 detailed study homes on 15th July 2013 for Flat 2 and 3 and on 22nd July 2013 for Flat 1. Feedback was provided at the end of the study in September 2014. Ad-hoc discussions have also taken place during the project. Overall, this engagement has been useful in both informing the residents on the performance of their properties and how potentially to improve their performance as well as residents providing useful information to us to help explain the findings from the study. This feedback is in addition to occupant feedback during the initial walkthroughs in Section 4.

In particular, the following list of items has been discussed with the residents.

- Heating, electricity, water consumption data
- MVHR and ventilation issues
- Energy use of appliances monitored via the plug monitors

Key feedback received from residents is as follows:

- All residents were interested in the data presented to them
- All residents were surprised at the relatively higher electricity consumption in their flats compared to the average of 17 other flats during the July 2013 meetings.
- Flat 1 highlighted during the July 2013 meeting that recent acquisition of a new television and kettle, which were both featured to be energy efficient and hoped that this will be reflected somewhat in subsequent data.
- At both the July 2013 meeting and subsequently, AECOM highlighted that the occupant was using the MVHR on continuous boost ventilation. Hence, during the latter part of the study, the MVHR operation was only switched to boost when needed.
- Flat 2 highlighted during the July 2013 meeting that the increase in heat and water consumption coincided with a lodger moving in, with whom a fixed all inclusive rent has been agreed. The lodger liked to frequently have long showers has been evident in the data presented to date. Flat 2 wanted to use the feedback to feedback to his lodger in the hope of influencing behavioural change. This was discussed again at the end of the study period and feedback was that there had been no change in behaviour but either the owner or lodger was away for much of the summer period.
- Resident in Flat 3 highlighted that due to recent major leak at the roof of Norfolk House over the Christmas period (end December 2013), which caused water ingress into the flat, the use of two electrical dehumidifiers subsequently to dry out the flat have had evidential impact on the electricity consumption in January 2014. The increase in heating consumption in December 2013 was also linked to the initial effort to dry out the flat through opening windows to ventilate the flat to mitigate mould growth.

8.3 Owner feedback

There has been on-going dialogue with Galliard Homes since the development of the project proposal. Whilst it has covered all issues, there was particular interest in the performance of the communal heating system.

A formal meeting was additionally held at the end of the study (19th September 2014) with both Galliard Homes and Amicus Horizons. The findings from the study were presented. Key feedback from the meeting was as follows:

- The homes were fitted with 100% low energy lighting which is higher than assumed in Part L (Part L 2006 assumes 30% low energy lighting). This may partly explain the relatively low lighting energy measured.
- The risk of overheating was rated as 'passed' by the SAP software and complied with Part L of the Building Regulations. None of the flats were rated as having a 'high' overheating risk.
- The Energy Centre appears to have been oversized. For example, the lowest output available from the 800kW biomass boiler is more than the daytime winter idling load of the completed scheme. This puts future use of the biomass boiler into question. This partly relates to the fact that there appeared to be no re-evaluation of the size of the heating systems by the contractors from the concept to final design stages. It is important that the design team understands the concept of community heating.

8.4 Conclusions and key findings for this section

Regular engagement took place between AECOM and both the participating occupants and Galliard Homes. This was very helpful both in reporting back results and getting feedback which helped explain the results observed.

Feedback from the occupants was that whilst a large amount of useful information was provided in the form of documentation, it did not provide all of the practical information. In particular, it was recommended that face-to-face orientation/handover would have been helpful. This should include the correct operation and maintenance of the MVHR system. Points raised in this study included the inappropriate use of the boost switch and dirty extract filters.

All three flats experienced periods of overheating during the summer of 2013 as evaluated against the CIBSE Guide A criteria. This contrasts with the risk of overheating being 'passed' by the SAP software. This suggests that the SAP software does not provide a robust measure of the risk of over-heating and care should be taken in relying upon it. Furthermore, this incidence of overheating could be due to a combination of: (i) the high amount of glazing rendering the flats susceptible to excessive solar gain, (ii) the MVHR ventilation rate in some of the flats being below that recommended by Part F of the Building Regulations, which also appears not to feature the capability for a summer by-pass, and (iii) likely distribution heat losses within the apartment building from the district heating system during the summer period.

Issues were identified with regards to the installation and commissioning of the energy plant, particularly with the system controls which have impacted on its operation. Key learning points are the need for more detailed design specifications for installation and commissioning and an experienced mechanical and electrical installation company capable of delivering it.

9 Wider Lessons

9.1 Recruitment

Recruiting study participants

During the project proposal development, we decided that we would focus monitoring on the Norfolk House apartment block. This block was shared ownership between the occupants and Amicus Horizon, a social housing provider. There were two key advantages of this strategy.

- Amicus Horizon agreed to support recruitment.
- As the properties in Norfolk House were shared ownership, the occupants were likely to be resident during the duration of the study. By comparison, within Seager Distillery Tower, a number of the flats were privately rented with potentially shorter-term tenants and thus change of occupants during the project

However, at the actual time of recruitment there were significant concerns by tenants that the heating tariff was higher than originally agreed. Whilst Amicus Horizon did provide some support, their efforts were limited as their view was that it was not a good time to recruit volunteers and steered AECOM away from directly contacting the residents. Hence, AECOM with support from Galliard Homes, had to directly recruit most of the volunteers which proved much more difficult (both in terms of time and resources) than planned.

The experience highlights the difficulty of recruitment and the importance of having local engagement if possible.

9.2 Installation and commissioning of monitoring equipment

We believe that we undertook reasonable practices during installation for it to progress successfully. However, in particular, issues particularly arose for the electricity sub-meter installation (see Appendix A). We spent a day in advance with the Galliard's electrician preparing in detail for the installation of the sub-meters. Unfortunately, this electrician was ill on the day of installation and, due to property access difficulties, we went ahead with another electrician who was not familiar with the equipment. We also paid for Eltek (equipment supplier) to attend on one of the first days to review the work to ensure that the equipment was correctly set-up but unfortunately work on that day needed to be aborted prior to installation. We subsequently had issues with the electricity sub-metering that took significant time and resources to resolve.

We had not considered paying for specialists to install and commission the equipment. Our understanding from the equipment supplier that this was something an electrician could do and Galliard's Homes provided us with one of their electricians. Given the difficulties, particularly in accessing the properties subsequently to undertake checks and make necessary modifications, it would have been more cost-effective to employ specialists from the start i.e. the larger upfront cost to specialists would have outweighed the cost by the AECOM team in addressing issues identified. However, now better knowing the potential problems, installation and commissioning may well progress well with the same team in future work. We note that the installation for the third flat installed (Flat 2) went well and we did not have to make any subsequent amendments.

9.3 Operation of monitoring equipment

We had several technical issues associated with measurement equipment throughout the course of the study. In particular we note the following which may provide valuable learning.

- Plug monitors
  7 out of 44 plug monitors to collect data on small power consumption became faulty during this study. This questions the long-term reliability of these monitoring devices. It is unclear whether this is indicative of the particular product (could be a bad batch) and/or plug-in monitors in general.

- In-situ U-value measurements
  We commissioned this work to specialist providers. There were issues of both the data loggers not working and staining on the walls from the equipment used. As discussed earlier, it is important that there is sufficient preparation prior to coming on-site and sufficient time is spent ensuring the equipment is working properly prior to leaving site. This is particularly important when evaluating the performance of domestic properties as there can be more difficulties in gaining access. AECOM also has concerns with the robustness of the methodology used to avoid staining from the use of thermal coupling paste between the heat flux probe and the wall.
- Thermographic imaging
  Whilst thermographic imaging survey is a useful technique to infer building fabric performance, its usability becomes somewhat diminished on modern building with highly-glazed or ventilated cladding façade. However, some salient features will remain distinguishable to provide some qualitative inferences to the performance of the fabric.

