One Brighton

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Innovate UK project number	450009
Project author	Good Homes Alliance
Report date	2014
InnovateUK Evaluator	Tom Kordel (Contact via www.bpe-specialists.org.uk)

No of dwellings	**Location**	**Type**	**Constructed**
5 apartments	Brighton, Sussex	Multi-story apartments	2008 - 2010
Area	**Construction form**	**Space heating target**	**Certification level**
Various (see report)	Reinforced concrete with Thermoplan infill walls	<30 kWh/m^2 per annum	2006 *Building Regulations*

Background to evaluation

One Brighton is a mixed-use development comprising residential blocks with office and community space. Five apartments were monitored, with fabric testing and an occupant survey. The buildings have an efficient thermal envelope, and use sustainable construction materials and low-energy appliances. Biomass and gas boilers and MVHR systems provide heat. A PV array was estimated to generate up to 7600 kWh per annum. Design targets for carbon emissions were less than 25 $kgCO_2/m^2$ per annum, with electrical consumption less than 45 kWh/m^2 per annum. Intensive monitoring of five occupied apartments was carried out for between 15 and 20 months.

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

The results from One Brighton revealed that a fabric-first approach to building design can result in a significant reduction in energy demand for space heating compared to the building stock. The designed performance of the fabric at One Brighton was slightly better than that required to meet the minimum Fabric Energy Efficiency Standards (FEES) for zero carbon homes targets in 2016. The measured carbon intensity for delivered communal heat at 0.5 $kgCO_2/kWh$ was ten times that predicted, and twice that which would have been expected had the development used individual gas boilers as the main heat source. Emissions were related mainly to high distribution losses, high pumping energy and the use of the back-up communal gas boiler in preference to the communal biomass boiler.

Occupant survey type	**Survey samples**	**Structured interviews**
BUS domestic	Various. See report (page 42)	Yes

Winter and summer occupant surveys were conducted on 172 dwellings (i.e. six months apart), generating response rates of 35% and 30%. The results from the first BUS survey showed that the majority of residents found the living conditions to be healthy and satisfactory. Around 80% of residents who responded indicated that the building met their needs. At the time of the first survey, comfort conditions in winter were thought to be better than in summer. The main health issues reported were related to noise, dust, pollution, air dryness, and the heating and ventilation systems. The results from the summer survey showed that most people remained satisfied and comfortable. Noise and antisocial behaviour were negative issues. In general, people were satisfied with space and layout.

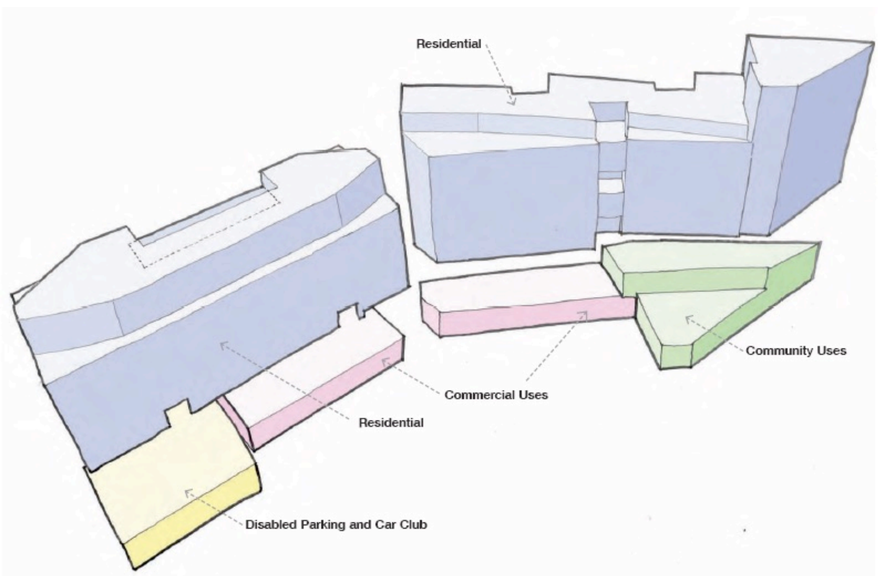
Contents

1 Introduction and overview

Technology Strategy Board guidance on section requirements:	This section of the report should be an introduction to the scope of the BPE project, the expected results and will include a summary of the key facts, figures and findings. Give an introduction to the project covering the project team and a broad overview of the energy strategy, design strategy rationale and soft and hard monitoring. Also summarise the building type, form, materials, surrounding environment and orientation, as well as related dwellings in the development (which may or may not be part of the BPE project). Other amenities, such as transport links, cycling facilities, etc. should also be outlined where relevant. Give information on any environmental requirements issues that are relevant to the site, but not to the research. Only the basic facts etc. should be included here - more detailed information should be given in the relevant sections in this document and added to the data storage system as appropriate.

This report details the findings of a Phase 2 Building Performance and Evaluation project that investigated both the post-construction and in-use performance of dwellings on the One Brighton scheme constructed by Crest Nicholson Bioregional Quintain on the larger New England Quarter development in Brighton. The New England Quarter development is a regeneration scheme located on an 8 hectare site adjacent to Brighton station. The One Brighton development was designed as mixed-use, with 172 dwellings, 925 m^2 of community space and 1134 m^2 of commercial space. The homes at One Brighton are a mixture of studio, 1-bed, 2-bed and 3-bed apartments, with 30% being affordable. The design comprises two blocks, with one 11-storey block (block named Brighton Belle) containing 109 dwelling units and one 8-storey block containing 63 dwelling units (block named Pullman Haul). The community and commercial spaces are all located on the ground floor (see design concept in Figure 1).

Figure 1 – One Brighton Design Concept (from FCB 2007)



The One Brighton development was designed in accordance with a set of ten key design values based on the One Planet Living Principles (Bioregional Quintain 2006). These principles are as follows:

1. Zero Carbon: Reducing carbon dioxide emissions by optimising building energy demand and supplying from zero carbon and renewable resources.
2. Zero Waste: Reducing waste arising, then reclaiming, recycling and recovering
3. Sustainable transport: Reducing the need to travel and providing sustainable alternatives to private car use.
4. Sustainable and local materials: Materials chosen for buildings and infrastructure to give high performance in use with minimised impact in manufacture and delivery.
5. Sustainable and local food: Consumption of local, seasonal and organic produce, with reduced amount of animal protein and packaging.
6. Sustainable water: Reduced water demand with rain and waste water managed sustainably.
7. Natural habitats and wildlife: Existing biodiversity conserved and opportunities taken to increase ecological value.
8. Culture and heritage: Cultural heritage acknowledged and interpreted. Sense of place and identity engendered to contribute towards future heritage.
9. Equity and fair trade: Create a sense of community. Provide accessible, inclusive and affordable facilities and services.
10. Health and happiness: Promote health and wellbeing. Establish long-term management and support strategies.

One Brighton was constructed between 2008 and 2010 using a traditional reinforced concrete frame. The infill walls comprised Thermoplan perforated clay blocks with an external layer of rendered wood-fibre insulation. Design targets for thermal performance required insulation levels to be in excess of 2006 Building Regulation minima by 15%, with proposed external wall U-value of 0.21 W/m^{2}K and window U-value of 1.3 W/m^{2}K. The window surface area for residential elements was to be greater than 15% of gross internal floor area. The design target for air permeability was 5 m^3/h.m^2. Heating and hot water are provided by a centralised community system linked t a biomass-fuelled boiler coupled to accumulator with back-up gas boiler. Summer time temperatures were designed to be limited by façade design, exposed thermal mass and night time purge by ventilation unit. A small scale array of photovoltaic panels of the roof was expected to provide 5% of electrical energy. The electrical supply was to be met via a REGO (Renewable Energy Guarantee of Origin) supply contract between renewable utility provider and community trust with sub-metering via private wire to individual residents certified ‘green tariff’.

Specific design performance targets for the One Brighton development are given in Table 1

Table 1 – Design Performance Targets for One Brighton Development

Overall carbon emissions from development	Net zero in-use
Carbon emissions from dwellings	<25 $kgCO_2/m^2.a$
Space heating demand	<30 $kWh/m^2.a$
Hot water demand	<45 $kWh/m^2.a$
Electrical consumption	<45 $kWh/m^2.a$

The completed development is shown in Figure 2.

Figure 2 – One Brighton Development (Brighton Belle Block East Facade)

The BPE project at One Brighton included the following measurements and activities:

- A Coheating test on one apartment, with infra-red thermal imaging carried out during the test.
- In-situ U-value measurements on the external wall.
- Flow measurements of the mechanical ventilation systems in six dwellings and an assessment of the specific fan power of the MVHR units.

- Air permeability tests on five dwellings carried out by an independent tester appointed by the developer.
- A review of the developer SAP calculations.
- Two sets of Building Use Survey (BUS) questionnaires were sent out to all dwellings on the development. The first survey was carried out in winter 2011 and the second in summer 2012.
- Walkthrough and focus group interviews with the One Brighton design and delivery team.
- Intensive monitoring of five occupied apartments was carried out for a period of between 15 and 20 months. Measured parameters included internal temperature and relative humidity, CO_2 concentration, delivered heat energy and disaggregated electricity consumption.
- Semi-structured interviews were conducted with the occupants of the five intensively monitored dwellings.
- An analysis of the delivered heat energy and electricity consumption of all 172 apartments over a period of 20 months.
- An analysis of the delivered heat and electricity consumption of the non-domestic spaces and common areas in the development.
- An assessment of the performance of the communal heating system including boiler efficiencies, distribution losses, parasitic electricity consumption and carbon intensity of delivered heat.

The results from One Brighton show that a fabric first approach to building design can result in a significant reduction in energy demand for space heating compared to the building stock. The designed performance of the fabric at One Brighton would be slightly better than that which would be required to meet the expected minimum Fabric Energy Efficiency Standards (FEES) for zero carbon homes targets in 2016. Measurements of fabric heat loss by Coheating, heat flux measurement and thermal imaging did show some degree of underperformance relative to design intent, but the impact of these factors was limited.

The measured carbon intensity for delivered communal heat at 0.5 $kgCO_2/kWh$ was ten times that predicted, and twice that which would have been expected had the development used individual gas boilers as the main heat source. The factors giving rise to the high carbon emissions at One Brighton were related mainly to high distribution losses, high pumping energy and the use of the backup communal gas boiler in preference to the communal biomass boiler. These results demonstrate that community heating systems do not always work as expected, and that carbon emissions can be considerably higher than those calculated using design estimates. District heating is a key technology in low carbon policy and further research is therefore required to better understand the efficiency and effectiveness of community heating. The results also demonstrate the need for improved design tools and models for district heating.

A range of issues were identified relating to the system conditions and performance of the mechanical ventilation systems at One Brighton. For example, air flow rates did not meet design targets and electrical energy consumption of the systems was very high relative to normal practice. Improvements in regulatory guidance for ventilation systems introduced as part of the 2010 review of Part L of the Building Regulations would be expected to start to address some of these issues, which are common across the UK housing industry.

Measurements showed that summer overheating in the bedrooms of the five monitored dwellings is an issue. These results were reinforced by the responses from the BUS surveys where many residents voiced concerns about high temperatures in the summer. The exact causes of the overheating at One Brighton are not fully understood but would be expected to be related to the performance of the MVHR system, occupant behaviour and gains arising from losses from the communal heating pipework. Further work is required to assess the incidence of overheating in other dwellings on the development and to check the operation of controls for the MVHR summer bypass mechanism. It is suggested that residents be provided with additional advice on simple measures that can be implemented to minimise overheating.

The evidence from One Brighton is that there can be significant errors in SAP inputs and inaccuracies in U-value calculations. There are opportunities therefore to improve the SAP assessment process and associated training, information and support for SAP assessors, Building Control Bodies, designers and housing developers. It was noted that SAP does not currently include options for MVHR heating systems as used at One Brighton. The consequence of this is that the SAP algorithms may underestimate ventilation heat loss and it is recommended that consideration be given to making MVHR heating an explicit option in the next revision of SAP.

The measured data show that common area electricity accounts for 21% of total carbon emissions associated with the dwellings at One Brighton. Existing protocols for the treatment of electricity use for common areas in the regulatory assessment of apartment blocks mean that this energy use is not included in the SAP assessment or the requirements of Part L1a and is instead considered as non-domestic use. In the case of One Brighton, the common areas are exclusively for the use of the residential part of the development, and it could be argued that Energy Performance Certificates should include some assessment of carbon emissions and service charges associated with common areas. This would give prospective purchasers and tenants better information when assessing the potential energy costs and environmental impact of living on such developments.

Data from this study indicates that residents of low carbon energy efficient dwellings are likely to live at higher temperatures in the heating season than existing energy models assume. There are implications for national energy policy, energy regulations and modelling tools such as SAP if occupants of low energy buildings tend to live at higher temperatures than standard assumptions. We are however currently unable to definitively determine what proportion of the higher temperature at One Brighton was due to active choices made by residents with respect to heating, and what proportion was down to other causes such as heat losses from the heat distribution system.

Many residents in interviews and BUS survey responses expressed concerns about the cost of delivered energy, standing charges and service charges. Comparisons of average energy costs at One Brighton show that typical annual energy bills were actually around half of that for a typical gas-heated dwelling in the UK, after taking into account the costs of boiler replacement and maintenance. Issues around energy costs at One Brighton may therefore be related more to expectation and a lack of understanding as to what is included in the charges. More could therefore be done to explain energy charges to the residents.

The results of humidity and carbon dioxide measurements in the monitored dwellings at One Brighton indicate that the internal air quality ranged from satisfactory to poor. The variable air quality was in some cases found to be related to the fact that residents had turned off the ventilation system, but this was not always the case. There are lessons to be learned here both in terms of the information given to residents about their homes and also in understanding the limitations of mechanical ventilation systems. Further research is required, to understand the impact of occupant understanding and behaviour on air quality in mechanically ventilated airtight dwellings, to understand the role of communication between developers and occupants about ventilation systems, and to investigate the effect on air quality of factors relating to the design and installation of the ventilation system.

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

Technology Strategy Board guidance on section requirements:	This section should cover the project up until before commissioning. Give more details on the building type, form, materials, surrounding environment and orientation, as well as related dwellings in the development (which may or may not be part of the BPE project). Other amenities, such as transport links, cycling facilities, etc. should also be outlined where relevant to the design specification. Also provide comments on the design intent, construction process and the product delivered (including references to drawings, specifications, commissioning records, log book and building user guide). If the original specification is available, describe how closely the final design meets it, what the discrepancies are and why these occurred. Indicate whether the explanation comes from the design team or from evaluator judgement. Identify any discrepancies between the design and SAP and whether the design accurately reflected in the SAP calculations and describe where these discrepancies lie. Does the SAP performance match the specified performance and was this informed through measured or calculated data. As far as possible provide an explanation of the rationale behind the design and any changes that occurred. In particular, it will be helpful to understand the basis for making key decisions on the choice of measures and technologies. These may have been chosen to suit the particular property or a physical situation, or they may have been chosen to test an innovative material or a new product. List and describe any aspects of the design that are likely to introduce performance issues – e.g. cold bridges? Describe any aspects of the design that were a challenge to construct robustly - e.g. introduction of air leakage paths. Finally this section should also outline the construction and construction management processes adopted, construction phase influences i.e. builder went out of business, form of contract issues i.e. novation of design team, programme issues etc. Describe the overall construction process, highlighting any supply chain issues, delays in construction, contract(or) issues Important: please describe steps taken to overcome any stated challenges and issues. Report perceptions, concerns and positive nuggets raised by the client, designers, and construction team. Complete this section with conclusions and recommendations.

2.1 Review of SAP Calculations

The dwellings on the One Brighton development were built under Building Regulations of England & Wales Part L1 2006 and the SAP calculations were carried out using SAP 2005 (BRE 2008). SAP worksheets and drawings were provided by the developer for two of the dwellings at One Brighton for analysis. These were for the Coheating test apartment and apartment F from the monitored dwellings. In addition, SAP building regulation checklists were provided for two further dwellings (Apartments A and B from the monitored dwellings).

The main dimensions for the Coheating test apartment and dwellings F were calculated from the drawings and then compared to those given in the SAP worksheets (see summary in Table 2). It can be seen that there are several discrepancies between the SAP dimension inputs and the actual values. For example, the SAP assessments for both dwellings omit the areas of semi-exposed wall and door between the apartments and the unheated corridor. This is a significant omission, as this means the SAP heat loss calculations will under calculate the heat loss coefficient. There are some small differences in internal floor area, but these are relatively insignificant. The area for external wall in the SAP worksheet for the Coheating test apartment was 41.1 m^2 compared to the actual value of 30.1 m^2. It is believed that this mistake would have arisen because the SAP assessor forgot to net off the area of glazing in their calculations. The SAP assessments both have the floor to ceiling height as 2.5m, whereas the actual value is 2.63m. This error has a knock-on effect on the calculated internal volume, which in turn will affect the calculation of ventilation heat loss. The values for total exposed area in the SAP worksheets are less than the actual values due to the omission of the semi-exposed areas from the calculation. The exposed area is an important parameter as it is used in SAP 2005 to calculate the heat loss due to thermal bridging. Taken together, the observed errors in dimension inputs will have a significant effect on the SAP calculation, and are concerning. It is not known how representative such calculation errors will be for the whole cohort of dwellings at One Brighton.

Table 2 – Dwelling Dimensions Derived from Drawing and Taken from SAP Worksheets

Dimension	Co-heating Test Apartment		Dwelling F	
	Derived from Drawings	From SAP Worksheet	Derived from Drawings	From SAP Worksheet
Floor area (m^2)	64.96	62.66	45.32	45.00
Room-ceiling height (m)	2.63	2.50	2.63	2.50
Area external wall (m^2)	30.09	41.44	8.27	9.24
Area semi-exposed wall (m^2)	7.95	none	14.77	none
Area semi-exposed door (m^2)	1.90	none	1.90	none
Area glazing (m^2)	12.17	12.06	6.83	5.88
Internal volume (m^3)	170.52	156.65	118.97	112.50
Total external area (m^2)	42.26	53.50	15.10	15.12
Total exposed area (m^2)	52.11	53.50	31.78	15.12

The U-value inputs in the SAP worksheets and SAP checklists were compared with the design and construction information provided by the developer (see Table 3). The nominal U-value of the wall at 0.21 W/m^2K is the same for the design information and in the SAP worksheets. The wall U-value was also calculated according to the conventions given in BR443 (Anderson 2006) using the wall dimensions and nominal values of thermal conductivity for the materials (Thermoplan perforated clay block = 0.11 W/mK, Diffutherm wood fibre insulation 0.043 W/mK). The calculated U-value was 0.21 W/m^2K which is the same as the SAP input. The SAP worksheets do not however include the additional wall U-values for areas where there are columns for the concrete frame or in areas above some of the windows where there is a service void containing the MVHR ductwork and terminal vents. The whole window U-values in the SAP worksheets at 1.20 W/m^2K are significantly higher than the actual whole window U-value of 0.80 W/m^2K for the triple glazed windows that were installed. The SAP worksheet for the Coheating test apartment did not include the U-value for the double glazed patio doors (1.40 W/m^2K), and instead used the same value as had been input for the glazing.

Table 3 – Comparison of Dwelling U-values from SAP Worksheets and SAP Design Checklists

Element	**U-value (W/m^2K)**	
	As Constructed or calculated	**From SAP Worksheets or Design Checklists**
External wall	0.21	0.21
External wall with hidden concrete column	0.38	None
External wall containing MVHR terminals	Unknown	None
Windows (triple glazed)	0.80	1.20
Windows with SAP curtain adjustment	0.77	1.15
Glazed patio door (double glazed)	1.40	None
Glazed patio door with SAP curtain adjustment	1.33	None
Semi-exposed front door	1.11	None
Semi-exposed wall to corridor	0.26	None

The SAP worksheets and checklists do not include any of the required U-values for elements adjacent to un-heated spaces. These elements include the corridor walls for all apartments, and the floor above the garage under croft for some 1st floor apartments. The effect of the errors in U-value inputs will add to the dimensional errors, and means that the calculated fabric heat loss coefficients will be incorrect. Predicted fabric heat loss is the key driver for the calculation of dwelling energy demand in the SAP algorithm, and consequently the outputs from the SAP worksheets for One Brighton will be inaccurate.

The assumption for the thermal bridging inputs in the developer SAP worksheets is for a y-value of 0.08 W/m^2K. This would require the use of construction details that match the generic details in the Accredited Details catalogue (DCLG 2007). Generally, the details as designed and constructed are consistent with those Accredited Details for externally insulated masonry dwellings which is in line with the use of a y-value of 0.08 W/m^2K.

The heating to the One Brighton apartments is provided by communal heating using a water-to-air heat exchanger in series with supply ductwork of the MVHR system. Whilst SAP2005 has options for warm air heating using internal air, it does not however include an option for warm air heating linked to an MVHR system that utilises external air. In full heating mode, the MVHR systems at One Brighton will provide a ventilation rate of the order 2.3 h^{-1} if commissioned according to the design specification. SAP2005 assumes a background ventilation rate of only 0.5 h^{-1}. This means that the SAP algorithm will significantly underestimate the actual ventilation rate for the One Brighton dwellings in the heating season. The latest version of SAP (SAP2012) includes correction factors for over ventilation in heating systems using exhaust air heat pumps, but not for MVHR heating systems. The SAP methodology was never designed to cover every potential scenario. In circumstances where the characteristics of the proposed heating or ventilation system are outside of the scope of existing options given in SAP, then advice should have be sought from BRE as how to proceed with the calculations. This does not appear to have been the case at One Brighton.

The input in the SAP worksheets for the efficiency of the communal heating biomass system was 85%, which would imply condensing operation – a challenging requirement for biomass boilers. The default value for all community boilers in SAP2005 is 75%. The designed efficiency of the plant at One Brighton is unknown. It is unclear why 85% was used in preference to the default value. The SAP calculations will therefore underestimate the fuel requirement for heating and hot water. As a point of interest, the information given in the SAP2005 appendix on community heating is unclear as to what factors should be taken into account when determining the efficiency of a communal system. It would be expected that this would include both the efficiency of any boilers and the electric consumption of the pumps and control system.

The SAP worksheets assume that 100% of communal heating would be provided by the community biomass boiler, with no use specified for the back-up gas boiler. It would perhaps have been realistic to make some allowance for use of the gas boiler.

The assumptions in SAP2005 for distribution losses from communal heating pipework are relatively optimistic. In the case of the system at One Brighton which uses pre-insulated pipework, the default distribution loss factor used in the SAP worksheet (1.05) is that given in Table 12c of SAP2005, which is equivalent to a distribution loss of 4.8%. Although the comparison is not a direct one, data for the performance of district heating systems in Denmark indicates that the average distribution loss from all Danish systems is much higher than this at around 20% (DEA 2007). The Danish district heating market is relatively mature compared to that in the UK, with around 55% of current net energy demand in Denmark being supplied by district heat (DEA 2012). Data from Danish DH systems would therefore be expected to reflect current best practice.

The sizing of the MVHR system at One Brighton was likely dictated by the heating requirement rather than the fresh air requirement. Consequently, the MVHR system installed at One Brighton was one with a high flow rate designed for non-domestic use or very large dwellings rather than for small apartments. This means that MVHR performance data for the system are not available in SAP Appendix Q, and hence the SAP2005 calculations for One Brighton had to use the very conservative backstop values for specific fan power (SFP) and heat exchanger efficiency. The default SFP value for MVHR systems in SAP2005 is 2.0 W/l/s, which is degraded to 5 W/l/s after applying the default in-use factor of 2.5. The default heat exchanger efficiency in SAP is 66%, which is degraded to 46.2% after applying the default in-use factor of 0.7 for un-insulated ducts.

The annual energy consumption, target carbon emissions (TER) and dwelling carbon emissions (DER) as calculated in the developer SAP worksheets and checklists are given in Table 4 for dwellings A, F and the Coheating test dwelling. The DER values are very low at around 9 to 10 $kgCO_2/m^2$.a and would easily meet the TER under the regulatory requirements for Part L1 2006.

Table 4 – Output from Developer SAP Worksheets and SAP Checklists

	Dwelling A	Dwelling F	Coheat Test Dwelling
Target Emission Rate ($kgCO_2/m^2.a$)	20.80	-	-
Dwelling Emission Rate ($kgCO_2/m^2.a$)	8.70	9.72	9.41
Space Heating Energy (kWh)	-	372.1	919.3
Domestic Hot Water Energy (kWh)	-	2894.3	3254.6
Electric for Fans and Pumps	-	686.3	955.6
Electric for Lighting (kWh)	-	218.8	282.9
Electric Produced by Photovoltaic Panels (kWh)	-	45.9	65.9

It is not known how the SAP assessor for One Brighton apportioned the energy produced by the photovoltaic (PV) panels. The SAP worksheet data for dwelling F and the Coheat dwelling give an average allowance for PV production of 1.035 kWh per m^2 of dwelling floor area. The total floor area of all dwellings at One Brighton is 9,293 m^2, which would give a total for PV electricity production of 9,618 kWh per annum. This is consistent with expectations from the installed 9.4 kWp PV array (see section 7.19).

Although the fixed lighting at One Brighton comprised 100% low energy fittings, Part L1 2006 does not allow any additional benefit from proportions of fixed lighting above the regulatory minimum of 30% low energy lights. The SAP worksheets for One Brighton will therefore have overestimated lighting energy consumption compared to the dwellings as constructed. It is interesting to note that the limits and lighting algorithms were changed for Part L1a 2010, which allows the full amount of low energy lighting to be input into the SAP calculations.