9.4 Building handover

Feedback from the occupants was that whilst a large amount of useful information was provided in the form of documentation, the occupants did not readily have all of the practical information to operate and maintain their equipment. This is likely to be increasingly of concern as new types of building services and renewable technologies are installed to meet Part L and local Planning requirements. In particular, the residents highlighted that it would be helpful to be provided with a face-to-face orientation/handover.

9.5 Overheating

All three flats experienced periods of overheating during the summer of 2013 as evaluated against the CIBSE Guide A criteria. This contrasts with the risk of overheating being ‘passed’ by the SAP software. This suggests that the SAP software does not provide a robust measure of the risk of over-heating and care should be taken in relying upon it. Furthermore, this incidence of overheating could be due to a combination of: (i) the high amount of glazing and the lack of external shading for these specific flats rendering the flats susceptible to excessive solar gain, (ii) the MVHR ventilation rate in some of the flats being below that recommended by Part F of the Building Regulations, which also appears not to feature the capability for a summer by-pass, and (iii) likely distribution heat losses within the apartment building from the district heating system during the summer period.

9.6 District heating system

The study highlighted that the efficiency of the district heating scheme was significantly below that estimated at design stage. AECOM is aware from wider discussions that others are similarly identifying this problem particularly where building relatively small new developments. As noted here, it is important to ensure detailed design specifications for installation and commissioning and an experienced organisation capable of delivering it. It is also important to accurately assess the likely distribution heat losses from a scheme at design stage when evaluating the best means to deliver heat to the buildings.

9.7 Conclusions and key findings for this section

In summary, this section highlights the following.

- Recruiting residents for participation in BPE studies is challenging and it is beneficial to involve an organisation that is in contact with the residents and has their trust.
- Given the difficulties of accessing residential properties, due to occupant availability, it is best that installation and commissioning of monitoring equipment is undertaken by an organisation with sufficient experience in doing such work.
- Those involved in any specialist testing should have sufficient training in advance to use the equipment and sufficient time spent on-site to ensure equipment left on-site is working correctly.

- Appropriate handover should be provided to the building occupants to enable them to operate and maintain their building services equipment properly.
- In designing the property, it is important to give adequate thought to minimising the risk of overheating and one should not rely on a 'pass-mark' from SAP.
- It is important to ensure detailed design specifications for installation and commissioning and an experienced organisation capable of delivering it. Furthermore, the likely distribution heat losses should be accurately determined when evaluating the most appropriate means of providing heat to properties.

10 Appendix A – Commissioning of monitoring equipment

10.1 Electricity sub-meter installation commissioning

The equipment was installed on the following dates by a Galliard Homes electrician. A day had been spent on-site with an initial electrician preparing for the installation but this electrician had to be replaced with an alternative who carried out all of the installations.

- Flat 1 – 12th and 13th February 2013
- Flat 2 – 27th February 2013
- Flat 3 – 25th February 2013.

However, commissioning was not finally completed until the end of May (although it demonstrated that data from 13th March was usable as discussed further below). Commissioning comprised the following two activities.

- For the total consumption recorded remotely from the sub-meters to equal (within equipment accuracy levels) to the consumption on the fiscal meter
- For the consumption recorded remotely from each of the sub-meters to equal the consumption on the digital display of the PRO1DE sub-meters themselves.

There were a significant number of issues which resulted in the fairly large period of time between initial installation and final comissioning.

- Access to commissioning information: AECOM was reliant on the occupant to send the PRO1DE sub-meter display readings to compare with the remote readings. Furthermore, initially, AECOM needed to visit Norfolk House to read the fiscal meters (round trip of half a day), although towards the end of the period Galliard Homes' staff provided this information.
- Data loss: We had transmission loss with Flat 3 in Norfolk House which was furthest from the data logger. We included a repeater in Flat 3 to increase the signal strength which resolved this problem.
- Labelling of circuits: Some sub-circuits were mislabelled on the consumer unit. This related to the first two flats installed (Flats 1 and 3). This was addressed by testing the circuits in subsequent visits to determine what devices they were supplying.
- Polarity of the connections between the PRO1DEs and the GD68 transmitter: Some of the circuits were incorrectly wired into the GD68 transmitter which could potentially result in erroneous readings. Eltek helped address this problem on visits to the properties to help resolve difficulties identified.
- Incorrect wiring of one of the PRO1DE devices: This resulted in a zero reading from this PRO1DE device and therefore a zero remote reading. This was identified and addressed by Eltek on the 28th May.
- Access to the flats: In order to make changes to the set-up, access was needed to the flats which proved difficult. The occupants typically worked during the day. Access had to be synchronised with the availability of Galliard Homes and Eltek personnel to resolve the difficulties.
- Resolution of meters: The remotely accessed sub-meters provided information at 0.5Wh resolution. However, the PRO1DE digital display was only resolved to 10Wh and the fiscal meter was only resolved to the nearly kWh. Hence, several weeks were often needed to provide the necessary resolution to undertake commissioning checks.
- Error in AECOM's calculation spreadsheet which suggested larger discrepancy between the remote and fiscal meters than was the case.

An original comparison of the main fiscal meter electricity consumption to that of the total consumption of the remote sub-meters readings between 12th March and the 5th April 2013 showed differences of 5%, 2% and 2% for Flats 1, 2 and 3 respectively (the fiscal meter being higher than the summation of the sub-meter readings). Whilst some refinements were made after this, given the close correlation, we have in this report included data from the 12th March.

A further comparison between Eltek sub-metered logged data and fiscal meter readings between the 28th May and 20th June produced the results shown in Table 10.1 in after all commissioning activities had been completed.

Table 10.1: Comparison of data logger data and fiscal meter (28th May to 20th June 2013)

Flat no.	Fiscal meter readings (kWh)			Total sub-meter readings (kWh)	% Discrepancy between data logger data and fiscal meter
	28th May	20th June	Total consumption, kWh	Total consumption, kWh	
1	1,622	1,765	143	139.46	2%
2	2,542	2,650	108	104.39	3%
3	2,732	2,809	77	73.46	5%

As the table shows, the discrepancy measured between the sub-meters and fiscal meters for each of the flats ranged between 2 and 5%. In all cases, the sub-meters showed a lower electricity consumption than the main fiscal meter. These discrepancies are within the accuracy of the instructions and can be accounted for by a combination of the following.

- We do not know the accuracy of the fiscal meters. However, regulations require them to be between +2.5% and -3.5% of the actual reading
- Information from the supplier of the sub-meters is that they are accurate to +/- 1%
- Information from the supplier of the sub-meters is that they could consume up to approximately 1 W per channel (a total of 8 channels per flat) which is not read by the sub-meter itself (hence a potential lower reading on the sum of the sub-meter readings compared to the fiscal meter).
- There is up to 1% data loss by the sub-meters e.g. there are no readings during the period when monitored data was downloaded.
- There will be some power consumption between the fiscal meter (located external to the property in a central riser) and the sub-meter e.g. the electrical pathway between the consumer unit and the fiscal meter is via cable, the consumer unit may also consume a small amount of electricity.

The consumption of each of the 8 sub-circuits measured by the PRO1DEs for Flats 1,2 and 3 have been compared with the remote readings for a period of approximately 4 months and have been found to be consistent. They have a small difference (less than 1%) which is explained by the difference in resolution - the PRO1DEs show data to the nearest 10Wh while the remote data is shown to the nearest 0.5Wh - as well as small levels of data loss (<1%).

10.2 Heat meter installation and commissioning

The original radio heat meters that were installed in the three flats were replaced with heat meters that generate a pulsed output to allow us to monitor the heat consumption of each flat at 5 minute intervals via the same monitoring equipment. The pulsed heat meters that were installed for monitoring purposes had their measurement resolution changed from 1 kWh to 0.1 kWh by the supplier of the heat meters. The heat meters were installed in each of the three flats by a plumber supplied by Galliards on the following dates:

- Flat 1: 12th February 2013
- Flat 2: 27th February 2013
- Flat 3: 25th February 2013

The heat meters were commissioned by comparing the manual readings displayed on the heat meters with the consumption recorded remotely via the logger over the period shown in Table 10.2.

Table 10.2: Heat meter commissioning results

	Commissioning test date	Consumption		Discrepancy (% remote readings lower than the heat meter)
		Manual readings (kWh)	Remote readings (kWh)	
Flat 1	13th Feb to 12th March 2013	251.2	245.1	2.4%
	12th March to 22nd July 2013	433.1	430.6	0.6%
Flat 2	28th Feb to 15th July 2013	1746.7	1742.2	0.3%
Flat 3	16th Feb to 12th March 2013	201.7	202.1	-0.2%

The small differences for Flats 2 and 3 are likely a combination of data loss (up to 1%) and resolution errors (all readings are to the nearest 0.1kWh). The larger initial 2.4% discrepancy for Flat 1 can be explained by the heat meter being installed (and read) a day before the logging of data commenced. The discrepancy of readings between the heat meter and the remote data is 6.1kWh. This is within the range of a day's heat consumption in the flat, which ranges between 6 to 15kWh based on data collected by the Eltek data logger to date. Further commissioning of the Flat 1 heat meter was carried out based on manual and remote reading for period between 12th March and 22nd July. The discrepancy between the readings has improved significantly to 0.6% which is within the range expected given data loss and resolution errors.

10.3 Water meter commissioning

The water usage monitoring equipment was installed by AECOM on the 26th February 2013 for all three Flats. The installation was carried out by AECOM as the installation was simple. Prior to this AECOM confirmed the wiring connections between the Elster PR6 pulse generator with Eltek.

However, the remotely read consumption data were incorrect. On the 12th March 2013, AECOM and an Eltek engineer visited Norfolk House. It was found that the water meter monitoring equipment was incorrectly set-up - the information supplied to AECOM on how to connect the PR6 units to the GC62 was incorrect. In addition, the PR6 pulse generator unit for Flat 2 was not operating properly. AECOM and the Eltek engineer visited Nolfolk House on the 5th April 2013 to correctly set-up the monitoring for all three propertes.

To commission the equipment, the consumption recorded remotely was compared to the consumption visually shown on the water meter between 5th April and 2nd May 2013. About half a day of data was lost from the data logger between the 20:15 on the 23rd April and 09:25 on the 24th April. Therefore, an adjustement was made to the consumption shown by the logger to estimate the water usage during the time when the data was lost. When this adjustment is made, all three flats show less than a 0.5% discrepancy between the fiscal water meter and the monitoring equipment. Table 10.3 shows the calculation to determine the adjustment to take account for data loss. Table 10.4 shows the comparison between the fiscal water meter and the monitoring equipment.

Subsequent commissioning of the water meters were carried out as more data was collected and compared with further manual reading of the fiscal meters.

Table 10.5 shows the second set of commissioning results. We repeated this work to confirm that our adjustment was appropriate. The results show satisfactory reconciliation between remote and manual reading had been achieved. The very small differences are easily explained by data loss and resolution errors.

Table 10.3: Calculation to determine adjustment to take account for data loss

	Weekdays on previous week (15th April to 19th April)	Weekdays a week ahead (29th April to 3rd May)	Average
	Corresponding usage (L)	Corresponding usage (L)	Corresponding usage (L)
Flat 1	56.8	68.3	62.5
Flat 2	102.5	82.8	92.6
Flat 3	71.0	66.0	68.5

Table 10.4: Water meter commissioning results

	Fiscal meter consumption (m^3)	Remote consumption (m^3)	Adjusted remote consumption (for half day data loss) (m^3)	Discrepancy (% lower than water meter) - not adjusted for half day data loss	Discrepancy (% lower than water meter) - adjusted for half day data loss
Flat 1	3.72	3.64	3.70	-2.3%	-0.58%
Flat 2	9.09	8.91	9.00	-2.0%	-0.98%
Flat 3	4.00	3.93	3.99	-1.8%	-0.09%

Table 10.5: Second set of water meter commissioning results

	Commissioning test date	Consumption		Discrepancy (% remote readings lower than the heat meter)
		Manual readings (m^3)	Remote readings (m^3)	
Flat 1	2nd May to 5th July 2013	9.59	9.57	-0.2%
Flat 2	2nd May to 5th July 2013	20.68	20.67	-0.1%
Flat 3	2nd May to 5th July 2013	6.39	6.38	-0.2%

10.4 Temperature, humidity and CO_2 sensor commissioning

Location of temperature, humidity and CO_2 sensors

The battery operated temperature and RH monitors in the bedroom and the bathroom were located 1-2m from the ground e.g. on a bookcase. The mains operated temperature, RH and CO_2 monitors were located on the ground near the sockets for practical reasons (limited length between mains adaptor and monitor and lack of suitable higher location near sockets).

There were some temperature spikes in Flat 53 of approximately 28 °C at about 2pm on a number of days which seemed unusual. On a site visit on the 28th May 2013, we planned to move the GD47 sensor from a position where it was expected that it would be exposed to direct sunlight. On visiting the flat, it turned out that the occupants had already moved the GD47 to a suitable location as part of the re-arranging of their living room to accommodate new furniture.

Data capture commissioning

On the initial stages of data collection, significant data loss was recorded. This was due to weak signal reception from the transmitters for Flat 3. A repeater was added to the instrument configuration to boost signal reception and this has proven to reduce signal losses to around 1% which was deemed acceptable.

11 Appendix B – Allowing for data loss in analysis

We outline how we have addressed data loss in our analysis. This data loss derives from three sources.

i. The first is when the equipment does not successfully transmit measurements to the central data logger. The utility and environmental metering equipment are set-up to wirelessly transmit data to the central logger every five minutes. If the data is not received by the central logger, the system is set-up to transmit repeatedly within the five minute interval until the next set of data is ready. If the data is not received, "no data" is recorded at that time step. If the temperature, RH and CO_2 data is not successfully transmitted, this data is lost. If the electricity, heat and water meter data is not successfully transmitted, the consumption is simply added to the next 5 minute reading. Hence, in this case, data is not lost but the time granularity is reduced i.e. if every other set of recorded data was not transmitted successfully, we would receive the full consumption data but at 10 minute intervals.

ii. The second is when the logger memory storage is full and it cannot record any more data. This occurred once between 31 March 2014 8.45pm and 2 April 2014 2.25pm due to a problem of connecting to the data logger to download the data. This issue is now resolved.

iii. The third is that the logger does not appear to record data whilst AECOM is downloading the data remotely. In this case, no data is captured during the period of remote download and there are missing times in the data download. However, the impact is relatively negligible as only one or two timesteps worth of data is used (i.e. 5 or 10 minutes of data each weekly download).

For temperature, RH and CO_2 data lost:

- In the case of the first cause of data loss, we have simply assumed that the missing reading is the same as last received data. This reading replaces 'no data' in the dataset.
- For the other two cases, we have not added any data. The evaluation in the analysis plan is based on time-based averages. Given the relatively small amount of missing data (<1%), it would not significantly impact on the results.

For utility data lost:

- In the case of the first cause of data loss, as noted above, the consumption data is simply added to the next successful transmission of data. Hence, simply time granularity is reduced.
- For the other two cases, we wish to obtain accurate total consumption. We have simply increased the monthly consumption data by the percentage of data loss.

12 Appendix C – Monthly utility data for the detailed flats

Table 12.1 summarises the monthly consumption data for each of the flats recorded from the commencement of the monitoring until the 30th June 2014.