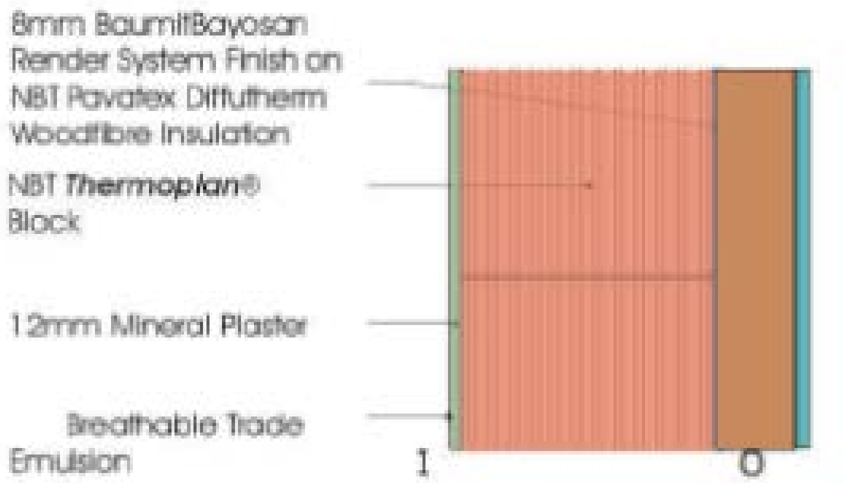
The solar gain calculations in the developer SAP worksheets use a solar transmittance g-value for the glazing of 0.63. This is the default value for double glazing with soft-coat low-E coat given in Table 6b of SAP2005 (BRE 2008). The installed windows were actually triple glazed, with a g-value likely to be lower than 0.63. The default g-value in SAP 2005 for triple glazing with soft-coat low-E is 0.57. The effect of using a higher g-value will be to overestimate the solar gains by about 9%, with consequently slightly higher space heating demand. This is not that significant in absolute terms, but is indicative of poor process.

The ventilation calculations in the developer SAP worksheets use an air permeability value of 5 $m^3/h.m^2$. This is consistent with the stated air permeability design target for the dwellings. The measured air permeability of test dwellings at One Brighton all met the design target (see pressure test results in section 3.3).

2.2 Designed Building Fabric

The main building fabric at One Brighton consists of a reinforced concrete frame with a wall infill of 240mm Thermoplan perforated clay blocks. The walls were externally clad with 100mm Pavatex Diffutherm wood fibre insulation boards bonded to the Thermoplan blocks and concrete frame. The walls had a breathable render on the outside and had a wet-applied mineral plaster finish to the inside. This created an airtight but vapour permeable and breathable wall. The blocks were laid using thin bedding joints of adhesive rather than traditional mortars. The Thermoplan blocks interlock on the vertical face and require no vertical mortared joints. The thin horizontal mortar joints would have a negligible impact on the overall fabric performance. The insulation boards were interlocking with tongue and groove joints. A schematic of the wall section is illustrated in Figure 3.

Figure 3 – Diagram of Wall Section



2.3 Designed Building Services

A communal biomass boiler system provides all space heating and hot water requirements to dwellings and non-domestic properties on the One Brighton development. A gas-fired back up boiler was installed for operational use when the biomass boiler was being maintained. The communal system includes two 10,000 litre insulated thermal storage vessels which are designed to provide rapid response during periods of high demand and smooth the demand on the boiler. The heat distribution system at One Brighton consists of primary horizontal distribution pipework from the main boilers at basement level, secondary vertical distribution pipes in a set of service risers, and tertiary horizontal distribution pipes at high level in corridor ceilings. These are connected to Heat Interface Units (HIU) located in each apartment. The installed unit is a Switch 2 indirect Type 3 Mini HIU (see Figure 4). The HIU contains two indirect circuits, each with their own heat exchanger to hydraulically separate the communal system from the dwelling heating circuits. A heat meter is fitted to the communal main input to the HIU in order to provide consumption data for billing purposes.

Figure 4 – Heat Interface Unit

Space heating within the apartments is delivered by warm air provided through the MVHR system. A heater matrix linked to the HIU is fitted to the supply air side of the MVHR heat exchanger (see Figure 5), with warm air provided via the air valves in the living room and bedrooms of the apartments. Instantaneous domestic hot water is supplied via a heat exchanger in the HIU. Control of the heating system is achieved using a combined control for temperature and MVHR fan speed as shown in Figure 6. The installed MVHR unit is an Xpelair Xcell 600 system. The fans have 3 speed settings. Speed I on the controller is the trickle mode and speed III is the boost mode. The boost mode is also activated when the light switch was on in the bathrooms.

Figure 5 – View Inside MVHR Casing Showing Heater Matrix and Supply/Extract Fans

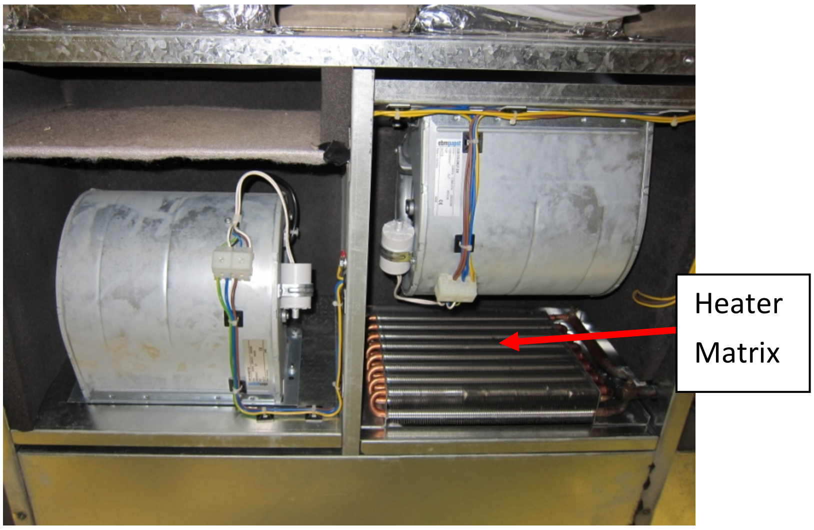


Figure 6 – MVHR and Heating Controls in Dwelling

2.4 Procurement Overview

The following section (4.2) was provided by BQL and gives their perspective on the procurement process at One Brighton.

The One Brighton development was initiated in 2004 by BioRegional Properties Ltd. (BPL), the pre-cursor company to BioRegional Quintain Ltd. (BQL). The latter company was formed in 2005 as a private equity funded joint venture between BioRegional Properties Ltd and Quintain Estates and Development PLC.

2.4.1 Background to the Joint Venture

One Brighton was conceived as a leading sustainable development project that would follow in the wake of the BedZED project, but be more mainstream and have wider appeal both to planners and the market. It was conceived as the first 'One Planet Living' project, with each of the One Planet Living principles to be integrated into each stage of the development process including briefing, design, construction, commissioning and long term management. The project was characterised also as a 'zero carbon' development, by which they meant that all of the energy requirements for the project would be met by a combination of on and off site renewable energy. The project formed part of the New England Quarter master plan.

According to BPL/BQL, they realised prior to the formation of BQL that it would need a joint venture development partner to realise the ambition for the One Brighton project. Crest Nicholson (Crest) was selected as the joint venture partner because they had an interest in sustainable development projects and an enthusiasm to partner with BPL, as well as its considerable resources and expertise in residential development. A joint venture company ("Crest Nicholson BioRegional Quintain" - or CNBQ - was thus formed on the basis that equity and project financing would be provided equally by the joint venture partners (so a 50-50 basis). There would be management agreements between each of the joint venture parties (i.e. BQL and Crest) and CNBQ in respect of the following responsibilities:

BQL

- Community engagement including community participatory design/ design briefing
- Sustainability planning and implementation
- JV and development governance
- Long term management arrangements for the development including management (on behalf of the residents) of the community ESCO and the green caretaker

Crest

- Design management
- Construction management (with a third party building contractor to be appointed and managed by Crest)
- Sales and marketing
- JV company secretarial and accountancy

Although the site already had an outline planning consent, this was increased through a participatory design process and detailed planning process to 172 flats and 2,000 sq m of commercial and community space. The participatory design process included for the hosting and facilitation of a number of workshops with a community and stakeholder group, which according to BQL, provided both valuable support for the planning process, as well as considerable local knowledge and ideas about aspects of the design. The latter was fed into the development brief.

According to BQL, the joint venture arrangements generally worked well, albeit with strong differences of opinion with regard to the appointment of the building contractor. Crest Nicholson wanted one main contractor to be appointed, whereas BQL wanted another to be appointed on the basis of their stronger technical resources. Crest's favoured main contractor was selected because of an ongoing third party contractual dispute between Crest Nicholson and Balfour Beatty.

According to BQL there were also divergent opinions in the joint venture regarding the proposed ziegel external walling system (Thermoplan) and the ownership of the centralised energy services (biomass boiler, plant room, distribution pipework, PV panels and private wire electrical system) and the formation of Community ESCO. But these were resolved through a frank and productive process and in general terms the governance and management arrangements worked well - with Crest being highly supportive of the One Planet Living and sustainability aspects of the development.

2.4.2 Project Brief and Design

The initial project brief was developed by BPL, working with the community group as above, and developing a set of initial concept designs with architects Feilden Clegg Bradley that were used in the community participatory design process. Part of this included a series of workshops and meetings with the services and environmental engineers, Fulcrum Consulting. These resulted in the development of the following energy and environmental strategy for the project which met the One Planet Living requirements for a zero carbon scheme:

- Centralised biomass boiler and thermal store with heat distributed to each apartment via Heat Interface Units (HIUs)
- Some PV and building integrated wind turbines (the latter omitted from the scheme after studies of in-use performance)
- Mechanical Ventilation with Heat Recovery (MVHR) units in each flat providing heating from each HIU

According to BQL, risks were identified with regard to the potential for overheating in the corridors (as a result of the inclusion of communal heating pipework in the corridors) and some thermal modeling was carried out in order to develop a mitigation strategy.

Fulcrum Consulting were appointed to develop a Performance Specification for the energy and environmental services aspects of the project and they worked with the other professionals in developing the design sufficient for the planning application. According to BQL, Fulcrum was selected because of their experience with other sustainable homes projects. Once planning permission had been obtained this was further developed in order to enable the procurement of the building contractor.

2.4.3 Construction

Quintain required BQL, as a condition of its funding, to use a Design and Build (D&B) form of contract for procurement of the building contractor. After a competitive tendering process and discussion within the JV, a D&B contractor was selected.

Crest Nicholson appointed a site-based construction project manager to oversea the construction process including for a regime of site inspections. According to BQL, Fulcrum did not appear to be willing to assist in the development of detailed designs with the D&B design contractor, and as a result the services engineers were changed to MLM, who had prior experience in working with Crest.

Midway through the project (with the concrete frame under construction) the financial crisis hit, and according to BQL, this resulted in re-structuring of the Crest business model, leading to a complete change in Crest’s One Brighton team, with the exception of their site-based construction project manager, and the sales and marketing team. The new team picked up their responsibilities very well and a good working arrangement was established right up to project completion and handover. While the construction programme was prolonged as a result of the financial crisis, this delay to completion enabled a closer match between net cash invested in the project and income from housing sales. The last unit was sold 3 months after completion of construction.

2.4.4 Management after Handover

The management strategy for the development included the appointment of a green caretaker who could assist the residents with the building, energy, lifestyle and sustainability aspects of the project. This post is now fulfilled by the managing agent who employs the green caretaker directly.

2.5 Conclusions and key findings for this section

A series of input errors were identified in the developer SAP worksheets. These included mistakes in dwelling dimensions, the omission of heat loss to un-heated space and differences in glazing U-values. The impact of these errors on calculated energy use and dwelling emission rates will be significant. The underlying causes of the errors are unknown, but are likely to be linked to training and the quality of information that was provided to the SAP assessor.

The MVHR heating system used at One Brighton is not one of the heating options available within the version of SAP used for assessing the development (SAP2005), and is still not included in the latest version of SAP (SAP2012). As a result, the SAP algorithms will underestimate the ventilation heat loss for the dwelling when used with this type of heating system. It is expected that MVHR heating will become more commonplace in the future, especially for very low energy designed according to Passivhaus principles. It is therefore suggested that future updates to SAP should include options for systems where heating is provided through the mechanical ventilation system.

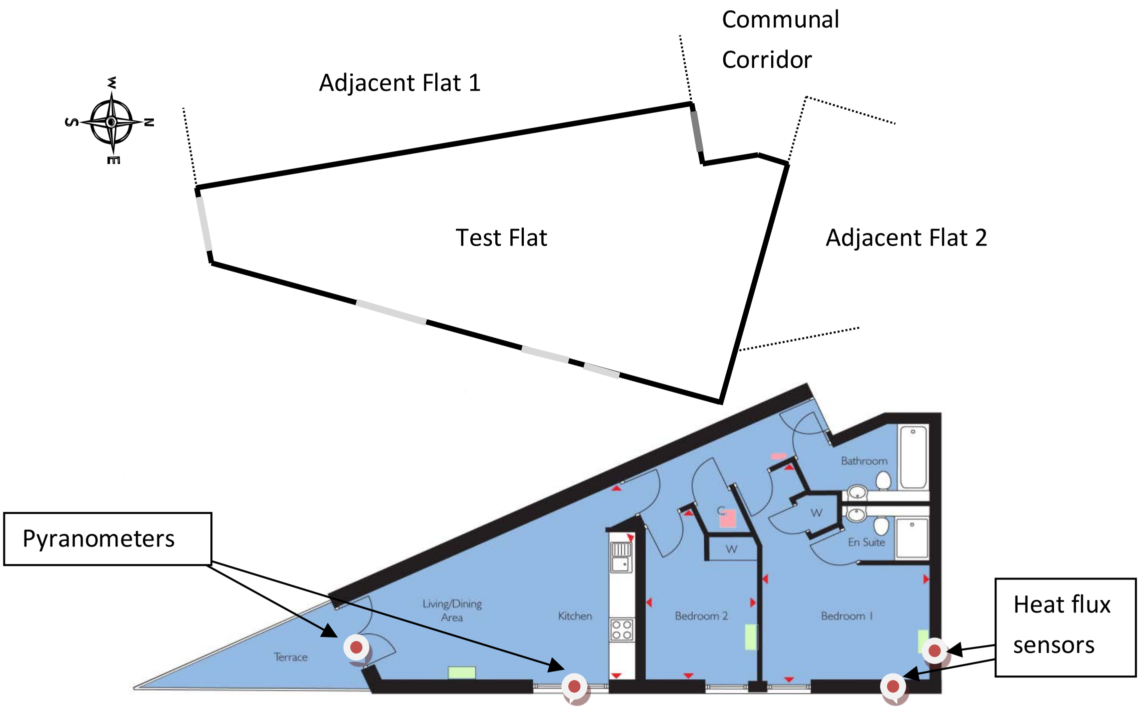
3 Fabric testing (methodology approach)

Technology Strategy Board guidance on section requirements:	This section should provide a summary of the fabric testing undertaken as part of the mandatory elements of the BPE programme, *plus* any other discretionary elements that have been undertaken. Ensure that information on u-value measurements; thermography, air-tightness, any testing on party wall bypasses and any co-heating tests are covered. Give an overview of the testing process including conditions for the test any deviations in testing methodology and any measures taken to address deficiencies. Confirm whether any deviations highlighted have been rectified. As some tests (particularly the thermographic survey) are essentially qualitative it is important that the interpretation is informed by knowledge of the construction of the elements being looked at. Comment on the use of particular materials or approaches or their combination or installation methods lessons learned. Complete this section with conclusions and recommendations for future projects.

3.1 Co-heating Test

A Coheating test was carried out on one unoccupied apartment on the One Brighton development between for a period of 4 weeks between 11th March 2010 and 7th April 2010. The apartment was a mid-floor corner flat located on the 8th floor of the Brighton Belle block. The test apartment had a complex shape (see schematic floor plans in Figure 7) and had adjoining apartments to two sides and identically shaped apartments both above and below.

Figure 7 – Floor Plan Schematics of Co-heating Test Apartment



The gross internal floor area of the test apartment was 65 m^2 with an internal volume of 170.5 m^3, total envelope area of 227.2 m^2 and external envelope area of 42.3 m^2. A photograph of the Brighton Belle block showing the location of the test apartment is shown in Figure 8. Control of test conditions for the Coheating test presented some difficulties due to the requirement to also control the conditions in the surrounding flats and communal spaces in order to guard against heat flow across party elements. Whilst it was possible to control the heating to the corridor and adjoining apartment to the west, it was not possible to control the heating to the apartments on the North or the occupied apartments above and below. In these cases, temperature sensors were placed in the apartments and heat flux sensors placed on the party wall, floor and ceiling in order to estimate the heat flow across these elements. This lack of control will introduce a higher level of uncertainty in the result than might otherwise have been achieved with full heat and temperature control.

Figure 8 – Location of Co-heating Test Apartment

For the duration of the Coheating test the internal temperatures in the controlled areas were maintained at 25°C using electric fan heaters and circulation fans. All monitoring data were recorded at 10 minute intervals using a mixture of wired dataloggers and self-contained temperature/relative humidity loggers. The energy consumed by the fans and heaters was measured using 4 pulse output kWh meters. The internal air temperature and relative humidity were measured at 4 locations in the test apartment. A weather station was located on the balcony of the apartment to measure the external air temperature, relative humidity and wind speed. Two pyranometers were located on the inside faces of the glazing, one on the south facing balcony door and one on the south-east facing living room window (Figure

7). In addition to the heat flux sensors on the party elements, 2 heat flux sensors were located on the external wall, one on the south east facing wall of bedroom one, and one on the north east facing wall of bedroom one (see Figure 7). The background ventilation rate was measured using the decay of carbon dioxide gas. Carbon dioxide gas was injected into the dwelling on a daily basis at 4 locations using timer-controlled solenoid valves on the gas cylinders. The CO_2 concentration was measured at 3 different locations in the dwelling.

The design estimate of external fabric heat loss was calculated using the dwelling dimensions, the nominal design U-values and nominal thermal bridging Y-value calculated using a combination of modelled psi-values and accredited detail psi-values. For the purposes of the Coheating test it was assumed that there is no heat loss through party elements or elements to communal spaces. The design estimate of fabric heat loss using these assumptions is 22.1 W/K (see Table 5). The design estimate for the non-repeating thermal bridging heat loss ignores any thermal bridges between party elements and gives a heat loss of 4.38 W/K (see Table 6). This is equivalent to a y-value of 0.10 W/m^{2}K using the external envelope area of 42.3 m^2. The psi-value for the floor-wall junction was obtained by thermal modelling whilst the psi-values for all other junctions were taken from Table K1 in Appendix K of SAP 2005.

Table 5 – Design Estimate for Fabric Heat Loss for Coheating Test Apartment

Element	**Area (m^2)**	**U-value (W/m^{2}K)**	**Heat Loss (W/K)**
External Wall	30.09	0.21	6.32
Windows	8.76	0.80	7.01
Patio Doors	3.41	1.40	4.78
Party Floor	64.96	0	0
Party Ceiling	64.96	0	0
Wall to Corridor and Front Door	9.84	0	0
Party Wall to West	32.29	0	0
Party Wall to North	12.86	0	0
Thermal Bridging	42.26	0.10	4.38
		TOTAL	**22.1**

Table 6 – Design Estimate for Thermal Bridging for Coheating Test Apartment

Thermal Bridge Junction	Length (m^2)	Psi-value (W/mK)	Heat Loss (W/K)
Floor-External Wall	10.68	0.04	0.43
Ceiling-External Wall	16.10	0.04	0.64
Window Sill and Door Threshold	5.42	0.04	0.22
Window Jamb	18.20	0.05	0.91
Window Head	5.42	0.30	1.63
External Wall Corner	5.25	0.09	0.47
External Wall-Party Wall	2.63	0.03	0.08
		TOTAL	**4.38**

No pressure testing was undertaken on the Coheating test apartment, so it is not possible to derive a value for the background ventilation heat loss from the air leakage rate. Instead, the data obtained from the analysis of the CO_2 tracer gas decay measurements undertaken during the Coheating test have been used to calculate the mean ventilation loss during the test period. The average measured background ventilation rate was 0.26 h^{-1}, which equates to a ventilation heat loss component of 14.6 W/K. The predicted total heat loss for the test apartment is therefore 36.7 W/K, as given by the sum of the fabric heat loss design estimate and the measured background ventilation heat loss (see Table 7).

Table 7 – Predicted Total Heat Loss for Coheating Test Apartment

Design Estimate Fabric Heat Loss (W/K)	22.1
Measured Background Ventilation Loss (W/K)	14.6
Predicted Total Heat Loss	36.7

Analysis of the Coheating test data was carried out using daily average data, using 6:00 am to 6:00 am periods in order to minimise the influence of solar gain across different days. Corrections for solar gain were made by adjusting the total daily power input using the measured solar insolation data on the 2 facades together with the window area and a frame factor. Corrections for heat flow across the unguarded party elements (party floor, party ceiling and north party wall) were calculated on a daily basis using the mean temperature difference between the spaces and the calculated nominal U-values for the party elements based on the design drawings (party floor and party floor = 1.5 W/m^{2}K, and party wall = 0.3 W/m^{2}K). A graph showing mean internal and external temperature for the duration of the test is shown in Figure 9. It can be seen that, in general terms, the internal temperature was maintained at the set point of 25°C, although there were occasional uncontrolled short-term increases to between 26°C and 27°C as a result of solar gain. The internal humidity remained below 50 %RH for the duration of the test (see Figure 10), with the trend following the external humidity trend indicating little drying or excess moisture during the test.

Figure 9 – Mean Internal and External Temperature during Coheating Test

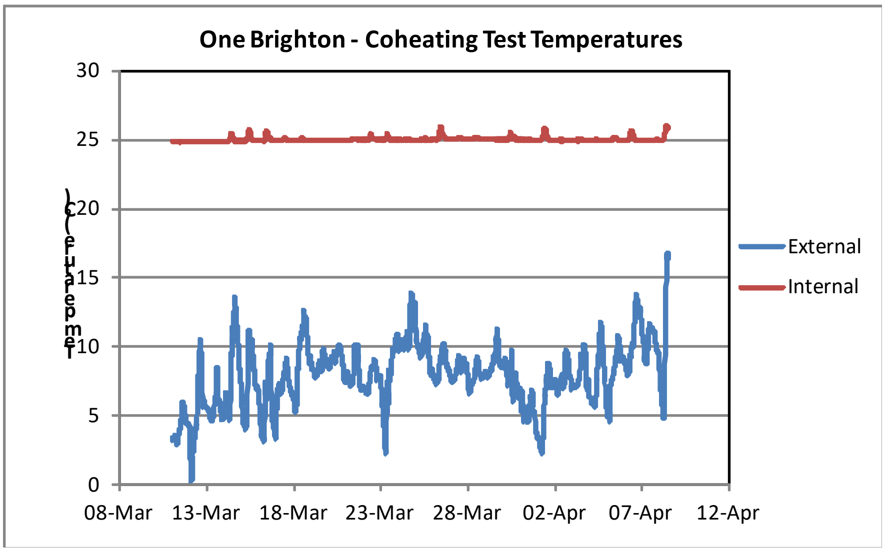
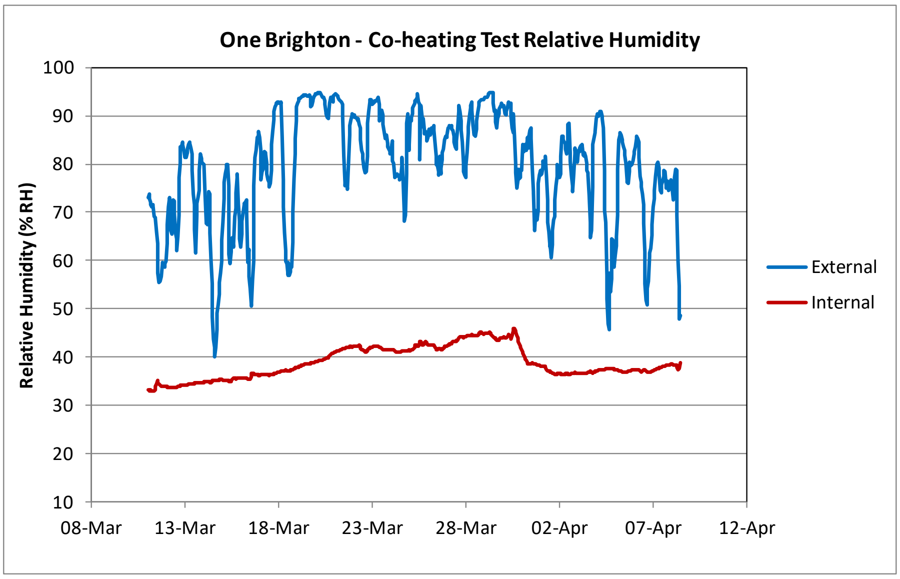


Figure 10 – Mean Internal and External Relative Humidity during Coheating Test



The plot of the adjusted daily heat input data versus the inside-outside delta-T is given in Figure 11. The intercept of the fitted linear regression line has been forced through the origin. It can be seen that there is a high level of scatter of the data points, which is not unexpected given the experimental difficulties and other uncertainties associated with tests on apartments. The regression analysis with heat as the dependent term gives the heat loss coefficient as 55.7 W/K with a standard error from the regression process of 1.9 W/K. Note that this error term excludes instrument errors and errors due to heat exchange with other apartments and the circulation space, so will underestimate the total error in heat loss coefficient. A comparison of the measured heat loss with the predicted heat loss (see Table 8) shows that the measured total heat loss coefficient is 19 W/K (52%) higher than the prediction. As the prediction includes the measured value of background ventilation heat loss, then the difference is all attributable to the fabric performance. The 19 W/K measured discrepancy in heat loss is therefore equivalent to a factor of 86% over the predicted fabric heat loss of 22.1 W/K.