Table 12.1: Summary of monthly electricity, heat and water consumption

Monthly consumption		Flat 1	Flat 2	Flat 3
Electricity (kWh)	March 2013	117	127	104
	April 2013	173	154	165
	May 2013	183	129	164
	June 2013	178	139	91
	July 2013	164	116	104
	August 2013	174	114	104
	September 2013	164	138	104
	October 2013	179	148	115
	November 2013	171	138	98
	December 2013	191	144	148
	January 2014	152	146	254
	February 2014	130	140	101
	March 2014	147	161	125
	April 2014	129	135	112
	May 2014	140	114	121
	June 2014	128	130	122
Heat (kWh)	February 2013	168	22	85
	March 2013	175	757	425
	April 2013	134	344	175
	May 2013	96	211	70
	June 2013	54	181	26
	July 2013	60	126	27
	August 2013	50	110	39
	September 2013	43	205	43
	October 2013	53	267	71
	November 2013	91	329	318
	December 2013	157	386	400
	January 2014	168	47	220
	February 2014	84	453	271
	March 2014	51	346	189
	April 2014	31	252	90
	May 2014	49	133	79
	June 2014	30	179	77
Water (L)	April 2013	3338	8414	3649
	May 2013	5577	9940	4522
	June 2013	3843	10760	1893
	July 2013	5401	8869	2495
	August 2013	4366	8988	3221
	September 2013	3494	12982	3042
	October 2013	3968	13775	3594
	November 2013	4569	11619	2510
	December 2013	4824	9633	2547
	January 2014	4427	9538	3911
	February 2014	3636	10405	3989
	March 2014	3967	12666	5043
	April 2014	2516	11949	4476
	May 2014	3653	7082	4855
	June 2014	3503	11569	5338

13 Appendix D – Detailed graphs of temperature data in each flat

13.1 Temperature data (°C)

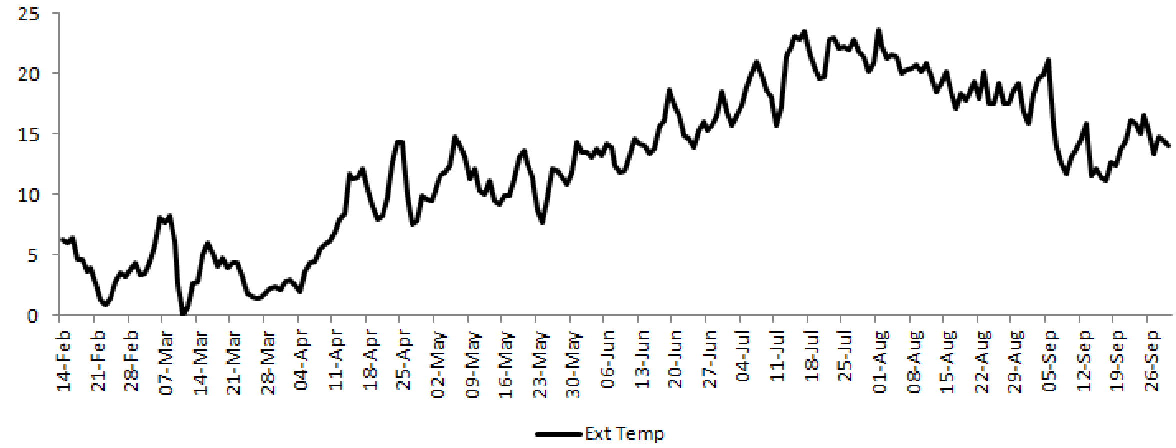


Figure 13.1a: External temperature over reporting period 14th February 2013 to 30th September 2013

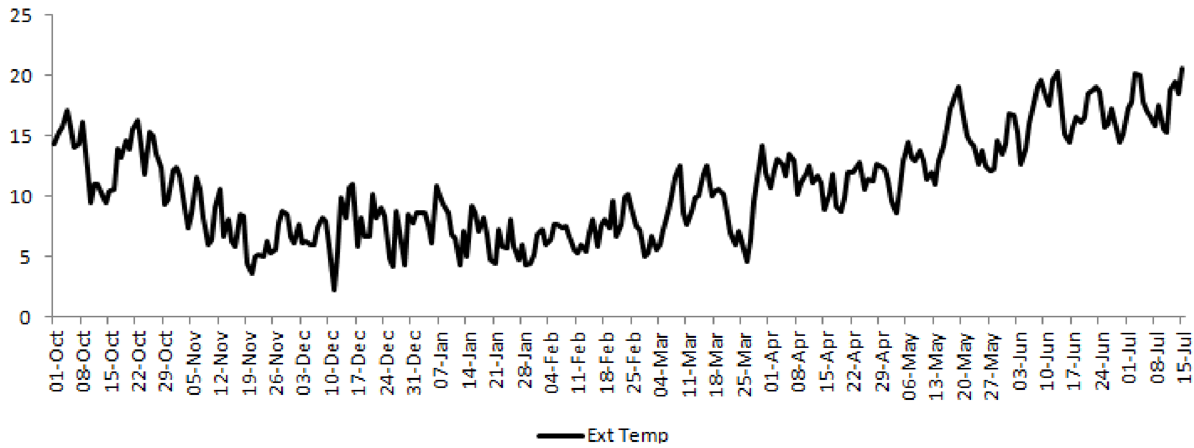


Figure 13.1b: External temperature over reporting period 1st October 2013 to 15th July 2014

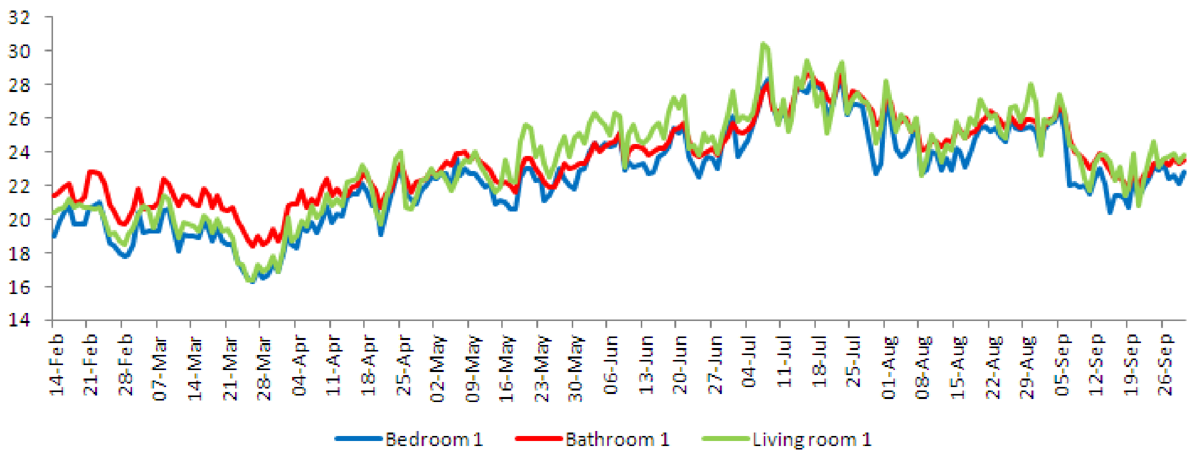


Figure 13.2a: Flat 1 internal temperatures over reporting period 14th February 2013 to 30th September 2013

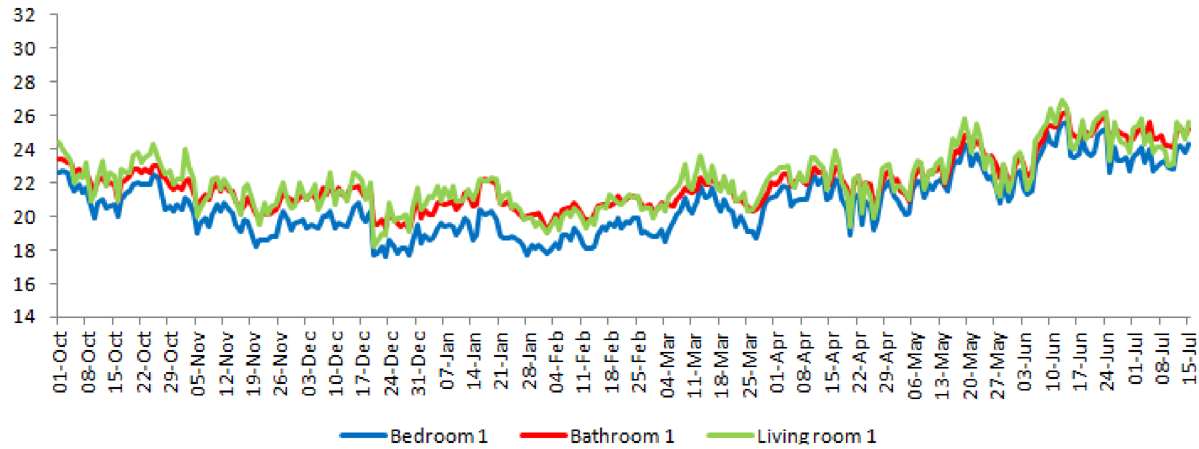


Figure 13.2b: Flat 1 internal temperatures over reporting period 1st October 2013 to 15th July 2014