Figure 11 – Coheating Heat Loss Plot adjusted for Solar Gain and Unguarded Heat Loss

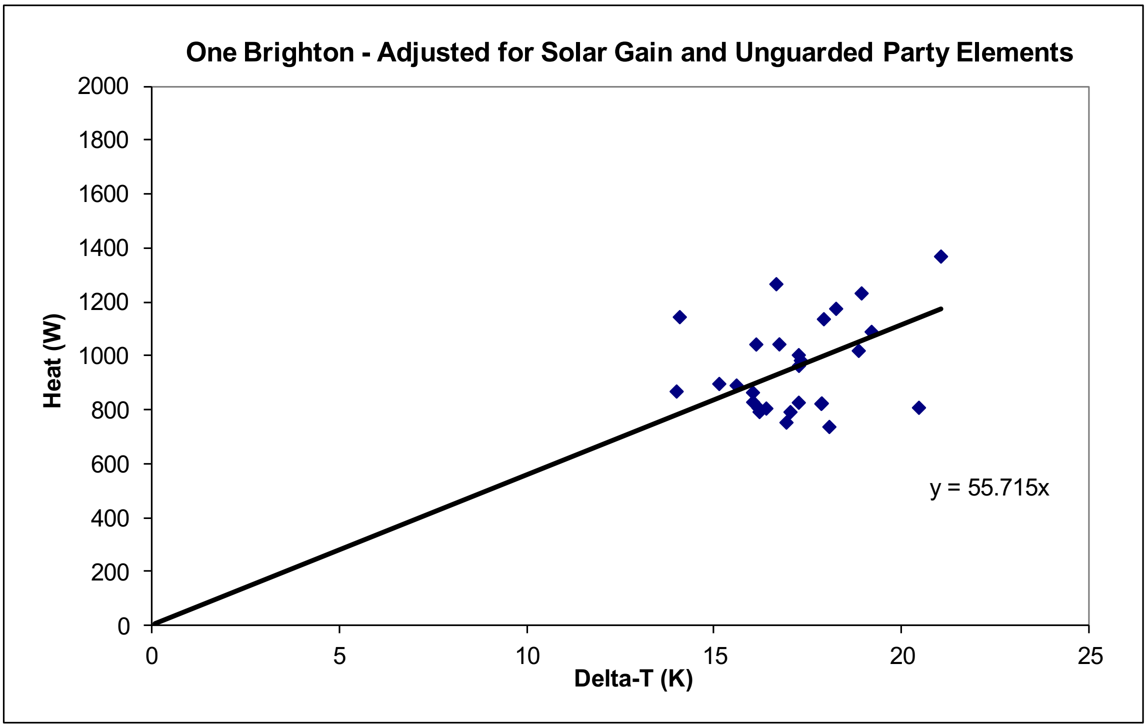
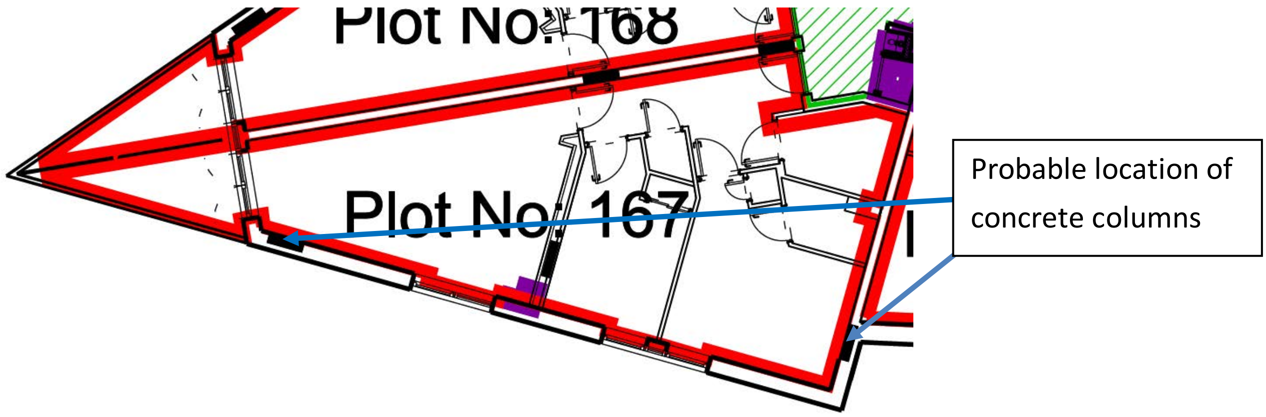


Table 8 – Coheating Test: Predicted versus Measured Whole House Heat Loss Coefficient

Predicted Total Heat Loss Coefficient (W/K)	36.7
Measured Total Heat Loss Coefficient (W/K)	55.7
Difference between Prediction and Measurement (W/K)	+19 (52%)

Care must be taken when analysing the results of this Coheating test due to the high level of experimental uncertainly, partly due to the timing of the test at the end of March and partly due to the potential errors that will arise due to the number of party elements. However, the measured 19 W/K discrepancy in predicted versus measured fabric performance indicates that there may be issues both with the assumptions used for the design estimate and the performance of the fabric as-built. As an example of a type of error that is known to be present in the design estimate, the wall U-values used did not include an allowance for the presence of hidden structural reinforced concrete columns. Where such columns are present in the external wall, they would displace the Thermoplan clay blocks and would increase the theoretical U-value from 0.21 W/m^{2}K to 0.37 W/m^{2}K due to the difference in thermal conductivity between reinforced concrete (nominal 2.3 W/mK) versus that for the Thermoplan blocks (0.11 W/mK). However, structural engineer's drawings showing the location and size of such columns in the test dwelling were not provided to the research team, so it was not possible to accurately determine the overall impact on heat loss. A single column of width 1 metre would increase the total fabric heat loss by 0.42 W/K, which would only account for 2% of the measured discrepancy, so the columns are likely to be of limited importance in terms of overall heat loss. General arrangement plans indicate that columns may be present in the living room wall and bedroom wall (see Figure 12). Another potential anomaly in the heat prediction will be the unknown wall construction between the bedroom windows which does not appear to be designed using Thermoplan blockwork. It is unclear what form the construction is at this point.

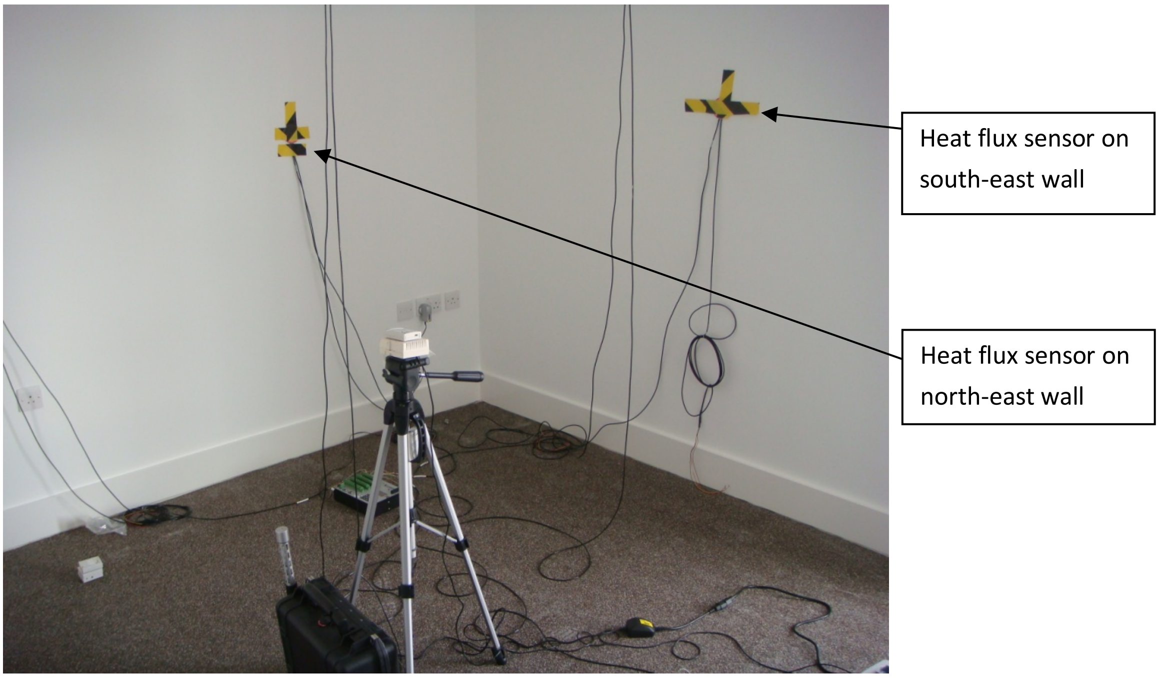
Figure 12 – Coheating Test Plot General Arrangement Plan Drawing showing Column Location



3.2 In-situ U-value Measurements

In-situ U-value measurements were carried out at two locations on the external wall (one on the north-east wall and one on the south-east wall, see Figure 7). The sensors used were Hukseflux HFP01 heat flux plates. These were affixed approximately half way up the wall with adhesive tape (see photograph in Figure 13). Silicone thermal paste was used to improve the contact between wall and sensor.

Figure 13 – Photograph showing Heat Flux Sensors on External Wall during Coheating Test

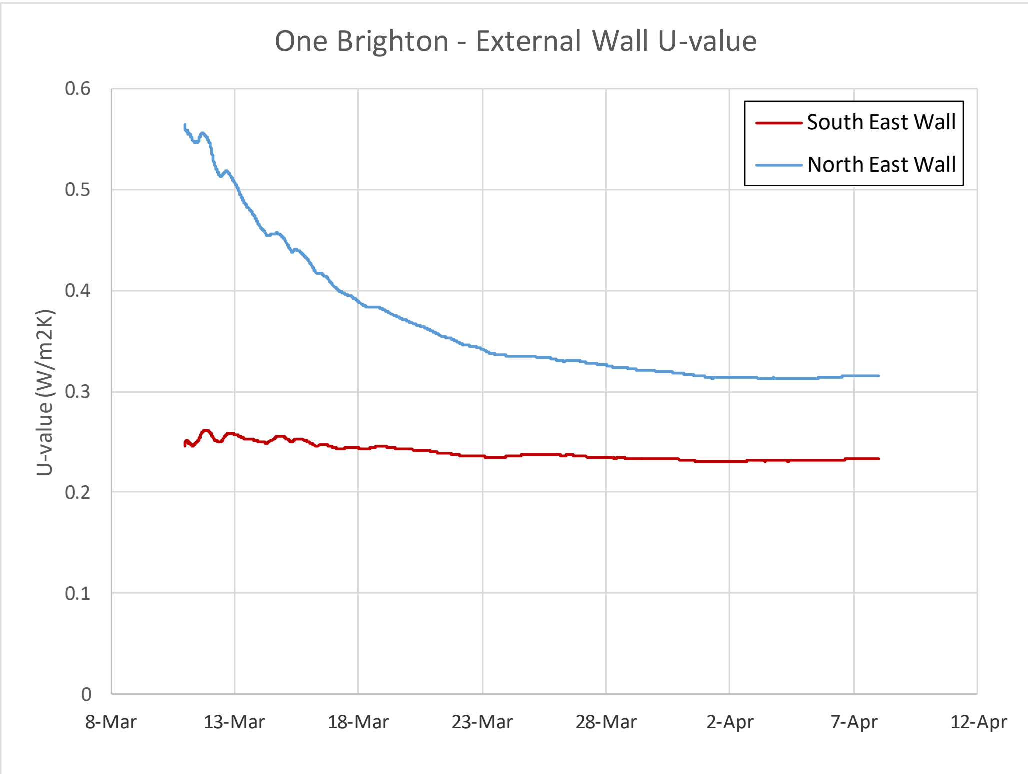


The wall U-value data were collected for the duration of the Coheating test and were analysed according to the method in ISO 9869:1994 (ISO 1994) using air temperature data rather than surface temperature data. The measured U-values are shown in Table 9, with the graph in Figure 14 showing the development of the measured U-value over time for both heat flux sensors. In both cases, it can be seen that the average U-value had reached a stable cumulative mean value by the end of the test (The U-value is within +/- 5% of the final value). There was a big difference in the final measured values, with that for the south east wall location (0.23 W/m^2K) being comparable to the calculated value of 0.21 W/m^2K, whilst that for the north east wall was much higher at 0.32 W/m^2K. It is possible that the difference between the two measured results might be a result of solar gain on the south east sensor. However, it is thought that the most likely explanation for the difference is that the north east sensor was located at (or close to) the probable location of a hidden concrete column, with the measured U-value 0.32 W/m^2K being comparable to that calculated for a wall with a concrete column instead of Thermoplan block (0.37 W/m^2K).

Table 9 – In-situ U-value Measurements

Heat Flux Sensor Location	U-value (W/m^2K)
South East External Wall	0.23
North East External Wall	0.32

Figure 14 – In-situ U-value Cumulative Average Measurements over Time



In order to assess the scale of measurement error for the in-situ U-values, the heat flux data for the two sensors were plotted against the inside-outside temperature difference as daily averages (see Figure 15). The data were then analysed using a linear regression, with the intercept forced through the origin. The regression coefficients for the slope (U-value) and standard error are shown in Table 10. For the south east sensor the standard error is of the order 2%, and for the north east wall the error is slightly higher at 5%, giving good confidence in both U-value measurements.

Figure 15 – In-situ U-value Measurements: Mean Daily Heat Flux vs. Mean Daily Temperature Difference

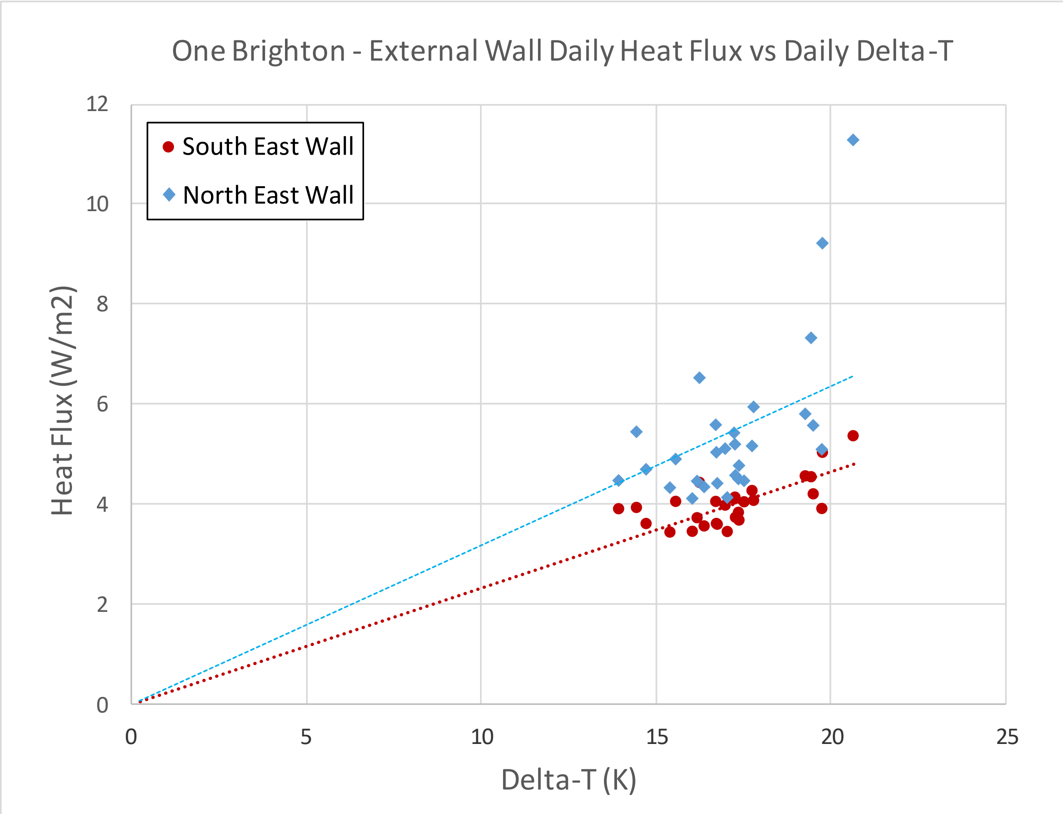


Table 10 - Regression Coefficients - Daily Heat Flux vs. Mean Daily Temperature Difference

Heat Flux Sensor Location	U-value (W/m^2K)	Standard Error
South East External Wall	0.233	0.004
North East External Wall	0.318	0.014

3.3 Pressure Testing

Airtightness pressure testing was undertaken by an external testing consultant working on behalf of the developer. Test certificates were provided for five pressure tests, although it is believed that more may have been carried out. The pressure tests were carried out according to the requirements of the ATTMA TS1 test standard (ATTMA 2007) and were conducted in depressurisation mode only. The results are summarised in Table 11. The design air permeability for all apartments at One Brighton was 5 $m^3/h.m^2$ at 50Pa, so it can be seen that all five tests met the design threshold, with the results ranging from 4.17 to 4.84 $m^3/h.m^2$ and a mean of 4.5 $m^3/h.m^2$. All five dwellings were comfortably below the Part L1 2005 maximum air permeability of 10 $m^3/h.m^2$. However, experience has shown that it should be relatively straightforward to achieve an air permeability of 5 $m^3/h.m^2$ and below with apartments that have solid concrete floors and ceilings, wet plastered wall finishes and where there are a limited number of service penetrations. In this respect, the pressure test results from One Brighton are somewhat disappointing. Previous work carried out on the airtightness of the One Brighton development indicated that the major air leakage paths were concentrated at the wall-floor junction, wall-ceiling junction and at cable and pipe penetrations (GHA 2008). In particular, there was a conflict between continuity of the air barrier and the requirement for a 35mm gap at the top of walls to allow for floor deflection. A flexible membrane was used to form the air barrier at this junction, but effective installation of this membrane proved troublesome.

Table 11 – Pressure Test Results

Test Date	Dwelling Code	Air Permeability ($m^3/h.m^2$ @ 50Pa)	Exponent	Envelope Area (m^2)	Comment
10/06/2009	A	4.69	0.62	164	Dwelling A was monitored
10/06/2009	24	4.17	0.78	246	-
07/08/2009	2	4.84	0.62	123	Temporary sealing used
07/08/2009	163	4.17	0.66	266	-
26/05/2010	157	4.69	0.60	268	-

In the case of dwelling No. 2, the test certificate stated that the result was achieved with temporary sealing, and it is unclear if remedial works were carried out and the pressure test repeated. It is perhaps interesting to note that current advice in Part F 2010 (HM Government 2010) for the maximum design air permeability for dwellings with MVHR systems is 3 $m^3/h.m^2$ in order to maximise the energy benefits of the recovery from the heat exchanger. It is unclear from the design documentation why a relatively high design air permeability value of 5 $m^3/h.m^2$ was used in combination with MVHR.

Another factor to take into consideration in the assessment of air permeability is the influence of the high area to volume ratios of single-storey apartments. For example, dwelling No. 2 has an envelope area of 123 m^2, but an internal volume of only 83 m^3, giving an area to volume ratio of 1.5:1. In comparison, a typical 2-storey dwelling will have an area to volume ratio close to 1:1. So, whilst the pressure test data for apartment No.2 gives an air permeability of 4.8 $m^3/h.m^2$, the volumetric air change rate is 7.2 h^{-1}. This means that background ventilation rate calculated from the volumetric air change rate will be higher than that calculated using air permeability. The background ventilation rate in SAP is calculated from n/20 multiplied by a shelter factor depending upon the number of sheltered sides. For apartment No.2 this would give a calculated background ventilation rate of 0.27 h^{-1} using the volumetric air change rate and 0.18 h^{-1} using the air permeability value. It is interesting to compare these data with the measured background ventilation rate from the Coheating test apartment (0.26 h^{-1}). This measured result is consistent with the calculated value for dwelling No.2 using the volumetric air change rate.

3.4 Thermal Imaging

A limited thermal imaging survey was carried out on the Coheating test apartment. The survey was conducted using a FLIR P60 infra-red thermal imaging camera. The thermal images in Figure 16 and Figure 17 show the external façade of the Coheating test apartment (location of test apartment is shown by the red dotted line on photographs). The external thermal images show no discernible thermal defects or anomalies, even after post-processing the images to look for small surface temperature differences. This is perhaps surprising, as it would be expected that it would be possible to identify the thermal bridges at the floor junctions and at the locations of the concrete columns. The conditions at the time of the imaging survey were however not ideal. The inside-outside temperature difference was of the order 10K, which is generally considered sufficient for thermal imaging. However, the images were taken on a sunny day, and solar effects would have likely masked any surface temperature differences arising from heat flow through the walls. In addition, the acute observation angle of the façade from the ground would also have caused problems.

Figure 16 – Thermogram and Photograph of South East Wall of Coheating Test Dwelling

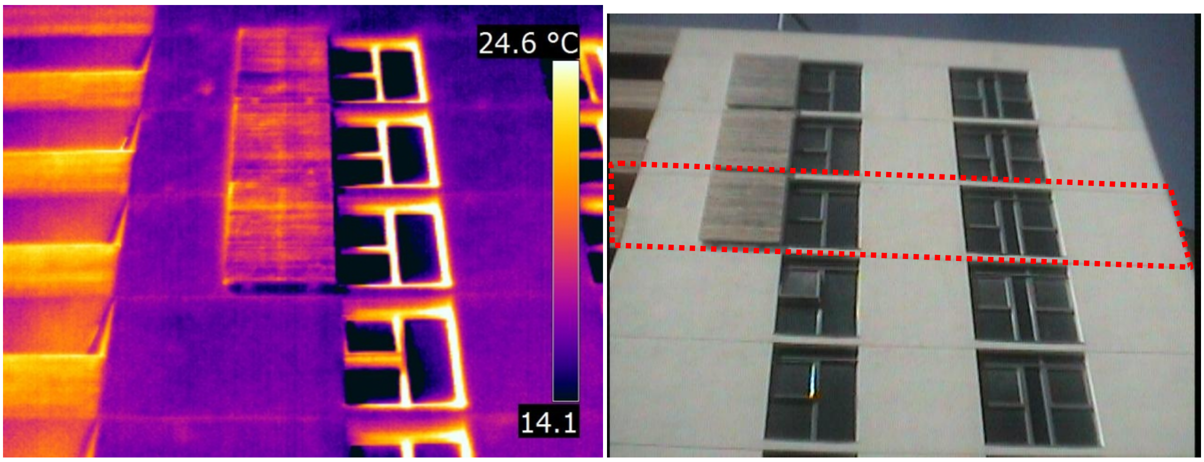
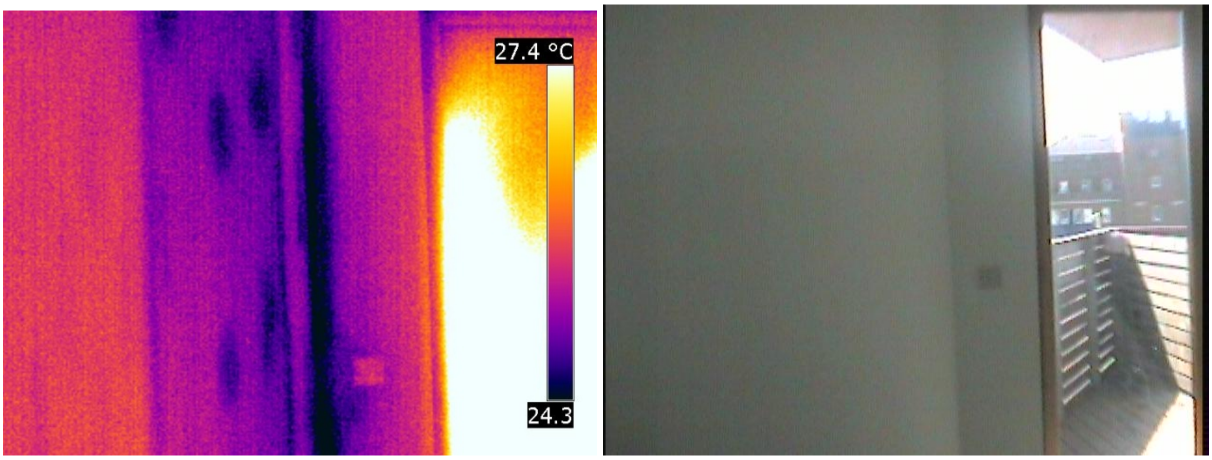


Figure 17 – Thermogram and Photograph of South East Wall of Co-heating Test Dwelling

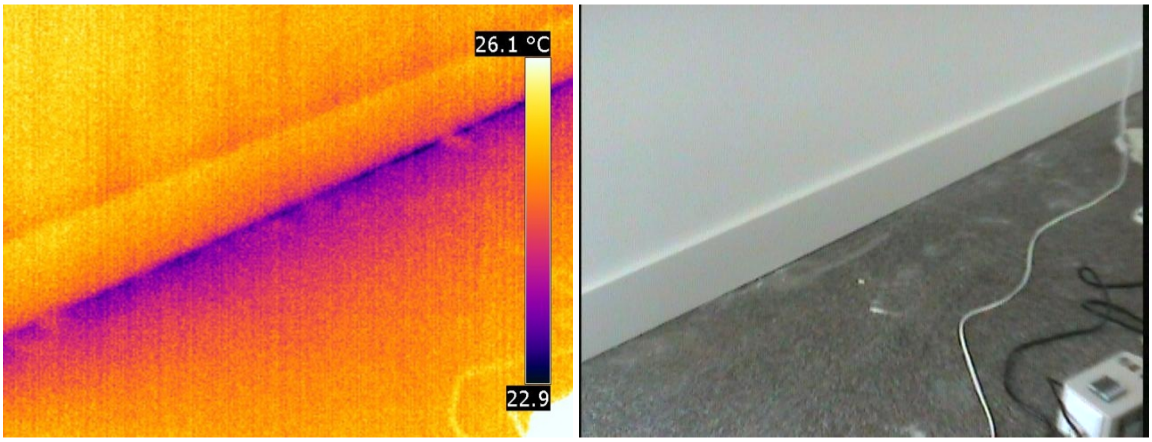
Thermal images were also taken from the inside of the Coheating test apartment. The thermal image in Figure 18 shows the external wall adjacent to the patio door. The position of the hidden concrete column is clearly apparent from the colder temperatures shown in blue/purple on the thermal image. There are also dark purple spots in this zone which are indicative of the presence of plasterboard adhesive dabs.