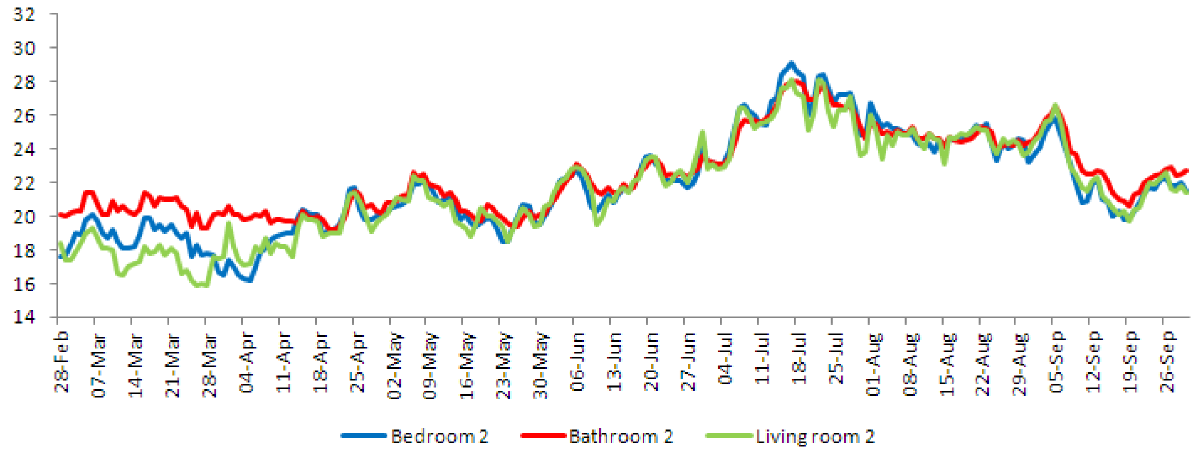


Figure 13.3a: Flat 2 internal temperatures over reporting period 28th February 2013 to 30th September 2013

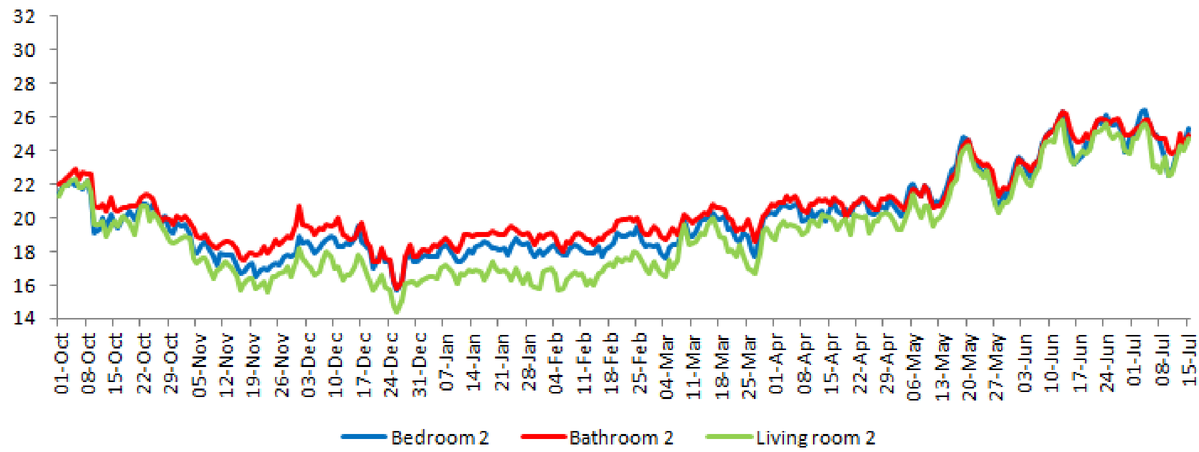


Figure 13.3b: Flat 2 internal temperatures over reporting period 1st October 2013 to 15th July 2014

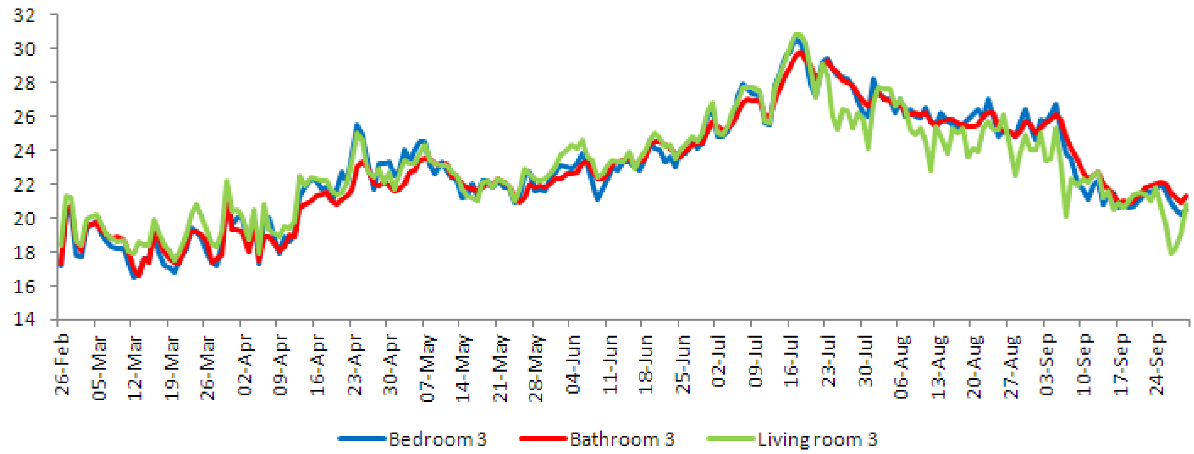


Figure 13.4a: Flat 3 internal temperatures over reporting period 26th February 2013 to 30th September 2013

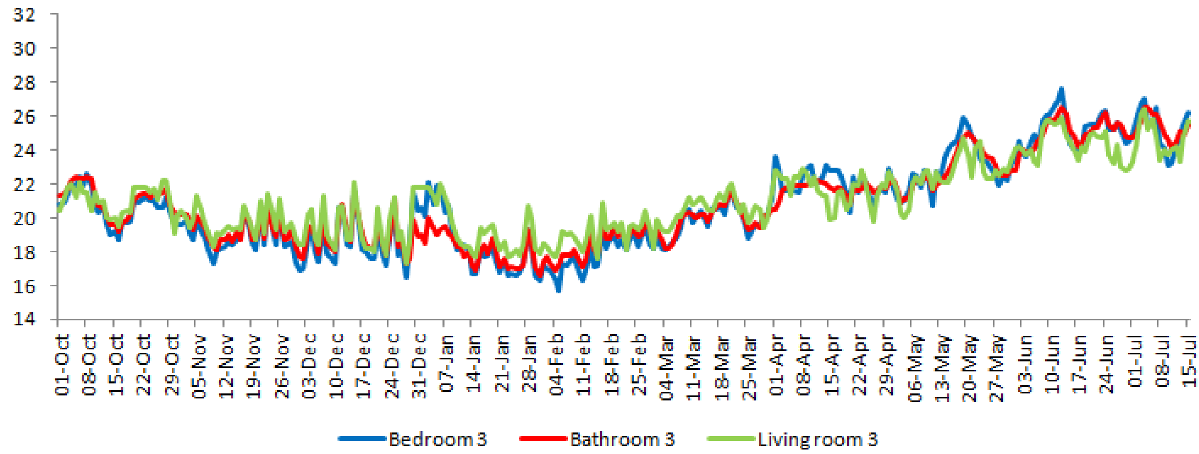


Figure 13.4b: Flat 3 internal temperatures over reporting period 1st October 2013 to 15th July 2014