Figure 18 – Thermogram and Photograph of Internal Face of South East Wall in Coheating Test Dwelling



The thermal image in Figure 19 shows the floor-wall junction in the living room. It can be seen that there is a purple cold pattern below the skirting board. This is indicative of the flow of cold air from outside into the heated space. This is consistent with the floor-wall junction being an important air leakage pathway.

Figure 19 – Thermogram and Photograph of Floor-Wall Junction in Living Room



3.5 Conclusions and key findings for this section

The results from a Coheating test of one of the One Brighton apartments showed that the measured heat loss coefficient was low in comparison to regulatory targets. However, there was still a discrepancy between the measured and calculated heat loss, with the measured heat loss being around 50% higher than predicted. This was partly due to the fact that the designed assumptions for heat loss had neglected to include the effect of hidden concrete columns in the wall.

The Coheating test procedure for the apartment was highly complex, with most of the experimental issues relating to the need to guard for heat loss across party elements to adjacent apartments. As a result, there is a relatively high level of uncertainty with the test result when for example compared to a Coheating test on a detached house when there is no requirement for guarding. The total uncertainty in this situation is difficult to estimate, but is likely to be significantly larger than the statistical uncertainty (equivalent to ±3.5%) derived from the regression analysis presented above, due primarily to the difficulty of adequately guarding against internal heat transfers. Uncertainty in Coheating testing is an active and difficult area of research (see for example, Stamp 2013). We therefore warn against over interpreting this particular piece of data.

In-situ heat flux data showed that the thermal performance of the external wall closely matched the calculated performance, although the measurement was carried out in two locations only. The implication is that walls constructed using perforated clay blocks and external wood fibre insulation provide for a thermally robust construction. This is probably a consequence of the lack of air cavities in the wall construction.

The measured air permeability values of the One Brighton dwellings were all less than the design target of 5 $m^3/h.m^2$, with a mean test result of 4.5 $m^3/h.m^2$. This result is slightly disappointing, as although the One Brighton dwellings are more airtight than a typical new UK dwelling (around 7 $m^3/h.m^2$), it should have been possible to achieve lower levels of air leakage given the use of concrete floors, high performance glazing and the lack of cavities in the construction.

Infra-red thermal imaging surveys carried out from inside the dwelling were able to identify the location of hidden concrete columns in the external wall. However, thermal imaging surveys carried out from the outside of the building would not detect the same columns. This was mostly a consequence of the survey being carried out on a sunny days, with solar effects on the wall masking the heat loss effects. This demonstrates the need to carry out external thermal imaging surveys at night or early morning when solar effects are minimised.

A comparison was made between the background ventilation rates measured using CO_2 tracer gas decay with ventilation rates estimated from pressure test results. It was concluded that, for apartments and other dwellings with high surface area to volume ratios, the ventilation rate calculated using the volumetric air leakage rate gives a closer approximation to the measured value than that calculated using the air permeability. It is therefore suggested that consideration should be given to changing the algorithms in SAP to use volumetric air leakage rather than air permeability. This would not require any change to current pressure test procedures other than an additional calculation in the data analysis.

4 Key findings from the design and delivery team walkthrough

Technology Strategy Board guidance on section requirements:	This section should highlight the BPE team's initial studies into possible causes and effects, which may require further study. The section should reveal the main findings learnt from the walkthrough with the design and delivery team covering the early stage BPE process and the design intentions. Comment on lessons learned, key findings, conclusions and recommendations on what would be done differently next time. A critical feature of this section is reviewing the original aspirations for the project as stated by the design team and comparing with the delivered building. This often goes beyond what is stated in supporting documentation and is a crucial initial discussion which then frames the discussion about what changed during the process and why. The purpose of the walkthrough is to compare design intent with reality and why there is a gap between the two. Explore the degree to which the design intent has been followed through in terms of delivery and subsequent adoption by the occupant(s). Focus on what constraints or problems they had to accept or address in delivering the project. Cover construction team issues and how these were cascaded through the project for example: training for design team on utilising specific technologies and new materials, sequencing of trades. Describe and evaluate the documentation generated to confirm and record the commissioning and hand-over from specialist contractor to house builder. Include in the appendix if necessary. How did this process influence the design and delivery team walkthrough? Can anything be improved? Capture and assess how decisions were made and captured when the team are together e.g. the materials being used and whether they are required or desired – is there the possibility of changing materials and if so it this known by the procurement and constructions teams. Are there any issues relating to the dwelling's operation? This would include: programmers; timing systems and controls; lights; ventilation systems; temperature settings; motorised or manual openings / vents. Do the developer / manufacturer produced user manuals help or hinder the correct use of the dwelling? Have there been any issues relating to maintenance, reliability and reporting of breakdowns of systems within the dwelling? Do breakdowns affect building use and operation? Have issues been logged in a record book or similar? Add further explanatory information if necessary. Explain any other items not covered above that may be relevant to a building performance study. This walkthrough should be compared and contrasted with the occupant walkthrough (see later section) with comments on whether the design intent was desired, delivered and valued by the occupant and where and how differences between intent and expectation have arisen. If action was taken to remedy misunderstandings, improve support or feed occupant preferences into future design cycles this should be explained. Graphs, images and test results could be included in this section where

	it supports a developing view of how well or otherwise the design intent has been delivered during the pre and post completion phases. This section should provide a summary of the initial aftercare process, post completion building operation, and initial maintenance and management – particularly in relation to energy efficiency, reliability, metering strategy, building operation and the approach to maintenance i.e. proactive or reactive. Guidance on walkthroughs is available in the document *TSB BPE Domestic - Guidance on handover and walkthroughs.doc*, which can be downloaded from the Building Performance Evaluation site on `_connect'.

4.1 Background to Design and Delivery Team Walkthrough

The purpose of the design and delivery team walkthrough was to provide an opportunity for core members of the project's design and delivery team to visit the completed development and discuss the delivery process. At the same time, the research team were able to provide feedback to the design and delivery team on the results of the Coheating test, BUS survey and in-depth interviews conducted with residents of the development. The walkthrough was carried out in July 2011, and members of key consulting and contracting organisations involved in the design and construction process were invited to attend. Attendees included representatives from the development partners, main contractor, architects, M&E consultants and the building management company.

4.2 Design and Delivery Team Walkthrough Process

The itinerary for the day started with an introductory meeting for all those involved. This was followed by a visit to one of the flats and then a general tour around the development. This included visits to key features such as the "sky gardens", allotments, communal heating plant room and the on-site waste management facilities. Following the walkthrough, the team reconvened for presentations and focus group discussions.

The apartment visited was chosen from one of those occupied by a resident who had agreed to give an in-depth interview about their experiences of living in the development. The visit to the flat lasted approximately 20 minutes, and design team members were able to speak directly with the resident. The walkthrough of the allotments, plant room and waste management facilities were led by the development "Green Caretaker".

The focus groups were organised and facilitated by the research team and were filmed. A transcription of the focus group discussions was produced following the event, and participants were invited to review and validate the transcription prior to analysis. Individual follow-up interviews were conducted with all the attendees and other members of the design team and development team who were unable to attend the walkthrough. These interviews were also filmed and transcribed.

4.3 Discussion of Design and Delivery Team Walkthrough

All those who attended the walkthrough enjoyed the experience and the presentations and focus group discussion that followed. Most said that they had not been involved in this type of feedback process for previous projects that they had worked on and felt that it was a valuable experience. All enjoyed talking to the resident and indicated that they would have liked to have spent more time doing this. It is interesting to note that one of the main client representatives explained that most of the key investors in the development had never actually visited the site. The general walkthrough of the site and the presentations were well received and helped to stimulate a broader discussion about the design and delivery processes and the final product.

4.3.1 Management of the Completed Development

The responses from the discussions highlighted issues with the day-to-day management of the development. For example, some externally contracted services such as cleaning of communal spaces did not necessarily deliver services as specified or anticipated by residents. There were also found to be discrepancies in the quality and levels of delivery of services between blocks with different tenures. The allotments and bike sheds were found to be very well used and loved, but other facilities, such as the car-sharing facility, were underutilised. This was attributed to the fact that the development is located very close to transport hubs for trains and buses and close to general amenities within Brighton. The design of the green hanging wall garden was also found not to work as planned due to the fact that it needed constant watering and maintenance. Facilities such as the roof garden and sky gardens were liked but less well used than the allotments.

4.3.2 Building Services

Discussions highlighted a range of issues related to the building services. For example, it was stated that there were problems with the procurement of the MVHR units, which were delivered to site with the wrong specification. The design and installation of the biomass boiler was complicated due to a lack experience with such systems by the design team. These issues were further compounded by a lack of information provided by UK representatives of the Austrian biomass boiler supplier and the fact that there was only a limited amount of product literature in English. Additional construction costs were associated with the biomass boiler installation, as the support base had been designed to accommodate a lower weight than that of the boiler which was delivered to site. This shows the importance of good communication between engineers and equipment suppliers.

A range of problems had been with experienced with the operation and maintenance of the biomass system. For example, the fire brigade had had to be called out several times to attend ‘apparent’ fires in the fuel store which were caused by smoke feeding back through the fuel supply auger. This was found to be caused by an inconsistent woodchip fuel supply. It was also noted that the biomass boiler has not functioned properly for long periods of time, meaning that a large proportion of heat has been provided by the backup gas boiler. The wood chip fuel for the boiler was sourced locally in line with the One Planet Living principles, and there were issues in obtaining local fuel of a consistent quality. Communal biomass boilers are still relatively rare in the UK. This means that supply chains are underdeveloped and immature, and there is a clear lack of design and construction expertise.

Technical issues were also encountered with the installation of lighting and door entry systems. For example, there were difficulties is setting up appropriate light levels for the PIR controls for the lighting. This resulted in the automatic lighting not switching off. There were initial problems with the set-up of door entry calls, which were found to be re-routed to the wrong telephone numbers.

4.3.3 Construction

The clay blocks used on the development were imported from Germany and their use is relatively uncommon in the UK. The contractors had to spend a considerable amount of time training their teams to install the blocks correctly. It was also stated that the engineers and design team did not initially trust the performance of the blocks due to a lack of experience and familiarity. UK insurers were reluctant to support the use of this new technology and an insurer from Zürich was eventually found who had knowledge of continental European construction techniques and was therefore willing to support the project.

4.4 In-Depth Interviews with Design Team

In-depth interviews were conducted with all those individuals who attended the walkthrough and others that could not attend the event. In general, feedback from the interviews supported the findings of the focus groups. All those interviewed felt that, on the whole, the finished building had met the original design intentions. Various issues were highlighted such as the problems with the performance of the biomass boiler and MVHR systems. It was noted that some design strategies employed caused knock-on effects during the construction phase. For example, a lack of understanding of the impact of deflection tolerances for posttensioned concrete slabs resulted in later difficulties in achieving the desired levels of airtightness due to air leakage at the floor-wall junctions.

One area of concern that came up during discussion with the architects was that space planning of the dwellings was largely controlled by the estate and letting agents for the development. This resulted in a lack of design freedom and, in the view of the architects, prioritised investment return over making the best use of space for occupants.

It was stated by one of the developers that the mechanical and electrical engineering design team had changed between the initial design phase and the building construction. This occurred as the engineers employed for the design had little experience in site delivery. The impact of this change on the delivery process was unclear.

4.5 Conclusions and key findings for this section

One Brighton was felt by the walkthrough participants to have been a success and the design and delivery team were proud to have been part of it. It was agreed by all that there had been good team co-operation during the project. The participants enjoyed the walkthrough process which they perceived as having been useful and productive. There was a feeling that all would be interested in taking part in similar processes in the future.

New Technologies: The project applied a number of new systems and technologies which had not previously been well tested in the UK. This presented problems in terms of understanding how to design and install them effectively, and in the development of new supply chains. Of particular note were issues relating to the biomass district heating system where the boiler supplier was Austrian and where there was a requirement to develop new supply chains to maintain and service the system and to provide locally sourced fuel.

Mechanical Ventilation with Heat Recovery (MVHR): Whilst MVHR is not a new technology in the UK, it was apparent that its design and installation at One Brighton presented numerous problems. For example, the location of the unit within the dwellings have given rise to access issues, difficulties in occupants changing filters and resulted in unnecessarily long runs of primary ductwork. There were also concerns with the design of the control interface systems, which feedback had shown to be complicated and not user friendly.

Allotments and Bike Stores: The allotments and the bike store were deemed by the team to have been a success and are well used by the resident. The car share scheme has however been less successful and underutilised, probably due to the urban location of this development.

Green Caretaker: The work of the Green Caretaker has been to help communicate the ethos and green systems to residents of the development. This has been essential considering the relatively high turn-over of residents. This role has also helped in part to smooth over some of the issues encountered with outside services who have been employed for maintenance such as cleaning the development.

Design Process: The feedback from this research has indicated some interesting findings in relation to the design process. For example, there were issues relating to space planning for the apartments and also on the co-ordination of details between the design and construction teams.

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

Technology Strategy Board guidance on section requirements:	This section should reveal the main findings learnt from the early stage BPE process and in particular from the Building Use Survey. This section should be cross-referenced with findings from the occupant handover process and be informed by the design and delivery team walkthroughs. This section should draw on the BPE team's initial studies into possible causes and effects, which may require further study. BUS information will be stored in the data repository, but the link for BUS anonymised results should be included in this report. The BUS results come in 3 forms: • An anonymous web-link that will contain the result and benchmark graphic for each variable (question), a summary of the 12 main variables and some calculated summary variables. • Appendix A (.pdf) which contains largely the same set of results and graphics as the link above. • Appendix B (.pdf) which contains all the text comments from the questionnaires Reference the variable percentile scores, which show the percentile that the score is ranked at in the benchmark set, and comment on as appropriate. **Important:** The comments from Appendix B can be used in this section. However, great care must be taken when using comments to ensure that no personal information is divulged, no individual can be identified and no confidentiality is breached when publishing the comments. This is especially important if referring to a respondents' background. Graphs, images and test results could be included in this section where it supports a developing view of how well or otherwise the design intent has been delivered during the pre and post completion phases. Note where the dwelling is being used as intended and where it is not; what they like / dislike about the home; what is easy or awkward; what they worry about. It should cover which aspects provide occupant satisfaction and which do not meet their needs, result in frustration and / or compensating behaviour on the part of occupants. Any misunderstandings occupants have about the operation of their home should also be addressed. Are there any issues relating to the dwelling's operation? This would include: programmers; timing systems and controls; lights; ventilation systems; temperature settings; motorised or manual openings / vents. Do the developer / manufacturer produced user manuals help or hinder the correct use of the dwelling? Have there been any issues relating to maintenance, reliability and breakdowns of systems within the dwelling? Do breakdowns affect building use and operation? Does the occupant have easy access to a help service? Does the occupant log issues in a record book or similar? Does the occupant have any particular issues with lighting within the dwelling (both artificial lighting and natural day lighting)? Add further explanatory information if necessary From the occupiers point of view what improvements could be made to the dwelling to make it more user friendly and comfortable to live in. Cover what the teams' would do differently in future (or wanted to do differently but could not) and why.

5.1 Building Use Survey Process

The One Brighton residents were asked to complete the Building Use Survey (BUS) questionnaire on two separate occasions. The first survey was carried out during the winter of 2011 and the second during the summer of 2012. The survey included additional questions on thermal comfort which were designed to assess the behaviours related to reducing heat, water and electricity use.

The distribution of the BUS questionnaires was coordinated with the help of the developers and the green caretaker. An introductory letter, information sheet and a paper copy of the survey were delivered to the post boxes of all 172 dwellings early in January 2011 and again in June 2012. The survey was promoted by posters displayed in communal areas of the development and by an advertisement in the resident's newsletter. Entry into a free prize draw was offered as an incentive to participate, with vouchers for a local food and natural products cooperative being offered as the main prize

A total of 62 completed surveys were returned from 60 apartments in the first survey, representing a 35% response rate. In the second survey a total of 51 completed surveys were returned from 50 apartments, representing a 30% response rate. A breakdown of responses for both surveys is given in Table 12.

Table 12 – Breakdown of BUS Survey Responses

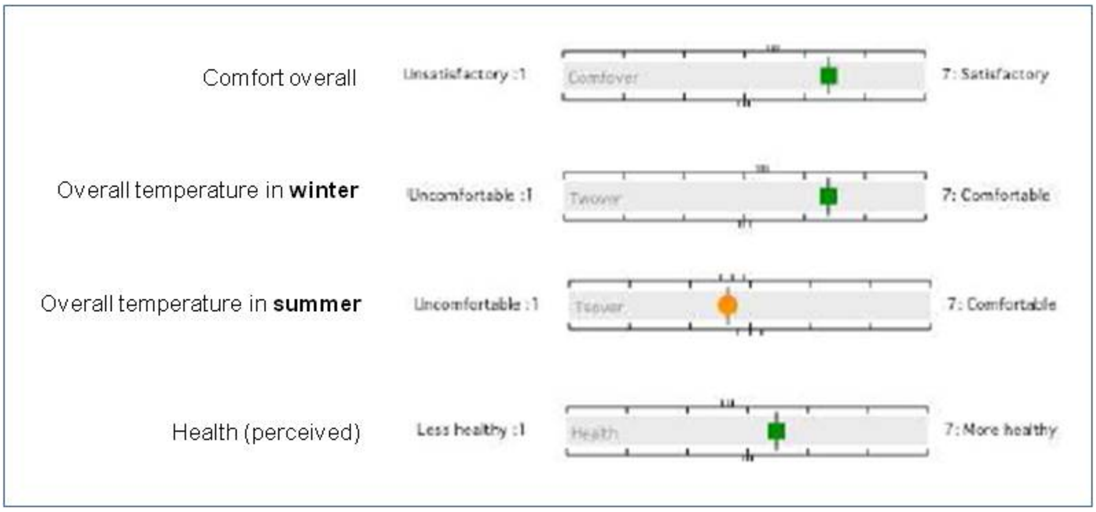
		Brighton Belle					Pullman Haul				
		Total	Apartment type				Total	Apartment type			
Period			Studio	1bed	2bed	3bed		Studio	1bed	2bed	3bed
Winter 2011	Number of surveys returned	41	4	15	22	0	21	1	12	7	1
	Percentage of dwellings & breakdown of response rate	36%	10%	36%	54%	NA	33%	5%	57%	33%	5%
Summer 2012	Number of surveys returned	29	5	9	11	0	21	2	11	4	4
	Percentage of dwellings & breakdown of response rate	26%	20%	36%	44%	NA	33%	10%	52%	19%	19%

5.2 Building Use Survey Results: Winter 2011

The results from the first BUS survey showed that the majority of residents found the living conditions to be healthy and satisfactory (see overall BUS comfort chart in Figure 20). Around 80% of residents who responded indicated that the building met their needs. At the time of the first survey, comfort conditions in winter were thought to be better than in summer.

A wide range of factors were mentioned that worked well. These included the apartment layouts, allotments, bike storage facilities, building location, recycling bins, the green caretaker, levels of thermal insulation and transport links. Examples of things that were perceived to be not working as expected included poor acoustic insulation, the intercom system and the heating/ventilation system. Residents also complained about the lack of on-site car parking.

Figure 20 – BUS Results for Overall Comfort – Winter 2011



The residents did not report any evidence of damp or mould growth. Air quality was generally reported to be dry or too dry, which is consistent with actual measurements of relative humidity in the monitored apartments (see Figure 40). This is a known potential side-effect of warm air heating systems. In general, residents were satisfied with the light levels and lighting systems in the apartments, with only 24% reporting too little daylight. One of the most significant areas of concern was overheating during the summer, with 75% of occupants reporting that it was either hot or too hot. It is worth noting that the summer of 2011 was relatively cool, with peak temperatures around 2°C lower than the heat wave of August 2003. This suggests that the development is likely to be at significant risk of overheating in a heat wave.

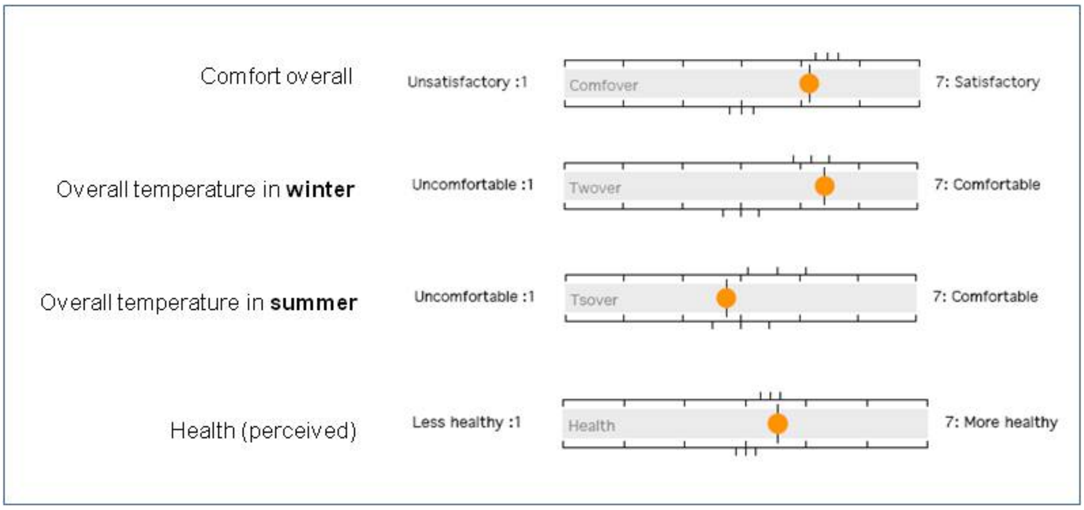
The main health issues reported were related to noise, dust, pollution, air dryness, and the heating and ventilation system. Nevertheless, 84% indicated that there had been no changes or perceived health effect while living at One Brighton.

A clear negative aspect apparent from the survey related to the cost of energy and associated service costs. Many residents thought that energy costs at One Brighton were higher than in their previous accommodation. In particular, the occupants were concerned about the standing charge which was perceived to be too expensive. It is not clear if residents realised that the costs of One Brighton standing charge includes the cost of maintaining and replacing the heating system when making any cost comparisons. Standing charges for district heat are always likely to be higher than typical fixed charges for gas supply from the grid (the average fixed cost for UK domestic gas customers in 2013 was £96/annum (DECC 2013b) compared to the One Brighton standing charge of over £500/annum).

5.3 Building Use Survey Results: Summer 2012

The results from the second BUS survey in the summer of 2012 showed that most people remained satisfied and comfortable at One Brighton (see Figure 21). The central location of the development and access to amenities are valued very highly and cited positively by residents throughout the survey. Location appears to be the most important factor for lifestyle change too. However, some residents did indicate noise and antisocial behaviour as negative issues related to the location of the site. In general, people are satisfied with the space and layout of the building.

Figure 21 – BUS Results for Overall Comfort – Summer 2012



A lack of control over the internal environmental conditions (e.g. temperature and noise) comes over as a particular issue for many residents. Even though most residents had been in occupation for more than a year, more than half reported some degree of dissatisfaction with the control of the heating system. This was especially so during warm summer days. Interestingly, residents perceived that they have less control over the temperature than in 2011. The option of opening windows at One Brighton can be problematic for some due to the high levels of outside noise and pollution from the surrounding area. Comments also indicated that the air from ventilation system was dusty and dry.

In terms of the mechanical ventilation system, 47% of residents reported dissatisfaction with the stuffiness of the air. This issue could perhaps be related to the cleaning and maintenance of filters, with feedback from the residents indicating that access to the filters was difficult. It should be noted however that the One Brighton management company did contact residents to provide the details of a maintenance contractor who could change their filters for a price. It is not clear how many occupants procured this service. Poor air quality could also be linked to the impact of external noise disturbance and the reluctance of residents to open their windows.

There were fewer negative comments regarding the lack of parking compared with the first survey. This would indicate that One Brighton residents have perhaps changed their lifestyles, with a reported increase in walking and use of public transport. The results from the survey were discussed with the green caretaker at the site in order to further explore some of the issues. In general, the caretaker thought that the BUS results painted an accurate picture of the situation at One Brighton.

5.4 Comparison of Building Use Survey Results

A comparison of the responses from the two BUS surveys is shown in Figure 22. The response rates were similar between the two surveys, with 63 responses received in January 2011 and 51 in 2012. It should be noted that 50% of those residents who responded in winter 2011 also returned their questionnaires in summer 2012.

In general, the differences between results from the two sets of surveys were small. However, the overall trend suggests a decrease in satisfaction levels in 2012 compared to those in 2011. We can propose some possible reasons for this. In the first survey in the occupants would have been in an initial “honeymoon period”, having only been in occupation for a relatively short time site (54% of respondents had lived at the site for less than one year). This would mean that, in the first survey, some residents would still be learning about the operational aspects of the dwellings, and had perhaps not yet experienced the full range of conditions and problems. In comparison, by the time of the second survey in 2012, 88% of the respondents had lived on the development for more than a year. In terms of comfort, there was little change in the perception of temperature in either winter or summer between the two surveys. However, a higher proportion of residents surveyed in 2012 indicated issues with stuffiness and air quality. This is likely to be related to high internal temperatures, and hence low relative humidities throughout the year. But it may also be related to maintenance issues with the MVHR systems. More residents complained about a lack of control of the internal environment in the second survey. This is perhaps surprising as it would be expected that longer periods of occupation would lead to a better understanding of controls.

Figure 22 – Comparison of BUS Surveys from Winter 2011 and Summer 2012

Questions		2011	2012	Change
The Residence Overall	Location: Un/Satisfactory	2	4	-2
	Space: Enough/Not Enough	16	26	-10
	Layout: Suitable/Not Suitable	3	16	-13
	Storage: Enough/ Not Enough	28	38	-10
	Appearance: Good/Poor	5	10	-5
	Needs: Very Poorly/Very Well	2	10	-8
Winter Comfort	Temperature Overall: Un/Satisfactory	16	12	4
	Temperature: Too Hot - Too Cold	20	23	-3
	Temperature: Stable - Variable	43	35	8
	Air: Still - Draughty	66	55	11
	Air: Dry -Humid	50	46	4
	Air: Fresh - Stuffy	18	43	-25
	Air: Odourless - Smelly	7	11	-4
	Conditions Overall	22	31	-9
Summer Comfort	Temperature Overall: Un/Satisfactory	49	43	6
	Temperature: Too Hot - Too Cold	50	53	-3
	Temperature: Stable - Variable	42	25	17
	Air: Still - Draughty	54	59	-5
	Air: Dry -Humid	52	52	0
	Air: Fresh - Stuffy	46	47	-1
	Air: Odourless - Smelly	10	24	-14
	Conditions Overall	43	47	-4
Noise	Noise Overall: Un/Satisfactory	29	37	-8
	Noise Between Rooms: Too Little - Too Much	34	34	0
	Noise from Neighbours: Too Little - Too Much	47	45	2
	Noise from Outside: Too Little - Too Much	54	53	1
Light	Lighting Overall: Un/Satisfactory	15	10	5
	Natural Light: Too Little - Too Much	22	22	0
	Artificial Light: Too Little - Too Much	22	20	2
Comfort	All Things Considered: Comfort Un/Satisfactory	7	18	-11
Health	Health: Less Healthy - More Healthy	16	18	-2
Control	Heating: No Control - Full Control	40	58	-18
	Cooling: No Control - Full Control	50	67	-17
	Ventilation: No Control - Full Control	30	48	-18
	Lighting: No Control - Full Control	13	18	-5
	Noise: No Control - Full Control	45	49	-4
Design	Design: Un/Satisfactory	15	17	-2

5.5 Energy and Water Efficiency Behaviour Survey

The survey on behaviour was used to calculate “behaviour scores” for water, heat and electricity use in terms of a percentage relating to whether the survey response was positive, negative or neutral (see Bainbridge 2011). Higher scores translate to a more efficient declared behaviour (i.e. behaviour oriented towards reduced resource consumption). The scores are summarised in Table 13.

Table 13 – Responses to Energy and Water Efficiency Behaviour Survey (Bainbridge 2011)

Question	Percentage of Responses			
General Questions	disagree	neutral	agree	did not answer
I consider myself to be environmentally friendly	0	24	62	15
I consider my behaviour to be energy efficient	4	20	62	15
I consider my house to be energy efficient	2	13	67	18
Living in an 'efficient' house means that I don't need to think about saving energy and water to be environmentally friendly	36	15	27	22
Water use Questions	disagree	neutral	agree	did not answer
In the UK we are using more water than we can source sustainably (without harming the planet)	11	51	38	0
The (water) fixtures, fittings and appliances in this house are efficient	7	18	75	0
I try to keep my personal cleaning time to a sensible level and take showers, not baths	16	18	65	0
I would feel good if I/we used less water than other apparments at One Brighton	13	47	40	0
I feel pressure to reduce water consumption through the media and government etc.	36	40	24	0
I could use less water from taps, showers and appliances (washing machine etc) if I thought about it	15	40	45	0
Heating Questions	disagree	neutral	agree	did not answer
I know how to change the thermostat and radiator valve settings throughout the house	9	20	71	0
I have optimised my thermostat and radiator valve settings for the way that I use the house	24	29	45	2
I would feel good if I knew I/we used less heating and hot water than other appartments at One Brighton	7	49	44	0
I feel pressure to reduce heating consumption through the media and government etc.	40	33	25	2
Reducing my heating and/or hot water consumption from its current usage will reduce my comfort	33	24	42	0
I can make myself comfortable in the home through other means than heating	4	24	73	0
In the future I could easily make changes to reduce my heating/hot water consumption	28	46	26	0
Electricity Questions	disagree	neutral	agree	did not answer
It is inconvenient to turn things off when I'm not using them	58	16	25	0
I think there are people in the UK who use far more electricity than I do	4	7	89	0
Any electrical reduction effort I make is offset by those who use excessive amounts of electricity	27	38	35	0
I would feel good if I knew I used less electricity than other homes at One Brighton	9	35	56	0
If I knew where I could reduce my electricity consumption I would make the effort to do so	9	22	69	0

In general terms, the majority of One Brighton residents describe themselves as in favour of energy and water efficient behaviour. For example, 26% of residents would be prepared to change their behaviour to reduce heating energy use and 69% to reduce electricity consumption. The difference in response to heat and electricity use is very interesting and indicates that residents are less willing to sacrifice thermal comfort. Approximately 40% of respondents did not feel any pressure to reduce water and heating use, while 35% believed that any electricity savings they made would be offset by other users. Around 50% of residents indicated that they would feel “good” if they knew they used fewer resources than other homes. No significant correlation was found between the responses from the survey and actual energy use.

5.6 In-Depth Interviews with Residents

In-depth semi-structured interviews were carried out in five households at One Brighton. The tenure of three of the dwellings was owner-occupied and the other two were rented. To maintain anonymity, the residents have been give numerical designations of 1 to 5. Summaries of observations and findings from the interviews are given in Table 14, Table 15, Table 16, Table 17 and Table 18. A series of common factors can be taken from the interview responses. For example, most of the interviewees were concerned about the control of internal temperature in the summer. This is consistent with the results of the BUS surveys which highlighted summer overheating as a major concern. There were also reports of problems with achieving adequate internal temperatures in the winter. The residents also had issues with the MVHR system, both in terms of the controls and with the filters. The residents liked the location and design of the development and the general quality of finish. However, they did not like the lack of internal space, poor storage facilities or the combined kitchen/diner. The cost of delivered energy, standing charges and services charges were thought by the occupants to be too high. The comment from resident 1 about “Warm cold water from taps” is consistent with heat transfer from poorly insulated parts of the heat distribution system to the cold water supply, either inside or outside the flat.

Table 14 – Summary of Interview Findings for Resident 1

Resident 1:	Most Likes	Most Dislikes	5 Key Points
Home Owner	Quality of finishes and community feeling	Balcony, letter boxes on ground floor + warm cold water	• Warm cold water from cold taps • Entry system directed to mobile phone with confusing interface • Balcony not large enough to stand on • Sockets wired wrong for relevant appliances • MVHR – filters – not easy to change and unclear who is to change them
Quotation	*"there is a slight user interface issue here – do I have to say hello – are they hearing me now – and it is hello, hello in front of me – every time I have let someone in it has been quite confusing' - when referring to the door-entry system"*		

Table 15 – Summary of Interview Findings for Resident 2

Resident 2:	Most Likes	Most Dislikes	5 Key Points
Home Owner	Location, aesthetics + roof terrace	Summer temperature + waste management	• Confusion about heating system control i.e. control of MVHR • Balcony doors designed so it is difficult to install curtain rail • Lamps (light bulbs) only available from specialist suppliers • Summer temperature too hot • Living space combined with kitchen makes it slightly small
Quotation	*"I mean there are things – design things – I did not mention that things are designed badly like that door – it has been designed so you can't actually fit a curtain rail' about balcony window doors"*		

Table 16 – Summary of Interview Findings for Resident 3

Resident 3:	**Most Likes**	**Most Dislikes**	**5 Key Points**
Home Owner	Location and modern design	Kitchen in living area	• Kitchen in living area • MVHR - filters • Services management and cost • Washer-drier • Waste management
Quotation	*'the first thing that comes to mind is yes I would like the little kitchen area separate from the lounge and that it is difficult for me, like I said when people do come I do find it difficult cooking in front of people, that is a big adjustment for me' about kitchen area"*		

Table 17 – Summary of Interview Findings for Resident 4

Resident 4:	**Most Likes**	**Most Dislikes**	**5 Key Points**
Tenant	Location	Temperature in winter + cost and quality of services	• Temperature in winter too cold • Acoustics – could hear noise from underground garage • Cost and quality of services • Electrical installation – sockets wired incorrectly • Bins located outside window
Quotation	*"well for two weeks Moat was closed there was nothing I could do and I wasn't the only one in that predicament and you could see that it was a problem because the ground floor and the corridor was so cold, but it you went to the third floor – second, third or fourth floor - you could see the difference in heat ' about heating"*		

Table 18 – Summary of Interview Findings for Resident 5

Resident 5:	**Most Likes**	**Most Dislikes**	**5 Key Points**
Tenant	Location	Cost and quality of services + kitchen in living area	• Cost and quality of services • MVHR – filters – never installed and difficult to change • Acoustics can hear noise from underground car-park • Temperature in winter too cold • Kitchen in living area + storage capacity in kitchen cupboards
Quotation	*"cos there are so many issues with it – cos there are so many things and problems … – and it has won all these awards and why? To my mind it seems to be more of a marketing tool rather than anything else' about the development as a whole"*		

5.7 Conclusions and key findings for this section

Overall the results from the BUS surveys show a relatively high level of satisfaction with the development. One Brighton performs well against other commercial and domestic developments in terms of user satisfaction and comfort. Nevertheless it has to be noted that although BUS has an extensive benchmark dataset for commercial buildings which contains data from 450 sites around the world (The One Brighton data from 2011 was compared to this commercial benchmark dataset), the BUS domestic benchmarking dataset is still in its infancy and little insight can be gained by comparing One Brighton directly against the limited number of dwellings in the database.

The key findings from the BUS surveys and in-depth interviews are as follows:

- In general, the building meets the occupants' needs.
- One Brighton delivers healthy and satisfactory living conditions for most occupants.
- Comfort conditions in winter are better than in summer.
- The main issue in summer appears to be overheating.
- There are issues with the maintenance and functionality of the MVHR system. In particular, access to the MVHR unit to change the filters was a real problem for some

residents. Again, it needs to stated that residents were provided with details of a maintenance contractor who they could contact to change their filters. It may be that occupants also disliked paying for filter changing services.

- Residents are concerned about the cost of delivered energy and service charges
- There appeared to be some issues with the ability of the heating system to maintain adequate temperatures in the winter. This is likely to be linked to the performance of the MVHR system rather than the delivery of hot water from the communal heating system to the dwellings.

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

Technology Strategy Board guidance on section requirements:	Provide a review of the building energy related systems, including renewables, regulated and unregulated energy and additional energy users that fall in to different areas (such as pumps for grey water use) and any results found. This section should enable the reader to understand the basic approach to conditioning spaces, ventilation strategies, basic explanation of control systems, lighting, metering, special systems etc. Avoid detailed explanations of systems and their precise routines etc., which will be captured elsewhere. The review of these systems is central to understanding why the building consumes energy, how often and when. Where possible this commentary should be split into the relevant system types. Explain what commissioning was carried out, what problems were discovered and how these were addressed. Discuss as to whether the initial installation and commissioning was found to be correct and any remedial actions taken. Prompt for any training scheme or qualifications that were found to be required as part of the study. Comment on whether the original operational strategy for lighting, heating/cooling, ventilation, and domestic hot water has been achieved. Compare original specification with equipment installed, referring to SAP calculations if appropriate. Give an explanation and rationale for the selection and sizing (specification) of system elements. Use this section to discuss the itemised list of services and equipment given in the associated Excel document titled *TSB BPE_characteristics data capture form_v6.xls*. For each system comment on the quality of the installation of the system and its relation to other building elements (e.g. installation of MVHR has necessitated removal of insulation in some areas of roof). Describe the commissioning process Describe any deviation from expected operational characteristics and whether the relevant guidance (Approved Documents, MCS etc.) was followed. Explanation of deviations to any expected process must be commented in this section. An explanation of remedial actions, if any, must also be given. Describe the operational settings for the systems and how these are set. Comment on lessons learned, conclusions and recommendations for future homes covering design/selection, commissioning and set up of systems. Also consider future maintenance, upgrade and repair – ease, skills required, etc. The document for capturing commissioning information is titled *TSB BPE_Domestic_commissioning sheets.doc*, which can be downloaded from `_connect'.

6.1 MVHR Flow Measurements

The flow rates of the MVHR systems at all settings were measured in two occupied dwellings (Dwelling B and Dwelling 62) using an Observator Diff powered flow hood. Further measurements of boost flow rate were carried out on the 5 monitored dwellings using a calibrated Testo 417 anemometer and flow hood. The design flow rates given in the M&E commissioning specification for the two dwelling types are listed in Table 19. These design flow rates are for the boost mode only and give total design flow rates of 76 l/s for the 1-bed apartments and 92 l/s for the 2-bed apartment. The construction specification gives no information on the trickle flow rates, other than to refer to the manufacturer's installation manual. The regulatory flow rates for the two apartments as required by Part F 2006 are listed in Table 20, which give minimum total extract boost rates of 21 l/s for the 1-bed apartments and 29 l/s for the 2-bed apartment. It can be seen therefore that the total design boost rates are around 3 times the minimum required by the regulations. This is because the design flow rates have likely been determined by the heating requirement from the hot air system rather than fresh air requirements. The Part F 2006 trickle flow rates are 6.4 l/s for the 1-bed apartment and 10.1 l/s for the 2-bed apartment.

Table 19 – MVHR Design Boost Flow Rates

Dwelling Code	Dwelling Type	Floor Area (m^2)	Boost Supply Flow Rate (l/s)				Boost Extract Flow Rate (l/s)			
			Lounge	Bed 1	Bed 2	Total	Kitchen	Bath 1	Bath 2	Total
A, B, C, D, F	1 bed	45	40	36	-	76	40	36	-	76
62	2 bed	71	40	26	26	92	40	26	26	92

Table 20 – MVHR Regulatory Minimum Flow Rates as per Part F 2006

Dwelling Code	Dwelling Type	Floor Area (m^2)	Trickle Flow Rate (l/s)	Boost Extract Flow Rate (l/s)			
			Total	Kitchen	Bath 1	Bath 2	Total
A, B, C, D, F	1 bed	45	6.4	13	8	-	21
62	2 bed	71	10.1	13	8	8	29

The MVHR boost flow rates in the 5 monitored apartments as measured using the Testo flow hood are given in Table 21. It can be seen that the total boost flow rates are of the order 60 l/s in both extract and supply and, with the exception of dwelling F, the flows are approximately balanced. In the case of dwelling F, the total extract boost rate at 31.5 l/s is around half the total supply rate, and hence the system is seriously unbalanced. This would reduce the efficiency of the MVHR heat exchanger and limit the ability of the system to control moisture. In all 5 cases, the systems fail to meet the commissioning target total boost flow rate of 76 l/s. Dwellings A, B, C, D and F easily meet the regulatory total boost extract rate of 21 l/s and the extract rates for the individual rooms. The reduced flow rate compared to the design target should therefore be expected to have little impact on air quality, but may affect the ability of the warm air system to deliver the designed heat output for those apartments with higher heat loss parameter.

Table 21 – MVHR Boost Flow Rates Measured using Testo Flow Hood

Dwelling Code	Boost Supply Flow Rate (l/s)			Boost Extract Flow Rate (l/s)		
	Lounge	Bed	Total	Kitchen	Bath	Total
A	30.1	29.9	**60.0**	25.6	34.6	**60.2**
B	32.6	33.0	**65.6**	29.8	28.4	**58.2**
C	27.9	30.5	**58.4**	25.9	34.8	**60.7**
D	30.5	21.5	**52.0**	29.3	26.8	**56.1**
F	29.1	26.9	**56.0**	16.5	15.0	**31.5**

The flow rates measured using the Diff flow hood for dwelling B are given in Table 22. It can be seen that the total boost rates at around 40 l/s are 30% lower that the measurements taken using the Testo flow hood (~60 l/s). As the measurements were undertaken at different times this could be a function of changes to the system, but it is more likely to be a function of the measurement variability when using anemometer flow hoods. Recent work by BSRIA has shown that powered flow hoods such as the Diff device will give more reliable results than unpowered flow hoods such as the Testo vane anemometer, especially at flow rates higher than 15 l/s (Roper 2013a, 2013b).

Table 22 – Dwelling B MVHR Measured Flow Rates using Diff Flow Hood

Room	Measured Flow Rate (l/s)			
	Trickle	Speed 2	Boost	Boost (filter cleaned)
Bedroom	8.4	15.2	20.5	21.7
Lounge	7.9	15.9	19.9	21.1
Total Supply	**16.4**	**31.1**	**40.4**	**42.8**
Kitchen	7.4	15.6	20.9	36.1
Bathroom	5.6	13.6	17.7	26.7

Total Extract	**13.0**	**29.2**	**38.5**	**62.8**

The total flow rates in trickle mode in dwelling (see Table 22) ranged from 13 l/s for extract to 16 l/s for supply. These rates are at least double the total trickle flow rate required by Part F 2006 for this dwelling (6.4 l/s) and indicates a degree of over-ventilation, with the potential for higher energy consumption than necessary for acceptable levels of fresh air. The results also indicate that the flow rates may have not been commissioned in accordance with the design flow rates although, as commissioning certificates were not provided, it is not possible to confirm that this was the case. Observations made at the same time as the Diff flow measurements showed that the MVHR filters were excessively dirty and clogged with dust (see Figure 23). The filters were cleaned, and this resulted in an increase in the extract flow rate of 20 l/s, but interestingly only a small increase in the supply flow rates. This clearly demonstrates the importance of regular maintenance of MVHR filters. Issues were also observed with poorly taped connections between flexible ducting connected to the MVHR unit (see Figure 24), indicating poor installation or maintenance practice and a lack of effective supervision. Gaps in the duct joints will have a significant effect on the performance of the MVHR system.

Figure 23 – Dirty MVHR Filter from Dwelling B

Figure 24 – Gap in Connection between Flexible Ducting in Dwelling B

The flow rates measured using the Diff flow hood for dwelling 62 are given in Table 23. It can be seen that the measured total boost rates (42 to 58 l/s) are significantly below the design rate of 92 l/s (Table 19) but easily meet the Part F boost requirement of 29 l/s. The minimum regulatory trickle rates of 10.1 l/s was met in both extract and supply. The total extract and flow rates were poorly balanced, with extract rates being around 50% higher. The MVHR filters were cleaned, which increased extract flow rates to 76 l/s. It was also noted that the air valves in the kitchen and 2nd bedroom were almost closed, so the valves were fully opened which increased the total extract flow rate to 82 l/s and supply flow rate to 64 l/s. Whilst this is a significant improvement, the boost rates still fail to meet the design target of 92 l/s.

Table 23 – Dwelling 62 MVHR Measured Flow Rates using Diff Flow Hood

Room	**Measured Flow Rate (l/s)**				
	Trickle	**Speed 2**	**Boost**	**Boost (filter cleaned)**	**Boost (kitchen and bed 2 air valves opened)**
Bedroom 1	12.0	20.9	26.8	27.1	28.6
Bedroom 2	4.0	7.9	11.4	11.9	16.4
Lounge	6.6	12.4	19.7	21.1	18.6
Total Supply	**22.6**	**41.2**	**57.9**	**60.1**	**63.6**
Kitchen	0.2	0.3	0.1	0.2	25.2
Bathroom 1	5.4	12.3	19.3	34.4	33.5
Bathroom 2	6.0	14.6	22.1	41.0	23.4
Total Extract	**11.6**	**27.2**	**41.5**	**75.6**	**82.1**

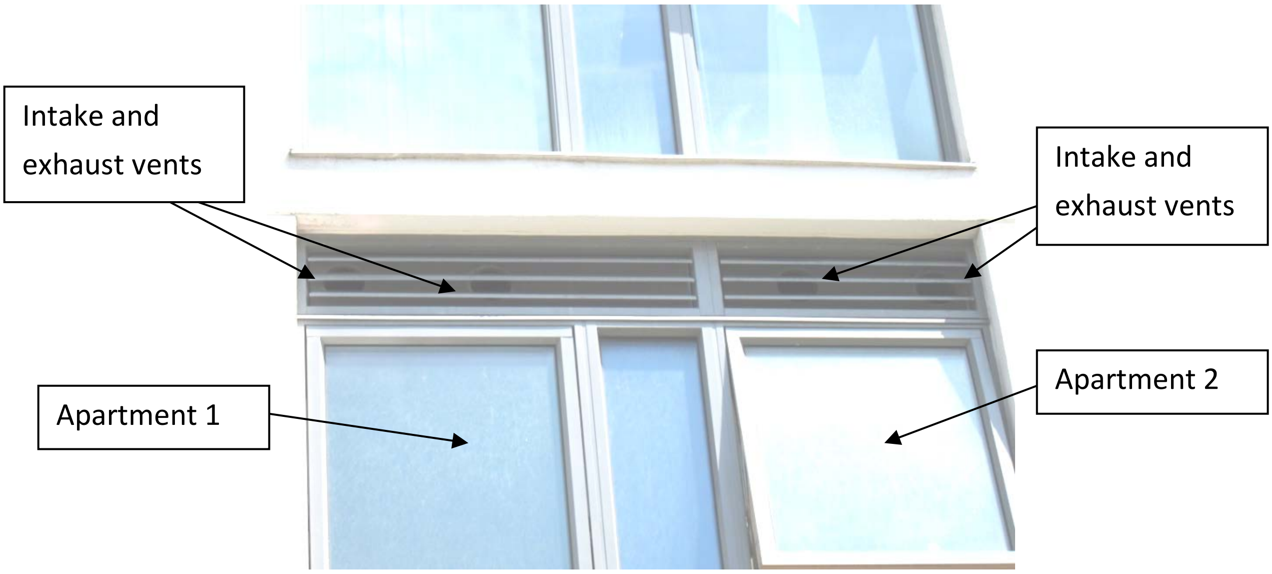
Observations made at the time of the flow measurements revealed that many of the flexible ducts leading to the MVHR units were constricted, damaged or crushed (see example from Dwelling 62 in Figure 25). It is imperative that, where flexible ducting is used in preference to rigid duct, it is fully extended and not constricted so as to minimise the effect on duct resistance. Current guidance from the NHBC (NHBC 2013) is to use rigid duct for the majority of the system, and to only use flexible duct in short lengths (maximum 300mm) to make the final connections to air valves and fan units. High duct resistance will lead to increased fan energy consumption. It was also noticed that some of the kitchen air valves had a build up of visible fat deposits (see Figure 26). These fat deposits will also build up inside the duct work. The effect of this will be to increase the duct flow resistance. The underlying cause of this issue is that the kitchen air valves will have been located too close to the hob and oven, coupled with the absence of an effective, or underutilised extract fan from the cooker hood. It is perhaps a good idea to suggest to both the residents and social landlord that cleaning of the kitchen valves should be included as part of the MVHR maintenance regime.

Figure 25 – Crushed Flexible MVHR Ducting in Dwelling 62

Figure 26 – Fat Deposit on Kitchen Air Valve

Another observation made at the time of the flow measurements relates to the location of the MVHR intake and exhaust terminal vents on the external walls. These vents are located above the windows of the dwellings in recesses protected by a louvre (see Figure 27). The photograph in Figure 27 shows the terminal vents for two adjacent apartments. In both cases, the intake and exhaust terminals are separated by a distance of around half a metre. Whilst this treatment of the terminal vents was clearly done for aesthetic reasons, there is likely to be an impact on the performance of the MVHR system. The main effect will be an increased risk of the recirculation of waste air from the exhaust terminal into the inlet vent. This will be due to insufficient separation between intake and exhaust vents, and because the exhaust air will not be readily dispersed as the recess will provide some protection from the wind. MVHR manufacturers generally recommend in their installation manuals a minimum separation distance between intake and exhaust vents of 2m to 2.5m. The guidance in TM21 (CIBSE 1999) also recommends that ventilation exhausts are not contained within architectural enclosures or behind screens, as this increases the risk of recirculation.

Figure 27 – MVHR Terminal Vents on External Facade for Two Apartments



6.2 MVHR Specific Fan Power

It was not possible to carry out direct measurements of the power consumption of the MVHR fan due to limited access to the MVHR unit and associated electrical wiring. However, data on fan power consumption have been derived from the in-use energy monitoring of the MVHR fan electric consumption. These power data have been used in combination with the more reliable Diff flow measurements for dwelling B to calculate the specific fan power (SFP) at different fan speeds. The data given in Table 24 show the calculated SFP values for apartment B at trickle, speed 2, boost and in boost mode after cleaning the filter. The calculation of SFP uses the supply flow rates in preference to the extract rates.

Table 24 – Specific Fan Power for Dwelling B

	Trickle	Speed 2	Boost	Boost (filter cleaned)
Supply Total Flow (l/s)	16.4	31.1	40.4	42.8
Fan Power (W)	58	133	250	250
Specific Fan Power (W/l/s)	3.5	4.3	6.2	5.8

It can be seen that the SFP for dwelling B varies from a low of 3.5 W/l/s in trickle mode up to a maximum of 6.2 W/l/s in boost mode before the filter had been cleaned. These SFP values are very high relative to a typical modern domestic MVHR system, which would be expected to have a measured SFP of less than 1 W/l/s when installed correctly. For example, the SAP Product Characterisation Database (PCDB) data for the commonly used Vent Axia Sentinel Plus MVHR unit gives SFP values ranging from 0.5 to 0.8 W/l/s, depending upon the flow requirement. However, it is interesting to note that, because the Xpelair Xcell 600 system used at One Brighton has not been tested for either SAP Appendix Q or the PCDB, the SAP assessments would have used the very conservative SAP default MVHR performance data. These give a default SFP of 2 W/l/s to which is applied the default in-use factor of 2.5, giving a total SFP for the Xpelair Xcell 600 MVHR system in SAP of 5 W/l/s – within the measured range.