13.2 Relative Humidity data (%)

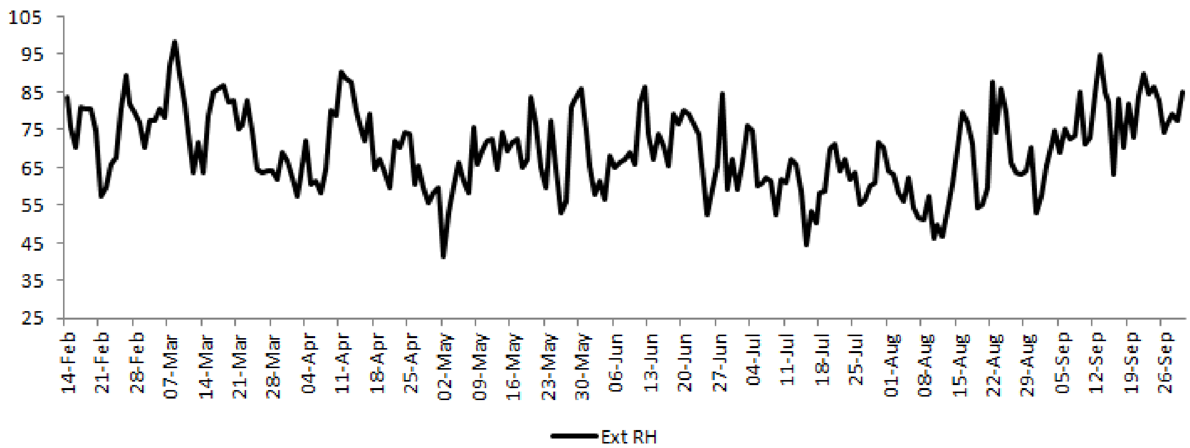


Figure 13.5a: External RH over reporting period 14th February 2013 to 30th September 2013

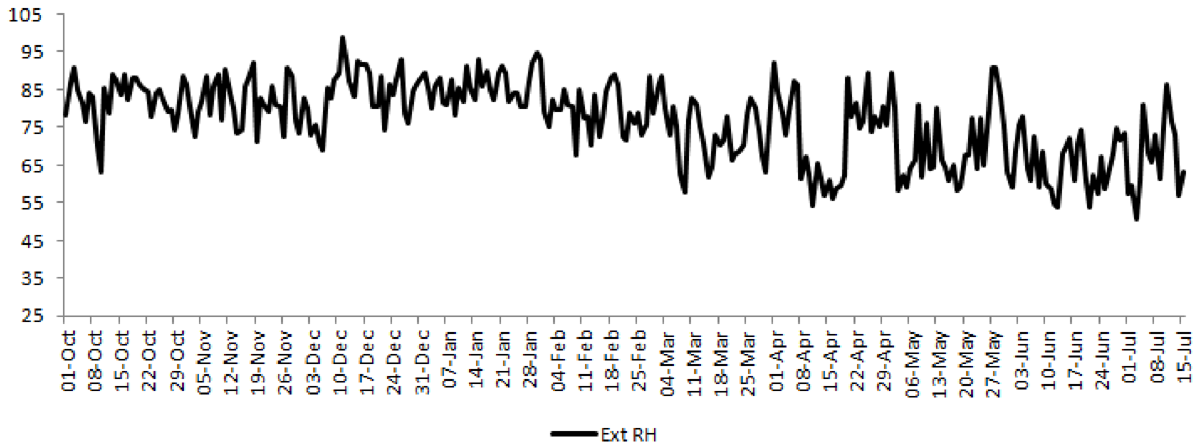


Figure 13.5b: External RH over reporting period 1st October 2013 to 15th July 2014

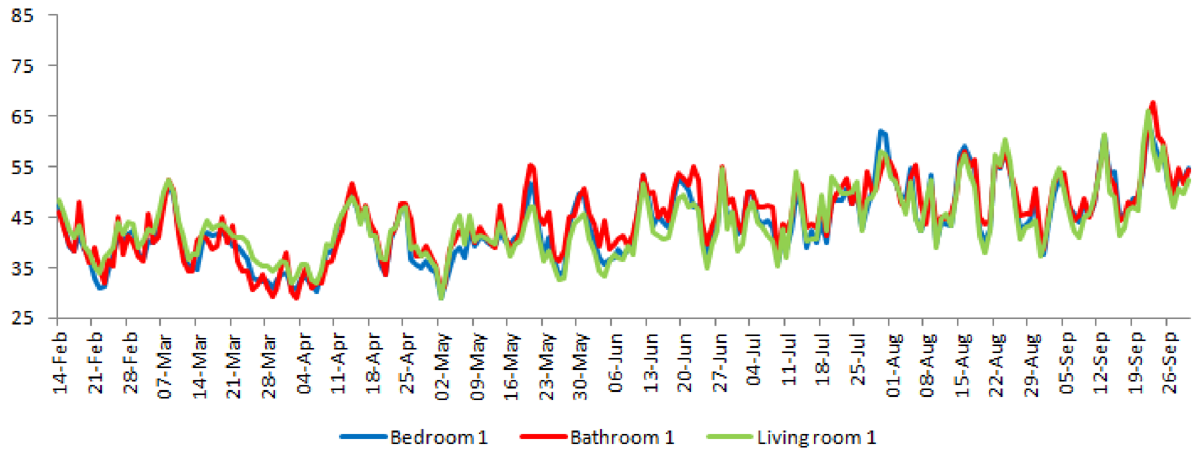


Figure 13.6a: Flat 1 internal RH over reporting period 14th February 2013 to 30th September 2013

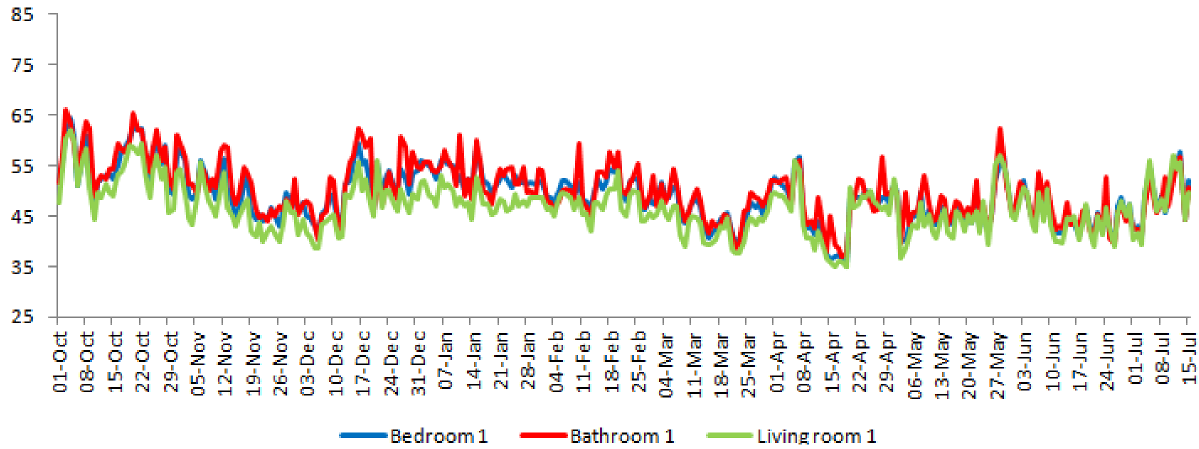


Figure 13.6b: Flat 1 internal RH over reporting period 1st October 2013 to 15th July 2014