6.3 Commissioning Data

Data on the commissioning of heating and ventilation systems at One Brighton was found to be limited. All available data sheets and results from the various commissioning processes carried out by the developer and sub-contractors were contained in the One Brighton building manual (Denne Construction 2011) and are summarised in Table 25.

Table 25 – One Brighton Commissioning Data in Building Manual

M&E System	Commissioning Certificate(s)	Commissioning Test Results
Biomass Boiler	Yes – dated 7/7/09	No test results available
Gas Boiler	No	No data from initial commissioning Data available from test results following repair to damper as follows: Efficiency 89.4% to 91.2%
PV Array	Yes – certificate of completion dated 2/6/09	No performance data for panels NICEIC inspection certificate gives safety data
DH circulation pumps	Yes – dated 3/6/09	Yes – data on flow rates and pump speeds
Dwelling MVHR	Yes – various dates	No data on flow rates or SFP
Dwelling HIU	Yes – various dates	Yes – flow temperatures for DH supply, dwelling DWH and dwelling heating flow

6.4 Conclusions and key findings for this section

Measurements of flow rates at the air valves of test dwellings at One Brighton showed that the system failed to meet the design specifications. In all cases, the measured rates were less than the design targets, with the discrepancy ranging from 20% to 50%. The effect of the reduction in flow rates will be to reduce the effectiveness of the MVHR system in heating mode. The measured flow rates easily exceeded the minimum regulatory requirements for fresh air under Part F.

Dirty filters and air valves were found to significantly reduce air flow, especially for the extract sides, for which the filters were more clogged. Regular maintenance of these systems is absolutely vital to their proper operation. As such it is imperative that emphasis is placed during the design and construction process to make access for maintenance as easy for the occupant as possible. Occupants also need greater system feedback – for example something similar to a 'check engine' light on the main controller could possibly be effective to alert occupants that filters need changing. Finally effective maintenance contracts need to be explored further. For this it may be advantageous to enable access to the system from within a communal area.

A range of ventilation system distribution problems were observed for the MVHR systems. These included crushed and distorted flexible duct, which would increase the duct resistance and as a consequence increase the fan energy required to run the MVHR system. The kitchen extract vents were located too close to the cooker and hob, and as a result were found to be severely contaminated with fat deposits. The terminal intake and exhaust vents on the outside of the building were sited very close to each other and were in recessed alcoves in the wall. Both these factors would increase the risk of recirculation of stale exhaust air back into the MVHR intakes, with the potential to detrimentally affect the internal air quality. It is strongly recommended that action is taken by the building landlord to further investigate the performance of the MVHR systems on the development and to provide advice and support to residents to rectify any issues found.

The measured specific fan power of the One Brighton MVHR units was very high at between 3.5 W/l/s in trickle mode to as large as 6 W/l/s in boost mode. This compares to a measured SFP value of around 1.2 W/l/s for a well installed, SAP appendix Q certified domestic MVHR system (Wingfield 2011). The impact of such poor SFP values can be seen in the electricity used to run the MVHR systems in the monitored dwellings at One Brighton, where the annual electricity consumption for the MVHR units was of the order 750 kWh/annum for those dwellings where the system was activated (see section 7.8). This constituted around 40% of measured total electricity use in these apartments. High electricity consumption is likely to be a disincentive for the residents to use their MVHR systems effectively. It is interesting to note that the current Domestic Building Services Compliance Guide (DCLG 2011a) recommends an upper limit on SFPs for domestic centralised MVHR systems of 1.5 W/l/s. The systems at One Brighton would therefore fail to meet this requirement by a significant margin. Indeed, the One Brighton MVHR systems would also fail to meet the maximum SFP limit of 1.9 W/l/s for non-domestic centralised mechanical ventilation systems with heating and heat recovery given in the Non-domestic Building Services Compliance Guide (DCLG 2011b).

Some differences were found for MVHR flow rates measured using a powered flow hood compared to those taken using a simple flow hood and anemometer. These differences are consistent with recently published results from BSRIA which indicate that powered flow hoods are more accurate than anemometer devices, especially at higher flow rates (>15 l/s). For normal domestic ventilation systems, where typical flow rate for individual air valves are unlikely to be greater than 15 l/s, these measurement differences are not expected to be a significant issue.

7 Monitoring methods and findings

Technology Strategy Board guidance on section requirements:	This section provides a summary breakdown of where the energy is being consumed, based around the first 6 months of metering results and other test results. Where possible, provide a simple breakdown of all major energy uses/producers (such as renewables) and the predicted CO_2 emissions. Explain how finding are affected by the building design, construction and use. This section should provide a review of any initial discoveries in initial performance in-use (e.g. after fine-tuning). If early stage interventions or adjustments were made post handover, these should be explained here and any savings (or increases) highlighted. Does the energy and water consumption of the dwelling meet the original expectations? If not, explain any ideas you have on how it can be improved. Are there any unusual design features that have not been accounted for previously (e.g. grey water recycling pumps). Summarise with conclusions and key findings.

7.1 Description of In-use Monitoring Programme

The in-use monitoring programme at One Brighton investigated the performance of five identical occupied one-bedroom apartments. In order to maintain the anonymity of the residents, the monitored dwellings have been given the identifying codes: A, B, C, D and F. Monitoring of the households commenced in February 2012, and this report includes an analysis of data up to September 2013, giving a total of 20 months worth of data. This therefore includes one full heating season and one full summer season. Three of the households (B, D and F) remained in the monitoring programme for the full 20 months. However, household A withdrew from the programme at the end of April 2013 and household C withdrew at the end of June 2013. In both cases, the residents were moving out of the apartments.

The monitored dwelling characteristics are detailed by the set-up given in Table 26. The details of the on-site weather station are also given in Table 26. With the exception of energy data obtained from the Energy Services Company (ESCo), all data were recorded at 5 minute intervals using a wireless Eltek datalogging system. Each monitored dwelling had its own datalogger, which was fitted with a GSM modem. The dwelling sensors and meter were all fitted with wireless transmitters, which transmitted data to the dwelling datalogger. The logged data were downloaded by modem, usually at fortnightly intervals. Data were checked and analysed on a regular basis to ensure there were no problems with the monitoring systems and to identify any developing trends. The ESCo energy meter data for communal heat and electricity were collected by the ESCo on a daily basis, and this was sent to the research team in the form of a spreadsheet.

Table 26 – Dwelling Monitoring Set-up

Dwelling Characteristic	Type of Sensor	Number and Location of Sensors
Total communal heat input to dwelling	Heat meter	1 ESCo heat meter fitted to communal heat main input to Heat Interface Unit (HIU) in each dwelling.
Total electricity input to dwelling	kWh meter	1 ESCo kWh meter fitted to main electrical board in each dwelling.
Space heating output from HIU to dwelling	Heat meter	1 heat meter fitted to heating circuit in each dwelling. Domestic hot water use was not monitored but was calculated by difference using the ESCo meter data.
Disaggregated electricity use	kWh meter	4 kWh meters fitted to 4 circuits (lighting, MVHR, cooker, ring main 1) on the consumer unit in each dwelling. One circuit (ring main2) was not monitored but was calculated by difference using the ESCo meter data.
Internal temperature and relative humidity	Temperature and RH sensor	2 temperature/RH sensors located in each dwelling, one in the living room and one in the bedroom.
Extract and supply temperature to/from MVHR system	Temperature and RH sensor	4 temperature/RH sensors located in each dwelling. These were inserted into supply (living room, bedroom) and extract (kitchen, bathroom) ducts via the room air valves.
Internal air quality	CO_2 sensor	2 infra-red CO_2 sensors located in each dwelling, one in the living room and one in the bedroom. Measurement range of CO_2 sensor from 0 to 5000ppm.
External weather	Weather station	Integrated Vaisala weather station fitted to roof of Brighton Belle block. Measured weather parameters include temperature, RH, barometric pressure, solar insolation, wind direction and wind speed

In addition to the data for the five intensively monitored dwellings, the ESCo provided daily heat and electricity data for all 172 dwellings on the development over the monitoring period. The ESCo also provided daily heat and electricity data for all the non-domestic properties located on the ground floor of the One Brighton development, as well as data for the electricity consumption for the communal areas (e.g. lighting, lifts, and security systems). Daily performance data were supplied by the ESCo from the plant room BMS for the communal heating system and are detailed in Table 27.

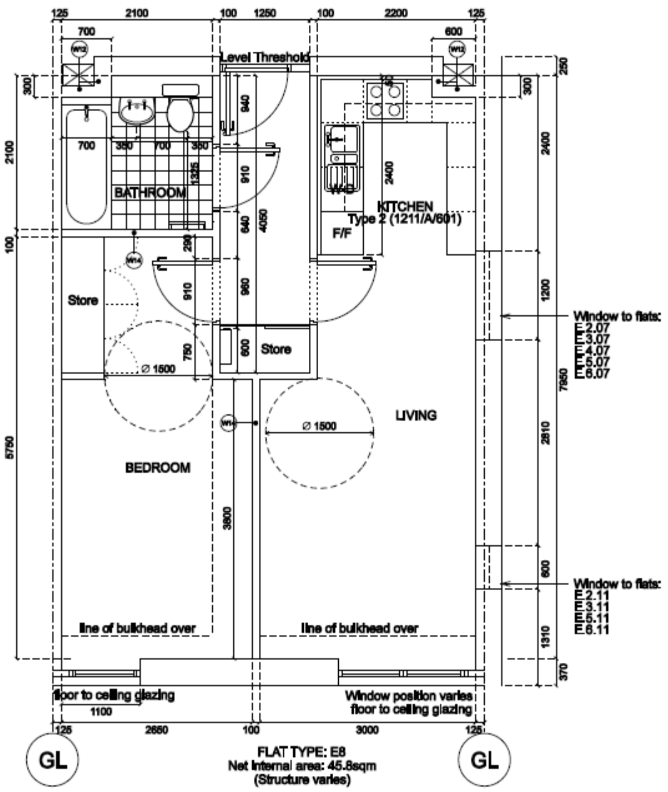
Table 27 – Plant Room Monitoring Set-up

Characteristic	Type of Data
Heat output from biomass boiler	1 heat meter positioned immediately after biomass boiler.
Heat output from backup gas boiler	1 heat meter positioned immediately after gas boiler.
Parasitic plant electricity consumption	1 kWh sub-meter for plant room. Data was not available for individual system components such as pumps and controls.
Plant room gas consumption	1 gas meter on supply to plant room.
Biomass consumption	Monthly delivery data for biomass.

7.2 Description of Monitored Dwellings and Households

The five monitored dwelling were all single-storey one bedroom apartments of the same dwelling type and with an identical floor area (45.3 m^2), although located in different blocks and on different floors within the development. The general floor plan is illustrated by the drawing in Figure 28. The layout has a living room/kitchen area to one side of the dwelling, a corridor in the middle and bedroom and bathroom on the other side.

Figure 28 – Floor Plan of Monitored Dwellings



The floor level, orientation and exposure for each of the monitored dwellings are given in Table 28. It can be seen that the dwellings all have completely different levels of exposure, with dwelling B having the highest number of exposed elements (2 external walls, 2 semi-exposed walls and a semi-exposed floor) whilst dwelling F has the lowest number of exposed elements (1 exposed wall and 1 semi-exposed wall). The general dimensions, areas and volumes of the dwellings are compared in Table 29. The highest total exposed area is that for dwelling B (117 m^2) and the lowest for dwelling F (31.7 m^2).

Table 28 – Monitored Dwelling Floor Level, Orientation and Exposure

Dwelling Code	Floor Level	Orientation of Main Glazed Facade	Fully Exposed Elements	Elements Exposed to Un-heated Spaces	Party Elements
A	1	South west	1 external wall	2 walls, floor	Ceiling, 1 party wall
B	1	South west	2 external walls	2 walls, floor	Ceiling
C	5	South east	2 external walls	1 wall	Ceiling, 1 party wall
D	6	East	2 external walls	1 wall	Ceiling, 1 party wall
F	3	East	1 external wall	1 wall	Ceiling, 2 party walls

Table 29 – Monitored Dwelling Dimensions

Dwelling Code	Floor Area (m^2)	Internal Volume (m^3)	Room Height (m)	Width (m)	Depth (m)	Envelope Area (m^2)	Glazed Area (m^2)	External Wall Area (m^2)	Total Exposed Area (m^2)
A	45.3	119	2.63	5.75	7.95	164.2	6.8	15.2	97.2
B	45.3	119	2.63	5.75	7.95	164.2	6.8	28.4	117.3
C	45.3	119	2.63	5.75	7.95	164.2	7.5	27.7	51.8
D	45.3	119	2.63	5.75	7.95	164.2	7.5	27.7	51.8
F	45.3	119	2.63	5.75	7.95	164.2	6.8	8.3	31.7

The dwelling dimensions and fabric design data were used to estimate the design fabric heat loss coefficients for the monitored dwellings. The ventilation heat loss component was calculated using the nominal effective air change rate from the SAP assessments of 0.36 h^{-1}, which takes into account the default efficiency of the MVHR heat exchanger. The predicted heat loss coefficients are summarised in Table 30. These range from 31 W/K for dwelling F to 55 W/K for dwelling K.

Table 30 – Predicted Heat Loss Coefficients for Monitored Dwellings

Dwelling Code	Fabric Heat Loss Coefficient (W/K)	Ventilation Heat Loss Coefficient (W/K)	Total Heat Loss Coefficient (W/K)
A	34.3	14.1	48.4
B	40.4	14.1	54.6
C	22.9	14.1	37.0
D	22.9	14.1	37.0
F	16.5	14.1	30.6

The details of the five monitored households are summarised in Table 31. All five dwellings are one-person households with a mixture of tenure. The occupant of dwelling A is unemployed, and would likely be expected to be at home more frequently that the occupants of the other four dwellings.

Table 31 – Details and Demographics of Monitored Households

Dwelling Code	Normal No. of Residents	Tenure	Employed Yes/No	Gender of resident(s)	Typical Occupation Pattern
A	1	Rented	No	Female	At home most days
B	1	Rented	Yes	Female	At work during week – occasional home working
C	1	Owner-occupied	Yes	Female	At work during week
D	1	Owner-occupied	Yes	Male	At work during week
F	1	Owner-occupied	Yes	Female	At work during week

7.3 Data Integrity

Prior to analysis, all datasets were checked for completeness and consistency. Where appropriate, spurious data points were removed and missing data were substituted with estimated values. In the case of the dwelling temperature, humidity and CO_2 data, occasional data transmissions to the Eltek dataloggers were lost due to transmission clashes. These were limited to one or two data points every week, and the missing data were readily substituted by data from the adjacent time period without affecting the integrity of the dataset or subsequent analysis. The dwelling energy pulse data were unaffected by transmission clashes, as the datalogger uses a cumulative pulse metering system. There were several occasions where a week-or-more's worth of dwelling or ESCo data were lost. In the case of the dwelling data, this was normally due to a resident mistakenly turning off the power to the datalogger. The time periods for the missing datasets and the action taken are summarised in Table 32. Where the missing data was for around a week or less, the data were substituted using data from the previous week as shown in the Table. For longer periods, the missing data were not substituted and were therefore not included in any subsequent analysis.

Table 32 – Missing Datasets

Dataset	Time Period of Missing Data	Action Taken or Comment
Dwelling A: Temp, RH, CO_2, Electric, Heat	17/12/12 - 19/12/12	Substituted using 14/12/12 - 16/12/12
Dwelling A: Temp, RH, CO_2, Electric, Heat	May-13 to Sep-13	Resident withdrew from project
Dwelling B: Temp, RH, CO_2, Electric, Heat	15/7/13 - 19/7/13	Substituted using 10/12/12 - 14/7/13
Dwelling C: Temp, RH, CO_2, Electric, Heat	29/7/12 - 8/8/12	Substituted using 18/7/12 - 28/7/12
Dwelling C: Temp, RH, CO_2, Electric, Heat	Jul-13 to Sep-13	Resident withdrew from project
Dwelling D: Temp, RH, CO_2, Electric, Heat	13/8/13 – 19/8/13	Substituted using 6/8/13 – 12/8/13
Dwelling F: Temp, RH, CO_2, Electric, Heat	21/11/12 – 21/12/12	Missing data left blank
Dwelling F: Living Room Temp/RH	Mar-12 to May-12	Missing data left blank
Dwelling F: Bedroom Vent Temp/RH	Mar-13 to Apr-13	Missing data left blank
Dwelling A, B, C, D, F: Kitchen Vent Temp/RH	Feb-12 to Sep-12	Missing data left blank
ESCo data for gas boiler heat meter	Mar-12 to Oct-12	Heat calculated from gas input at 86%

ESCo data for non-domestic heat/electric	Feb-12 to Oct-12	Missing data left blank

An initial analysis of the data indicated a problem with the space heating data for all five dwellings. It was found that, when the space heating data were subtracted from the total ESCo heat data, the residual heat for domestic hot water (DHW) in winter was up to five times the amount of heat used for DHW outside of the heating season. An investigation of the installation of the heat meter on the space heating circuit showed that the temperature t-piece pocket for the hot-side heat meter temperature sensor was too long for the sensor, and consequently the sensor was not immersed fully in the hot water flow (see Figure 29). The result of this is that the sensor will record a lower temperature reading than the actual flow temperature, and will therefore under-record the heat output to the space heating circuit. In order to overcome this issue, the DHW data in the heating season were estimated from the average of the ESCo data when there was no space heating. This is believed to be a reasonable approximation as the temperature of the incoming water is not likely to vary significantly over the year, due to the cold water supply for the apartments being pumped from a large storage tank in the plant room.

Figure 29 – Heat Meter and Temperature Sensor on Space Heating Circuit

7.4 Weather

Monthly mean, maximum and minimum temperatures from the on-site weather station at One Brighton are listed in Table 33, with time-series graphs of heating degree days, external temperature and external relative humidity shown in Figure 30, Figure 31 and Figure 32. The peak summer time temperature in 2012 was 26.5°C in July. The summer in 2013 was warm by comparison, with peak temperatures of 27.7°C in July and 29.4°C in August. The degree day data show that the winter of 2012-13 was slightly colder when compared to the 20-year mean for the south east region (S.E. region data from Vesma 2013). The total degree days for November to April were 1762 DD for the One Brighton weather station versus 1658 DD for the 20-year mean.

Table 33 – One Brighton: Monthly External Temperatures and Degree Days

Month	Mean External Temperature (°C)	Standard Deviation (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)	Degree Days at 15.5°C Base (DD)	Degree Days S.E. Region 20 Year Mean (Vesma 2013)
Feb-12	4.0	4.0	11.6	-4.9	334.5	297
Mar-12	8.9	3.3	20.2	2	205.5	267
Apr-12	8.2	2.4	17.3	0.5	220.1	192
May-12	12.4	4.4	25.5	4.2	116.6	120
Jun-12	13.9	1.9	22.3	7.5	51.3	54
Jul-12	15.7	2.6	26.5	9.8	18.3	27
Aug-12	17.1	2.2	25.6	6.8	3.1	25
Sep-12	14.2	2.8	22.9	5.4	45.1	58
Oct-12	11.6	3.0	16.7	1.7	119.8	131
Nov-12	8.5	2.9	13.2	0.1	210.5	236
Dec-12	6.6	3.2	11.4	-2.5	276.1	331
Jan-13	4.8	3.7	10.8	-2.3	331.6	335
Feb-13	3.7	2.4	11	-1.1	329.7	297
Mar-13	4.0	3.2	14.2	-2.4	356.0	267
Apr-13	6.9	3.0	15.1	-1.4	258.5	192
May-13	10.6	2.7	21.7	4.6	151.5	120
Jun-13	14.0	2.5	25	7.9	50.8	54
Jul-13	17.9	3.3	27.7	7.5	6.4	27

Aug-13	17.3	2.4	29.4	11.3	0.3	25
Sep-13	14.8	2.7	23.8	7.2	35.7	58

Figure 30 – Monthly Degree Days for One Brighton and S.E. Region 20-year Mean

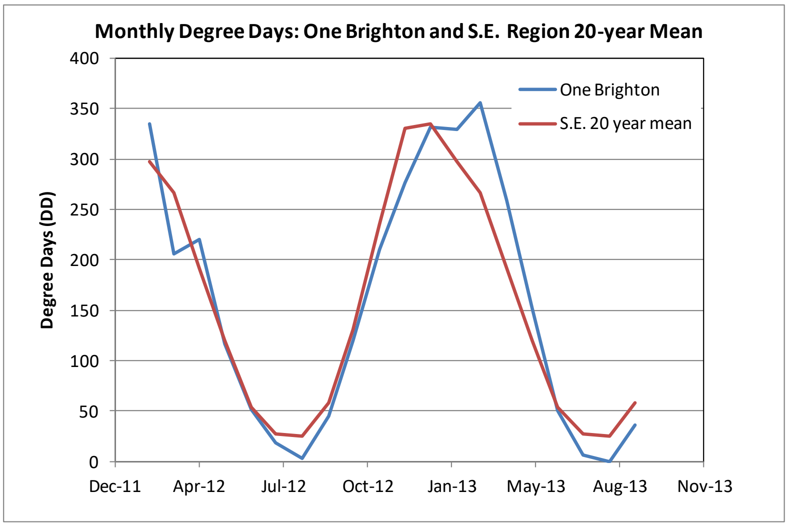


Figure 31 – Graph of Daily External Temperature at One Brighton Feb-12 to Sep-13

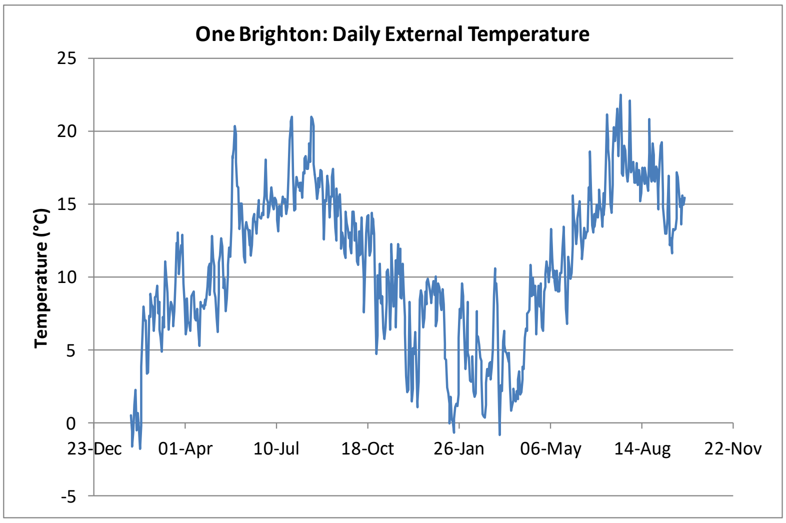
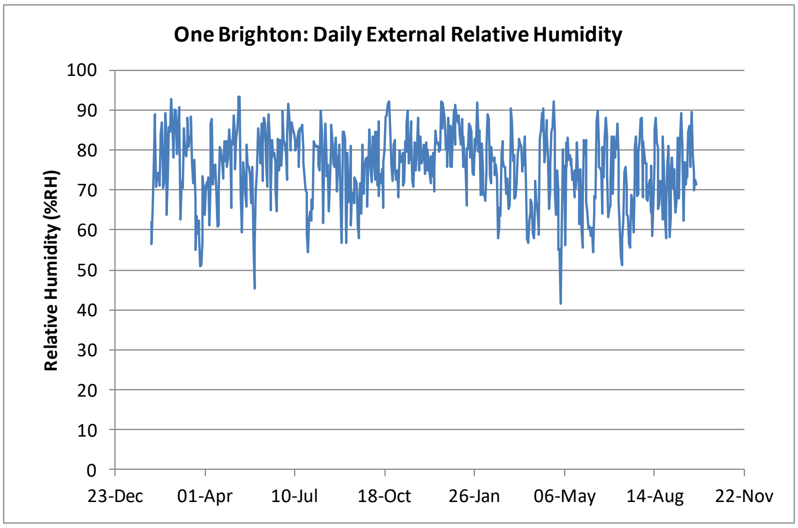


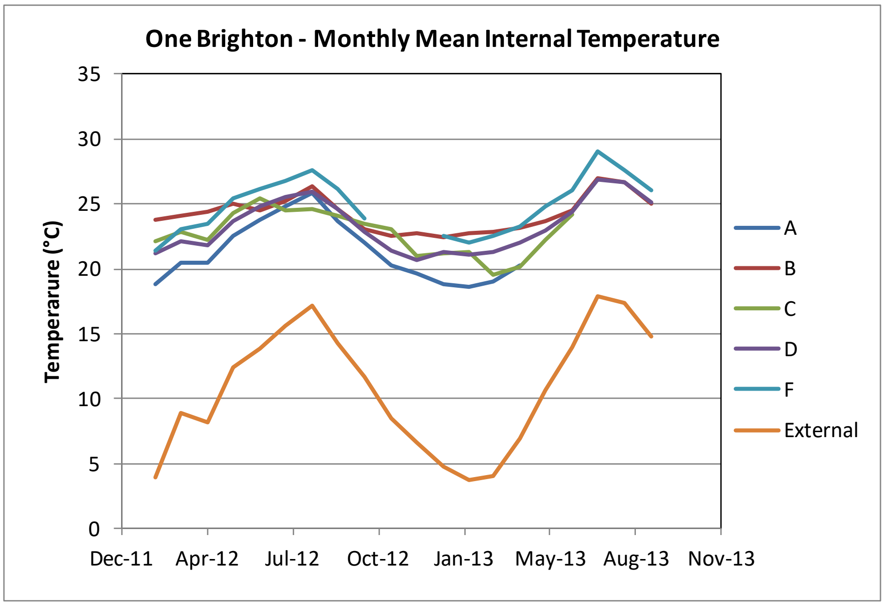
Figure 32 – Graph of Daily External Relative Humidity at One Brighton Feb-12 to Sep-13



7.5 Internal Temperature

A graph of mean monthly internal temperatures for the five monitored dwellings is shown in Figure 33. These temperatures are the mean of the living room and bedroom temperatures. It can be seen that the trend in internal temperatures for all five dwellings matches that of the external temperatures quite closely. The lowest temperatures in the winter heating season were for dwelling A, which had a mean temperature between October 2012 and April 2013 of 19.8°C. The highest winter time temperatures were in dwellings B and F which had a mean temperature between October 2012 and April 2013 of 22.9°C. In all cases, the internal temperatures are higher than the standardised assumptions in the SAP2005 calculations for the dwellings, which used a derived mean internal temperature of 19.5°C. The average internal heating season temperature for all five dwellings was 21.7°C. The SAP model will therefore underestimate the heating load. The implication therefore is that the One Brighton residents are living at higher internal temperatures in winter than is typical for the UK. The average living room temperature in February 2012 ranged from a low of 19.4°C in apartment A to 23.9°C, with a mean of 21.5°C. These data are higher than those in a recent study of internal temperatures in 292 dwellings in Leicester (Kane 2011) which showed a mean living room temperature in February of 18.4°C for all dwellings in the dataset. Interestingly, 34 apartments in the Leicester study had a high mean living room temperature of 19.6°C. The comparison with the Leicester data is further evidence that the internal temperatures in winter at One Brighton are higher than the UK norm. There are clearly implications for both national energy policy and modelling inputs if occupants of low carbon low energy dwellings tend to live at higher internal temperatures than is generally assumed.