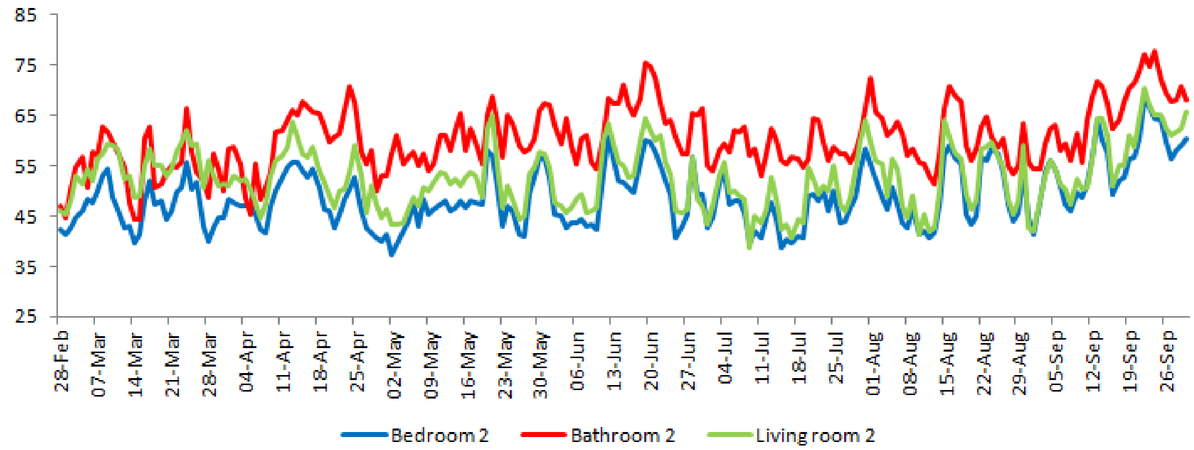


Figure 13.7a: Flat 2 internal RH over reporting period 28th February 2013 to 30th September 2013

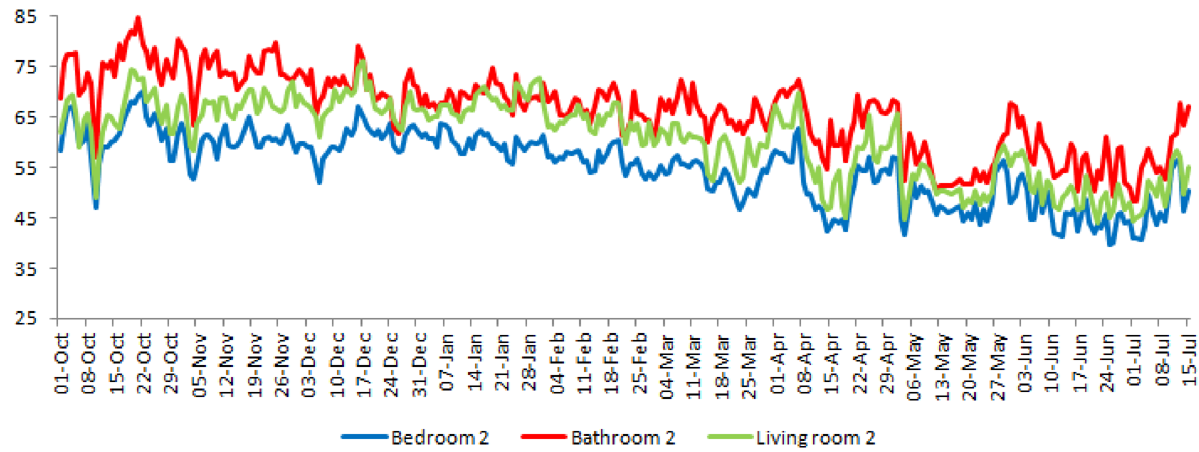


Figure 13.7b: Flat 2 internal RH over reporting period 1st October 2013 to 15th July 2014

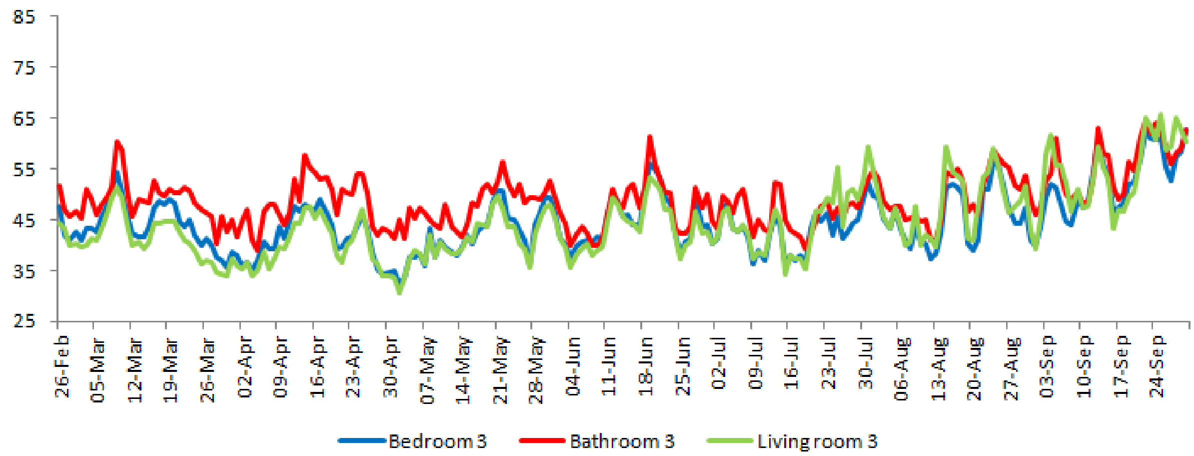


Figure 13.8a: Flat 3 internal RH over reporting period 26th February 2013 to 30th September 2013

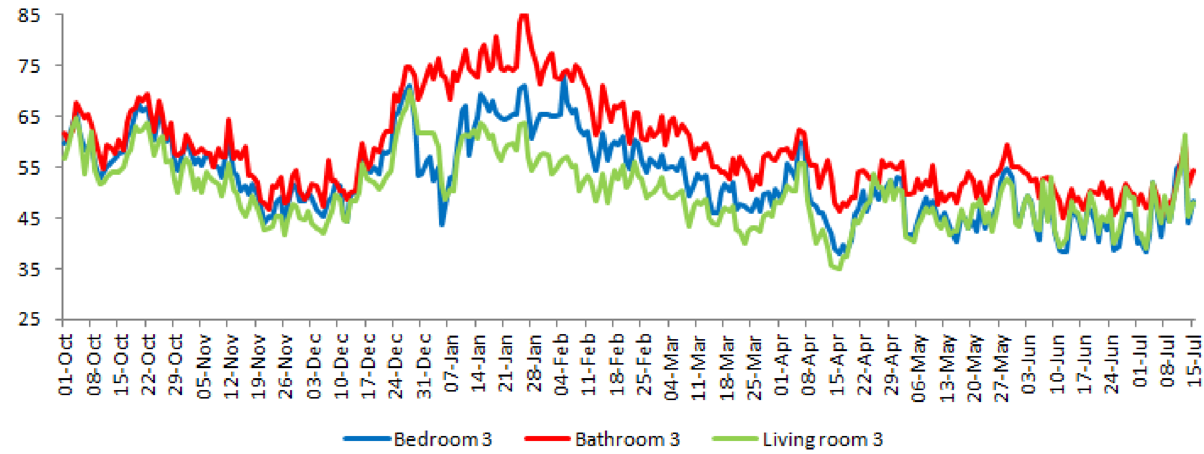


Figure 13.8b: Flat 3 internal RH over reporting period 1st October 2013 to 15th July 2014