Figure 33 – Mean Monthly Internal Temperatures for Monitored Dwellings



In order to assess the overheating potential of the dwellings, an analysis was undertaken using the CIBSE overheating peak threshold temperatures of 28°C for the living room and 26°C for the bedrooms (CIBSE 2006), for which 1% of hours is given as the acceptable limit. The percentage of time the internal temperature exceeded these thresholds was calculated on a daily basis during the summer for the living room and bedroom in all five monitored apartments. The graphs in Figure 34 and Figure 35 show the percentage of time above the overheating threshold by month for the bedroom and living room for the five apartments. There is some limited overheating in the living room of apartment F. However, the bedrooms of all five dwelling regularly exceed the 26°C threshold. The overheating data were annualised for the period February 2012 to January 2012 in order to compare the results with the CIBSE annual 1% limit (see Table 34).

Figure 34 –Percentage Time above CIBSE Overheating Threshold in Bedroom by Month

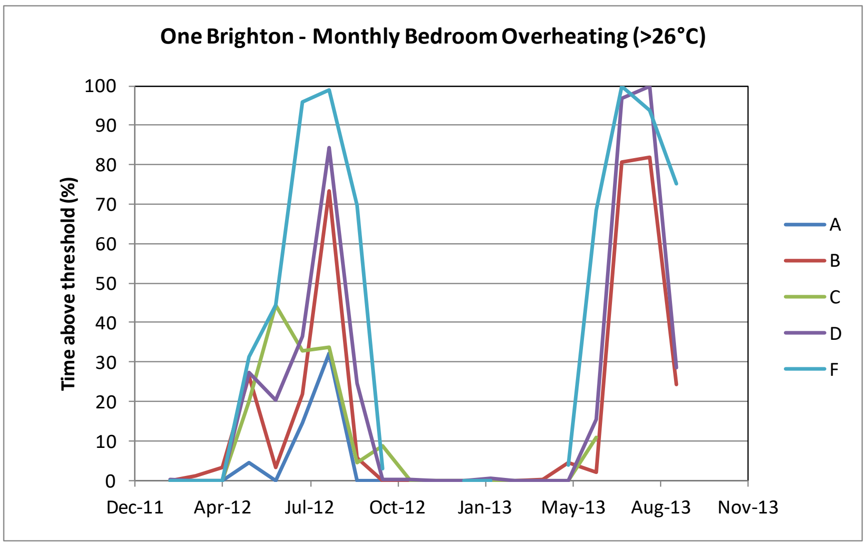


Figure 35 – Percentage Time above CIBSE Overheating Threshold in Living Room by Month

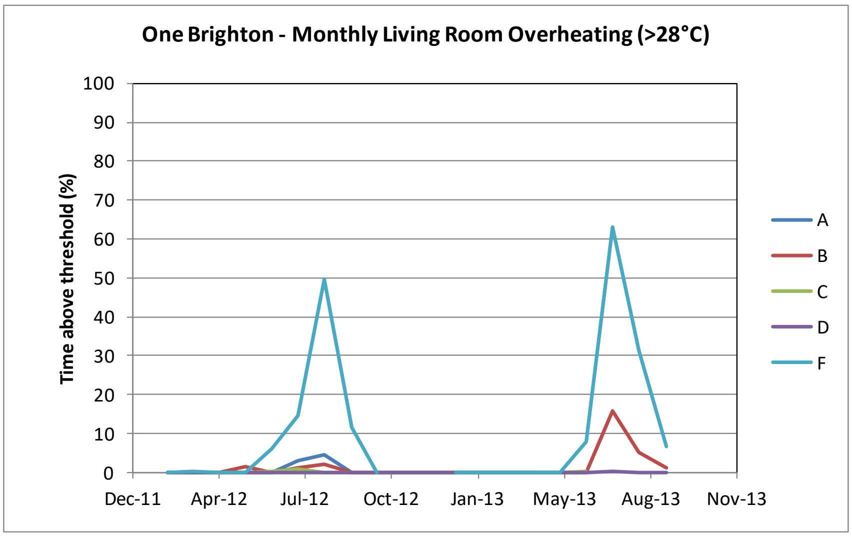


Table 34 – Annualised % Time above CIBSE Overheating Threshold (Feb 12 – Jan 13)

	Dwelling A	Dwelling B	Dwelling C	Dwelling D	Dwelling F
Bedroom (% year)	4.3	11.4	12.1	16.3	28.7
Living Room (% year)	0.6	0.4	0.1	0.0	8.4*

* Note that F has missing living room data for March-June and Nov-Dec but this will have little effect.

There are some differences in overheating rates between the 5 dwellings, with apartment F having the highest level of bedroom overheating (29% of hours) and apartment A having the lowest (4.3% of hours). The differences in overheating would suggest that the occupants are perhaps employing different ventilation strategies and making different use of the MVHR “free-cooling” mode. (Free-cooling is a mechanical services term describing the usage of fresh, untreated ambient air, with a lower temperature than indoor air, to provide a degree of space cooling. In this MVHR system design, in free-cooling mode the incoming fresh air bypasses the heat exchanger and is thus delivered at ambient air temperature.) Other factors would include window opening behaviour, the use of curtains for shading or variations in the level of internal gains due to metabolic and appliance loads. The east facing apartments (D and F) overheated more often than those facing south east and south west, suggesting that low level sun is an important factor.

Graphs of the maximum monthly bedroom and living room temperatures are shown in

Figure 36 and Figure 37. The peak bedroom temperatures in the summer reached 32.5°C in the bedroom of Flat F in August 2013 (external August 2013 peak temperature was 29.4°C). Peak living room temperature in the summer reached 36.1°C in apartment C in July 2012 (external July 2012 peak temperature was 26.5°C). There were some short lived winter time peaks in internal temperatures above 30°C, lasting 10 or 15 minutes on occasional days. These are believed to relate to use of appliances such as hair dryers rather than the heating system.

Figure 36 – Maximum Bedroom Temperatures by Month

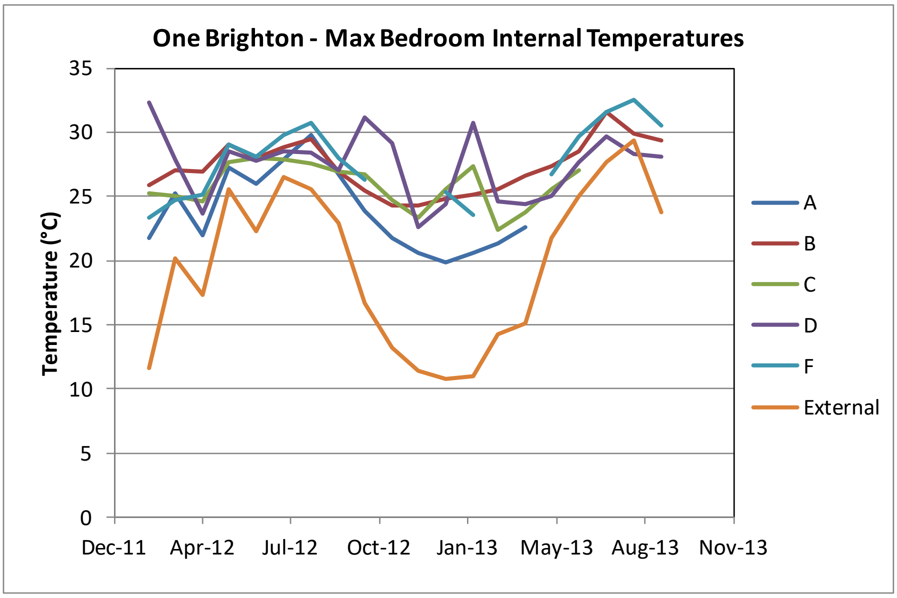
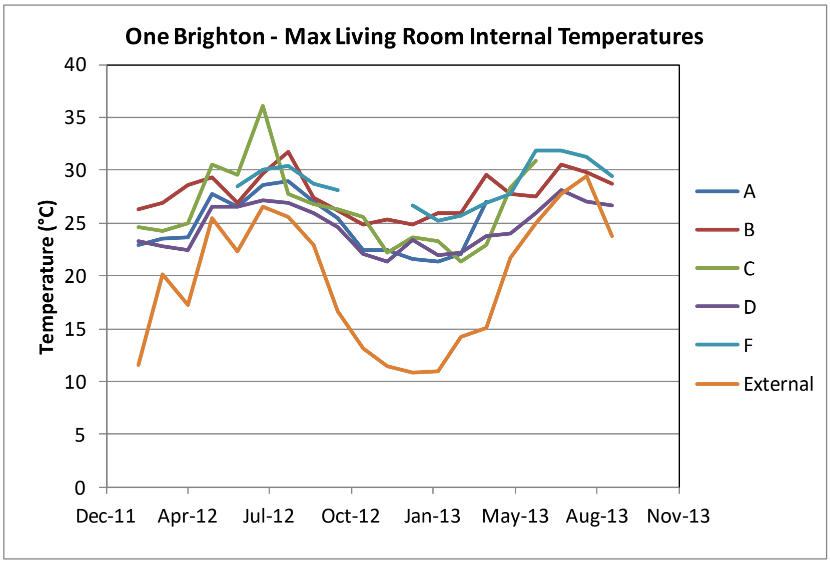


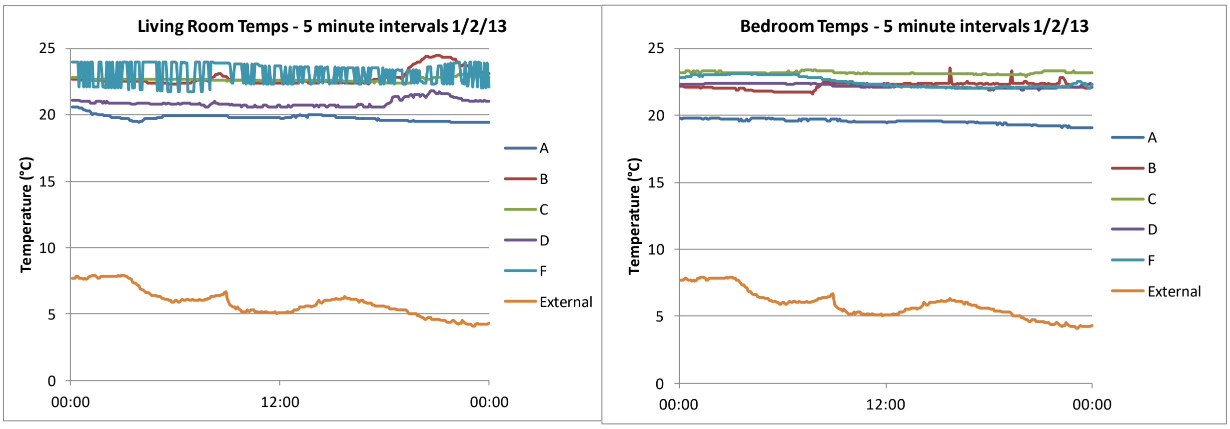
Figure 37 – Maximum Living Room Temperatures by Month



The 5-minute internal living room and bedroom temperature data for all five dwellings for the 1st of February 2013 were compared to identify any difference in diurnal patterns in winter time (see graphs in

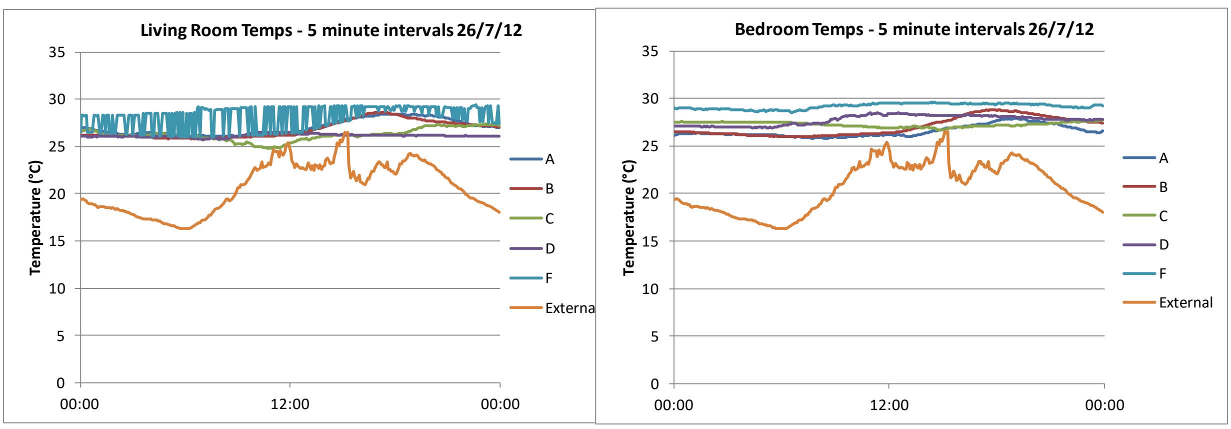
Figure 38). It can be seen that, in general the temperature profiles are fairly stable. There is clearly a problem with the living room temperatures sensor in apartment F. The temperature peaks in apartments B and F due to the input from the heating system are most readily apparent in the living room in the evening.

Figure 38 – Living Room and Bedroom Temperature Trend 1st February 2013



The 5-minute internal living room and bedroom temperature data for all five dwellings for the 26th July 2013 were compared to identify any difference in diurnal patterns in summer time (see graphs in Figure 39). It can be seen that the temperatures in the living room and bedroom are stable for the first part of the day. The temperatures start to rise in response to the high external temperatures and probably solar gains in the afternoon, and peak at around 17:00. There was no correlation between high internal temperatures and measured window opening behaviour.

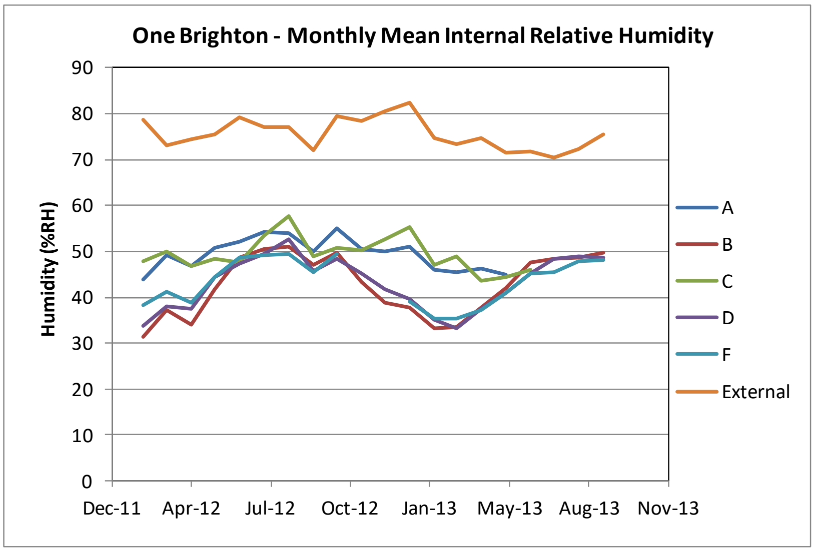
Figure 39 – Living Room and Bedroom Temperature Trend 26th July 2012



7.6 Internal Humidity

A graph of the monthly mean internal relative humidity is shown in Figure 40. It can be seen that, for most of the year, the internal humidity is within the acceptable range of 40%RH to 70%RH as defined by CIBSE (CIBSE 2006). However, in the case of dwellings B, D and F the mean humidity drops below 40% during the winter time. This is fairly typical behaviour for dwellings with low heat losses and adequate ventilation, and is caused by the combination of high internal temperature, and effective exhausting of internally generated moisture. Potential effects of dry air will be to cause irritation to the nose and throat and dry skin conditions. It is interesting to note that the reduction in relative humidity is not seen in apartments A and C, and is consistent with energy and other data which indicate lower internal temperatures and that the residents in those 2 apartments have turned off the MVHR systems. There is no indication from the data of relative humidity in excess of 70% for any significant period for any of the dwellings.

Figure 40 – Mean Monthly Relative Humidity for Monitored Dwellings



The data in Table 35 show the annualised time within the three different CIBSE relative humidity ranges (<40%RH, 40-70%RH, >70%RH) for the period February 2012 to January 2013. It can be seen that in the case of dwelling B and D the relative humidity falls below 40%RH between 30% and 40% of the year. Apartment F is not included in this comparison due to the lack of data in March to June and November to December.

Table 35 – Annualised % Time within CIBSE Relative Humidity Ranges (Feb 12 – Jan 13)

	Dwelling A	Dwelling B	Dwelling C	Dwelling D	Dwelling F*
Bedroom <40%RH (% year)	3.5	33.1	5.2	32.0	-

Bedroom 40-70%RH (% year)	96.5	66.9	94.8	68.0	-
Bedroom >70%RH (% year)	0	0	0	0	-
Living Room <40%RH (% year)	4.2	41.0	2.8	29.7	-
Living Room 40-70%RH (% year)	95.8	59.0	95.7	70.3	-
Living Room >70%RH (% year)	0	0	1.5	0	-

* Note that F has missing data for March-June and November-December which will affect means

The graphs in Figure 41 and Figure 42 show the time profile of the three different CIBSE relative humidity ranges (<40%RH, 40-70%RH, >70%RH) by month for dwelling B in the bedroom and living room. It can be seen that the low humidity levels are most prevalent during February, March and April. Similar patterns were observed for the other four dwellings, with peaks in the winter time but with varying maximum levels.

Figure 41 – Dwelling B Bedroom % Time at CIBSE Relative Humidity Range by Month

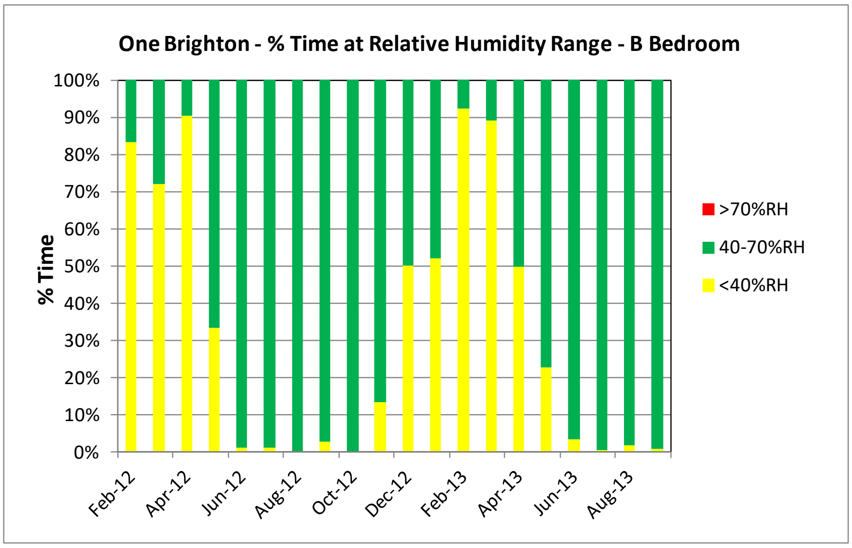
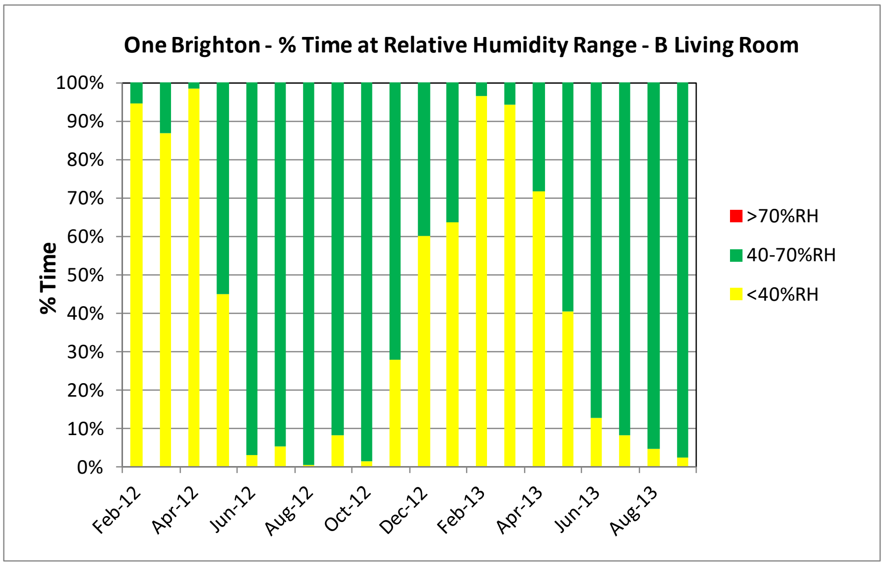


Figure 42 – Dwelling B Living Room % Time at CIBSE Relative Humidity Range by Month



7.7 Carbon Dioxide Concentration

The data in Table 36 give the mean annual CO_2 concentration for the five apartments for the period February 2012 to January 2013. In the case of dwellings A, B, C and F, the mean levels of CO_2 are around 750 to 850 ppm. A recent meta-analysis of peer reviewed research into the effects of ventilation and air quality (Wargocki 2013) suggests a CO_2 level of around 900 ppm represents a good air quality proxy threshold above which research has shown there to be statistically significant effects on human health. Satish et al. (2012) showed statistically significant effects on human cognitive performance at 1000 and 2500 ppm, with a dose-response relationship. Though withdrawn in 2005, DIN 1946-2 (Raumlufttechnik; Gesundheitstechnische Anforderungen) gave an upper limit of CO_2 of 1500 ppm, and recommended a value (originally proposed by Pettenkofer) of 1000 ppm. The highest mean concentrations were in dwellings A&C, in which it appears that ventilation systems had been turned off. The mean CO_2 concentration in apartment D is lower, at around 570 ppm.

Table 36 – Mean Annual CO_2 Concentration for Period Feb-12 to Jan-13

	Dwelling A	Dwelling B	Dwelling C	Dwelling D	Dwelling F*
Bedroom (ppm CO_2)	891	812	881	579	789
Living Room (ppm CO_2)	752	674	780	570	758
Overall (ppm CO_2)	821	743	831	575	774

* Note that F has missing data for March-June and November-December and is therefore not included.

Looking in more detail at graphs of monthly mean CO_2 data (

Figure 43 and Figure 44), it can be seen that the CO_2 concentrations tend to be higher in the winter. Probably unsurprisingly, the highest concentrations were in one of the two (dwelling C) in which it appears that MVHR systems had been turned off. The highest monthly concentration for dwelling C is in January 2013, with mean CO_2 of 1282 ppm in the bedroom and 1100 ppm in the living room. As would be expected, overnight and hourly values were much higher. The maximum recorded CO2 level was 4415 ppm also in apartment C and such high levels of CO_2 are a cause for concern. The lower levels of CO_2 during the summer are consistent with an expected increase in window opening behaviour in warmer weather.