13.3 CO_2 data (ppm)

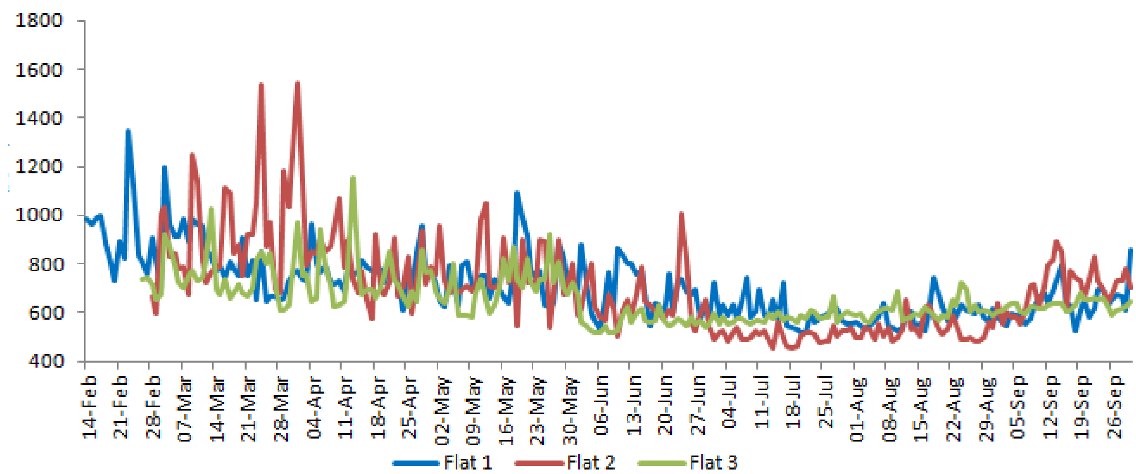


Figure 13.9a: CO_2 over reporting period 14th February 2013 to 30th September 2013

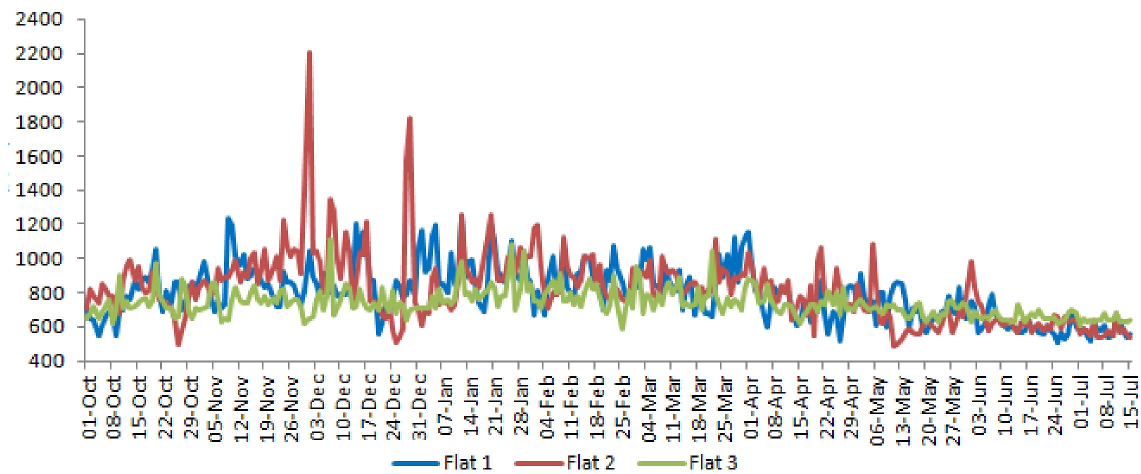
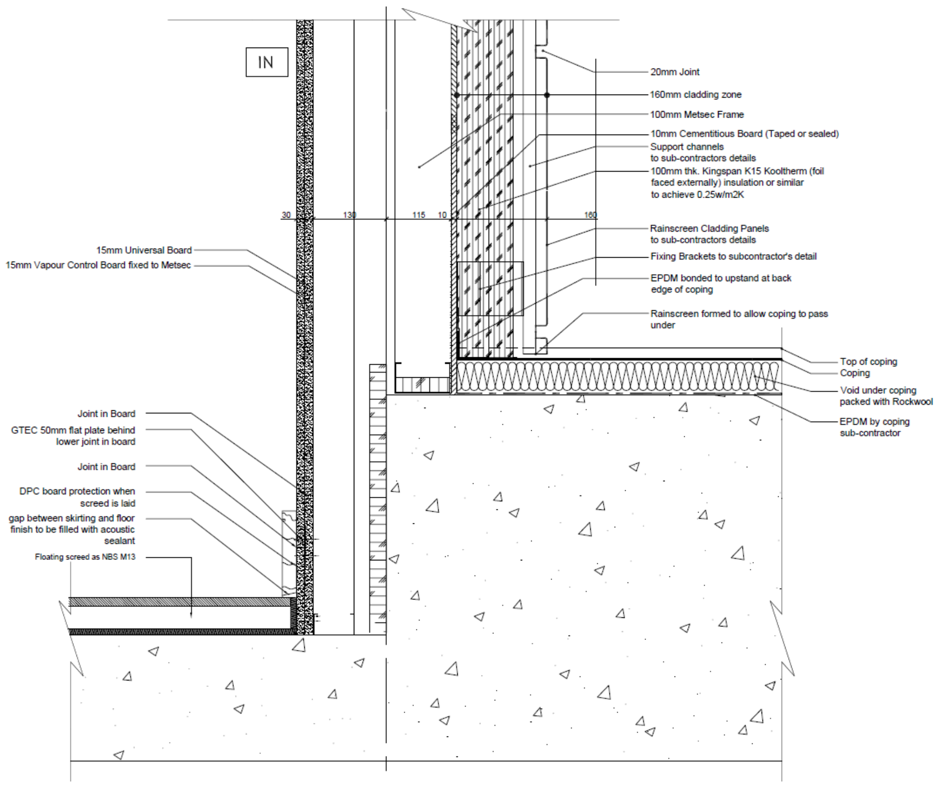
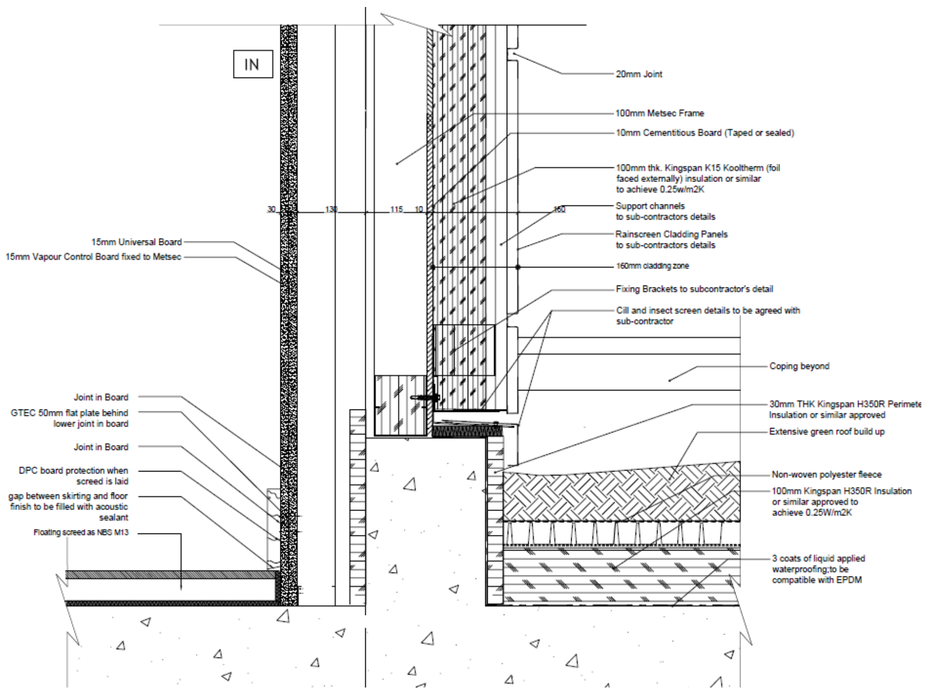


Figure 13.9b: CO_2 over reporting period 1st October 2013 to 15th July 2014

14 Appendix E – Example Construction Details



Rainscreen / Coping junction @ 5th Floor North and South elevations



Rainscreen base detail @ 5th Floor North and South elevations