Figure 43 – Mean Monthly CO_2 Concentration in Bedroom for Monitored Dwellings

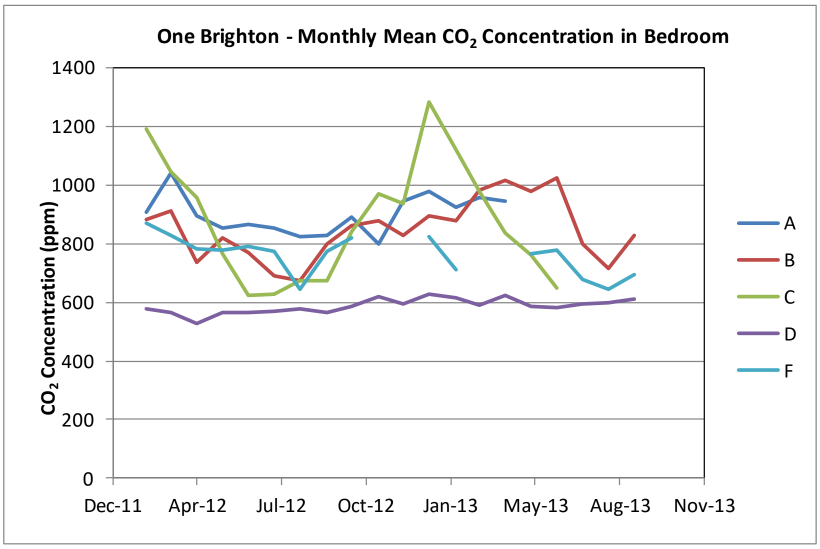
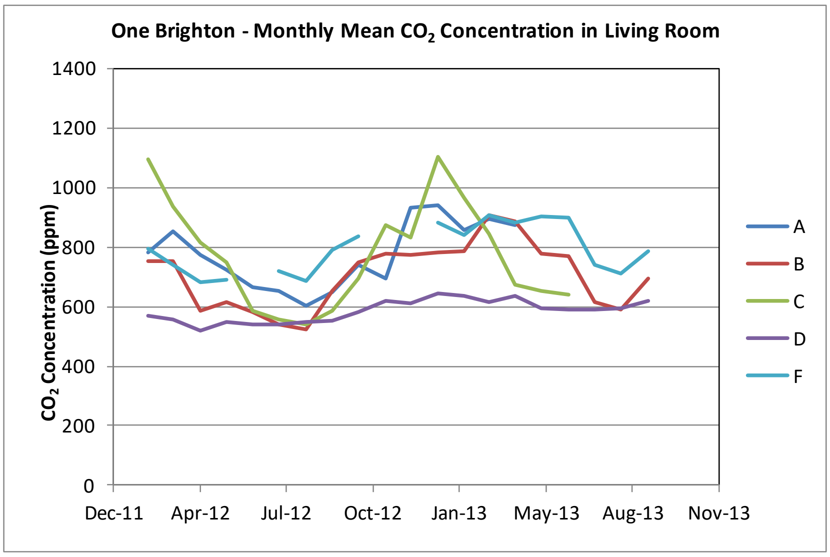


Figure 44 – Mean Monthly CO_2 Concentration in Living Room for Monitored Dwellings



The graphs in Figure 45 and Figure 46 show the time profile for three different CO_2 ranges (<800ppm, 800-1000ppm, >1000ppm) by month for the living rooms of dwelling C and D. It can be seen that there is a considerable difference between the two dwellings, with the CO_2 concentration in dwelling D rarely exceeding 1000ppm, but with the concentration in dwelling C being frequently higher than 1000ppm, especially during the winter. The evidence is therefore quite strong that the occupant of dwelling C has turned off the MVHR system, especially when considered in combination with the high relative humidity data. Perhaps more worrying, is that high levels of CO_2 are also seen in dwellings B and F, even though the humidity and MVHR energy data show that the MVHR systems are on. It is unclear what the underlying reasons are for this is, but the observations of the MVHR installation would suggest that a possible explanation could be related to recirculation of air from the exhaust to the intake or other technical issues relating to the system installation. Alternatively, there may be sources of external pollution in proximity to the fresh air intakes.

Figure 45 – Dwelling C Living Room % Time within CO_2 Concentration Range by Month

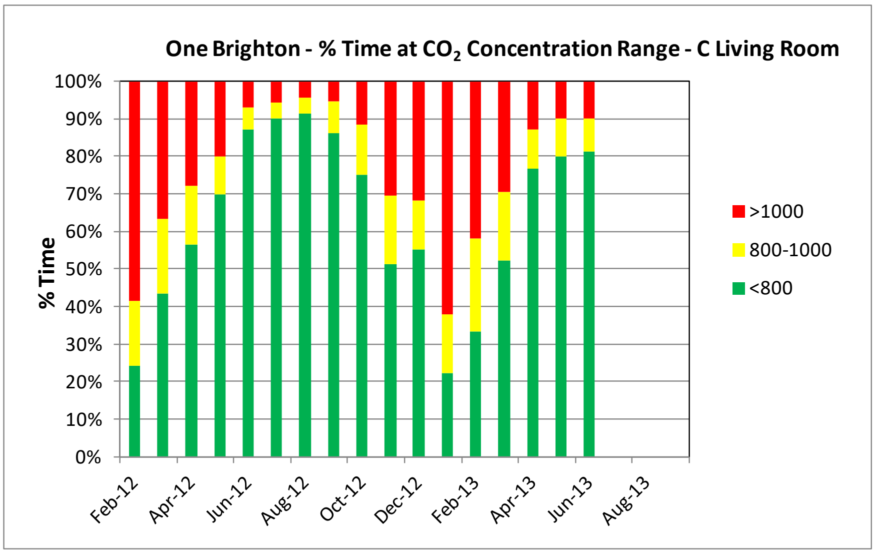
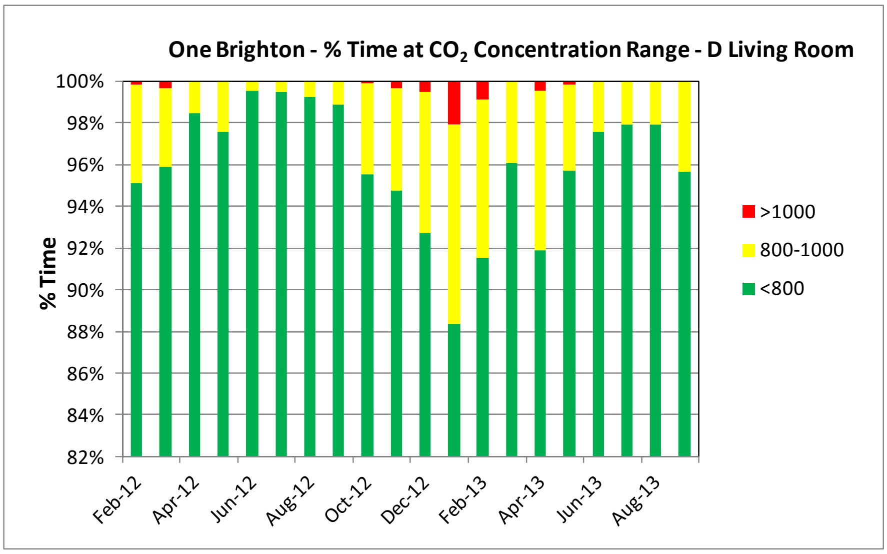
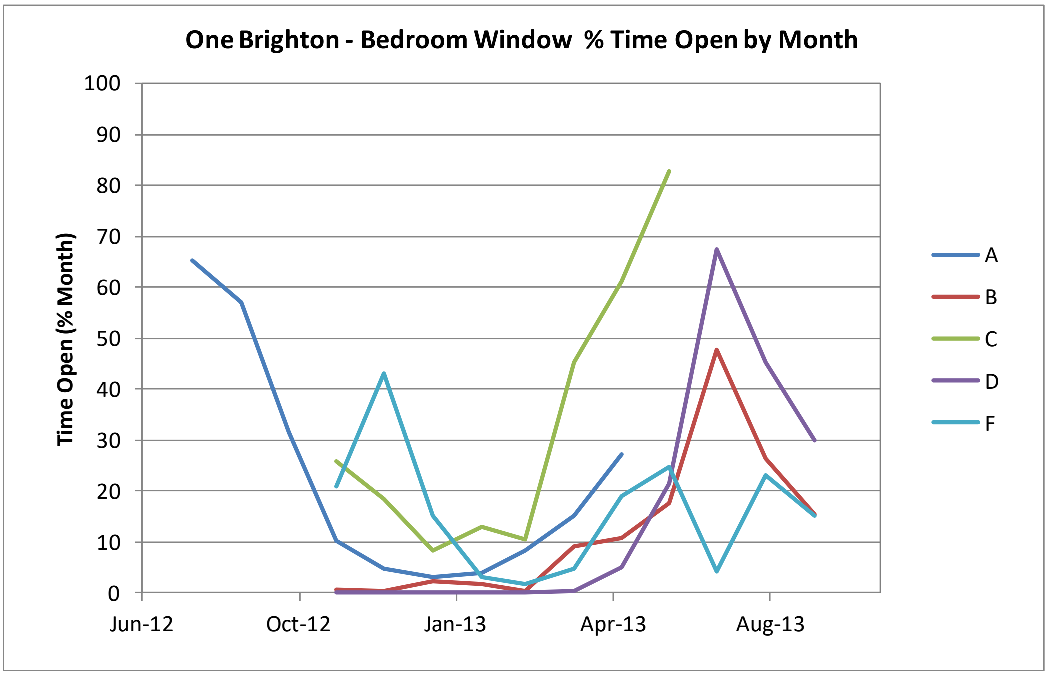


Figure 46 – Dwelling D Living Room % Time within CO_2 Concentration Range by Month



An analysis of data on window opening behaviour (from window proximity sensors in the apartments installed as part of a different project) does show that that residents tend to modify their window opening in winter compared to summer. The graph in Figure 47 shows the percentage time the bedroom window was open in each apartment by month. It can be seen that opening falls to between 0% and 10% of the time in winter, rising to as high as 60 to 80% of the time in some apartments in summer. The implication is therefore that all residents are opening windows in summer, presumably to try to moderate the high internal temperatures, and are not relying solely on the free-cooling mode of the MVHR system. It can be seen that the resident of apartment D does not open the window at all in winter, whereas the residents of B and F open the window around 5% of the time. The residents of all three apartments kept the living room windows closed in winter. Differences in window opening behaviour cannot therefore explain the fact that apartment D has lower CO_2 levels in winter than those in apartments B and F, and the mechanisms involved must be more complex.

Figure 47 – Bedroom Window Opening as % Time Open by Month



7.8 Monitored Dwelling Electricity Consumption

The total electricity consumption for the five monitored apartments for the period February 2012 to January 2013 ranged from 1107 kWh (A) to 2526 kWh (F) (see Table 37).

Table 37 – Annual Total Electricity Consumption for Monitored Apartments (Feb-12 to Jan-13)

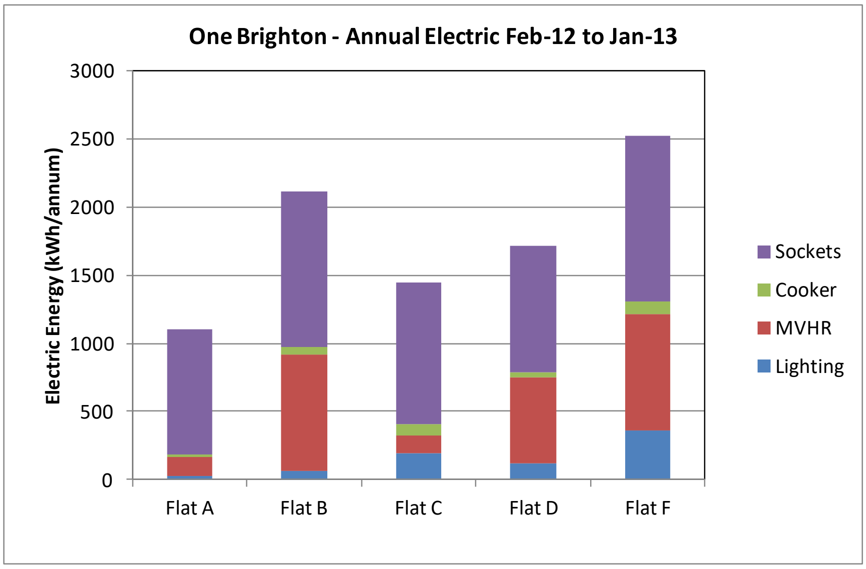
	A	B	C	D	F
Lighting (kWh)	21.7	66.5	191.4	117.2	363.5
MVHR (kWh)	141.5	848.4	132.7	635.0	854.0
Cooker (kWh)	25.3	56.2	80.6	37.1	94.3
Sockets (kWh)	918.5	1146.9	1038.3	929.7	1214.1
Total (kWh)	1107	2118	1443	1719	2526

The bar chart in

Figure 48 shows the annual electricity consumption split by end use. It can be seen that electricity use is dominated by plug-in appliances. The amount of electricity used for appliances is fairly similar for all five apartments, ranging from 918 kWh/annum in A to 1214 kWh/annum in F. By contrast, there are big differences in the amount of electricity used by the MVHR system. In apartments A and C the MVHR energy use is very low at around 140 kWh. In apartments B, D and F, the MVHR electricity use is much higher at 650 to 850 kWh/annum, constituting around 40% of total electricity use. It can therefore be concluded that the residents of A and C have the MVHR system turned off for most of the time, whereas those in B, D and F are using the MVHR as intended. There is also a big difference in the amount of electricity used for fixed lighting. The lowest lighting electricity use is in dwelling A at only 22 kWh/annum ranging to a high of 364 kWh/annum in dwelling F. The fixed lighting energy use in A is equivalent to a daily power of only 2.5 W. It is therefore possible that the resident may be using plug-in lighting in preference to the fixed light fittings. Electricity use for the cooker was a small proportion of overall use in all five dwellings and ranged from 25 kWh/annum in A to 94 kWh/annum for dwelling F.

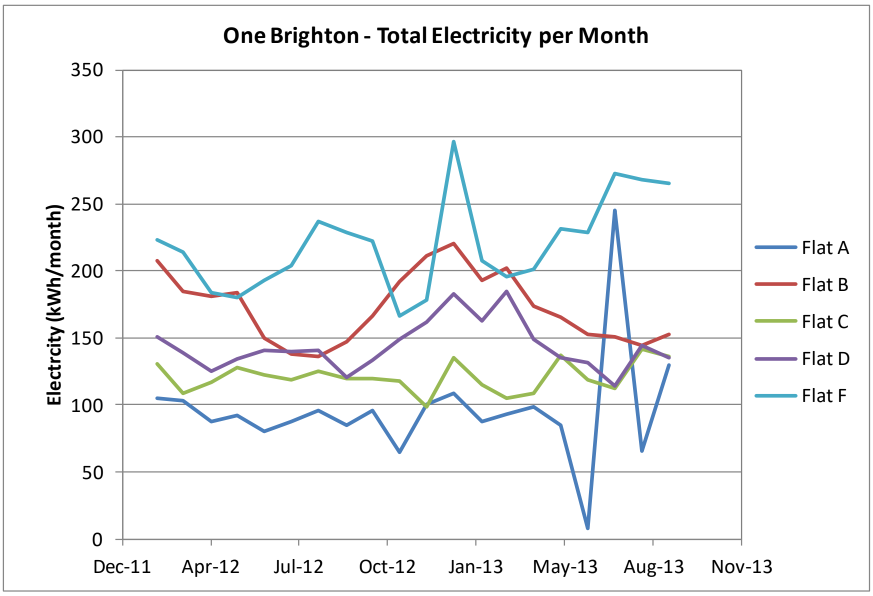
The annual electricity consumption in all five dwellings is well below the OFGEM typical medium UK electricity use for all dwellings of 3300 kWh (OFGEM 2010), showing that the residents of the monitored households at One Brighton have a relatively low use of electricity. This would be expected given that the One Brighton dwellings are all relatively small apartments. A more recent DECC analysis of UK domestic electricity consumption (DECC 2013a) gives a mean for 2011 of 4,200 kWh/annum, median of 3,400 kWh/annum and a lower quartile of 2,200 kWh. So, with the exception of F, the electricity consumption at One Brighton is in the lower quartile. The DECC report also gives electricity data by dwelling type, floor area and number of bedrooms. For purpose-built apartments, the median electricity consumption in 2011 was 2,500 kWh/annum. The median for dwellings with a floor area of 50 m^2 of less in 2011 was 2,300 kWh/annum. The median for a dwelling with one bedroom in 2011 was 2,100 kWh/annum. The electricity consumption in Flat F at 2,500 kWh/annum is therefore typical of UK dwellings of the same size and type, whereas that for A, B, C and D is below that of similar dwellings.

Figure 48 – Bar Chart of Annual Total Electricity Consumption Split by End Use (Feb-12 to Jan-13)



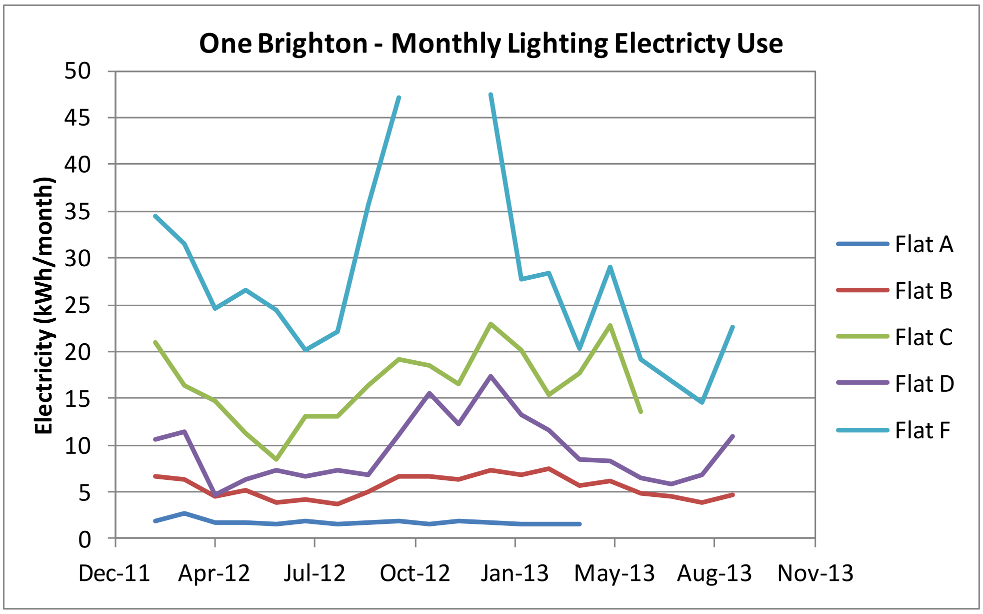
The trend in monthly electricity consumption for the whole monitoring period is shown in Figure 49. The only significant trends over the year are for dwellings B and D where there is an increase in electricity use in the winter. This is likely to be related to the additional energy required to run the MVHR system in heating mode and for additional lighting use when sunshine hours are lower.

Figure 49 – Monthly Total Electricity Consumption for Monitored Apartments



The graph in Figure 50 shows the monthly lighting electricity for the five apartments. The large change over the year was observed for apartment F, where the lighting use in winter at around 45 kWh/month was nearly double that in summer (20 - 25 kWh/month). A similar doubling in lighting energy in winter was also seen in dwellings C and D. There was little change in lighting electricity consumption over the year for dwellings A and B, where lighting energy remains at a relatively low level in both summer and winter.

Figure 50 – Monthly Lighting Electricity Consumption for Monitored Apartments



The monthly electricity use for the MVHR system in the five dwellings is shown by the graph in

Figure 51. MVHR energy use in apartments A and C remains low throughout the year at around 11 kWh/month. This is equivalent to an average electrical power consumption of 15W. As it is thought that the MVHR units in dwellings A and C are normally off, 15W will be the standby power for the MVHR unit. It can be seen that the MVHR energy in flats B and D increases in winter, which is consistent with the higher fan speeds when the unit is in heating mode. Conversely, the MVHR energy in apartment F tends to be higher in the summer, which is consistent with higher fan speeds required for free-cooling mode. The graph of MVHR power at 5 minute intervals shown in Figure 52 indicates that the MVHR power consumption in trickle mode is around 60W, in speed 2 is around 140 to 170W and in boost mode is around 250W.

Figure 51 – Monthly MVHR Electricity Consumption for Monitored Apartments

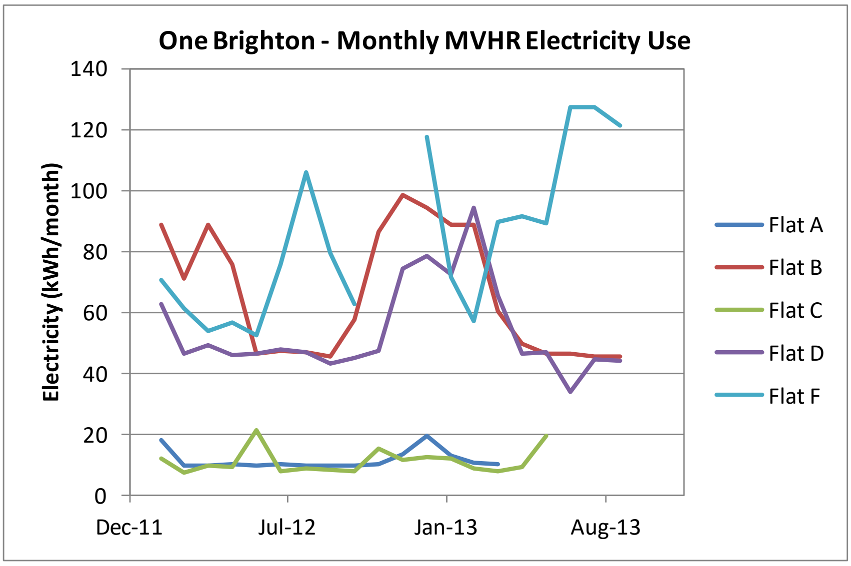
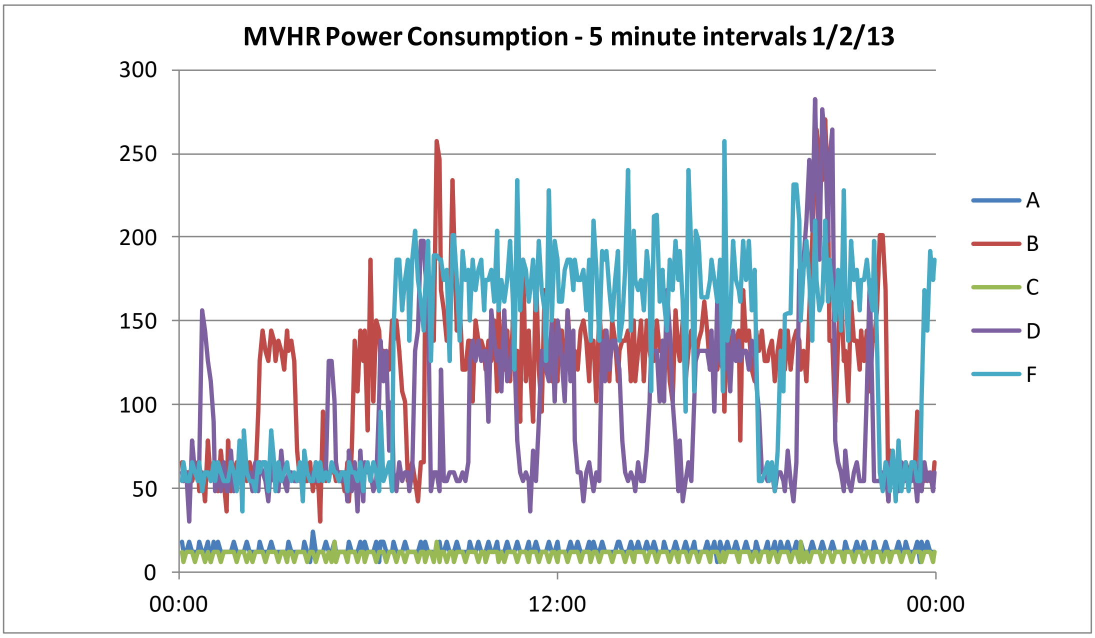


Figure 52 – 5 Minute MVHR Electrical Power Trend over 1st February 2013



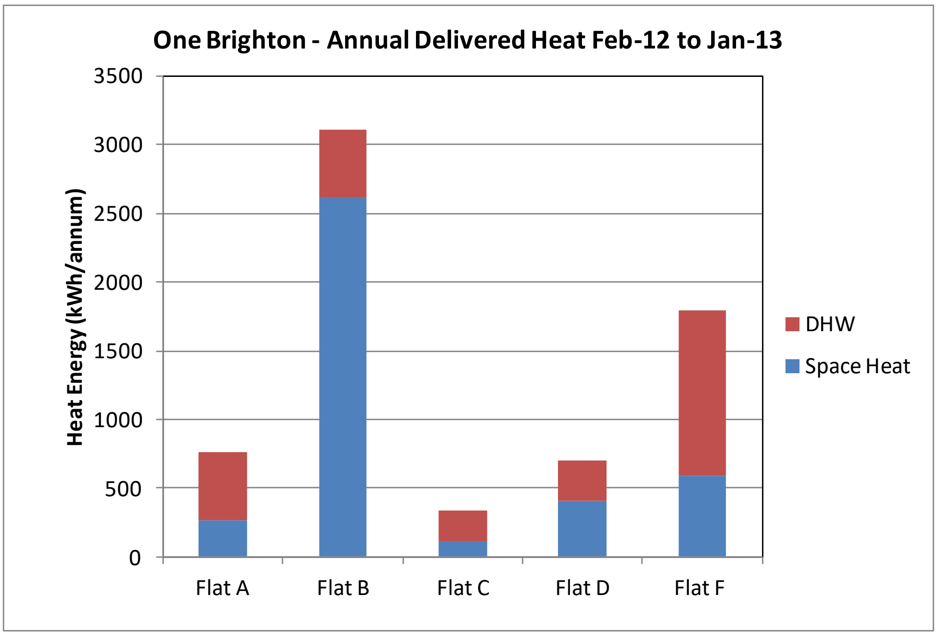
7.9 Monitored Dwelling Heat Consumption

The total communal heat input to the five monitored apartments for the period February 2012 to January 2013 ranged from a low of only 333 kWh for dwelling C (7.4 kWh/m^2)to a high of 3113 kWh/annum for dwelling B (68.7 kWh/m^2) (see Table 38 and Figure 53). The highest space heating use was in apartment B at 2614 kWh/annum. The highest domestic hot water use was in apartment F at 1207 kWh/annum. There are clearly big differences in the way that the residents heat their homes and in how they use hot water. It would be expected that dwelling B would have the highest space heating requirement as it has the highest number of exposed surfaces, the highest heat loss coefficient of the five dwellings (see Table 30) and the highest internal temperature in winter (22.9°C). What is more surprising are the very low levels of space heat input in apartments A, C and D even though the internal temperatures in winter in these apartments remained quite high at between 18 to 21°C. It is thought that these dwellings must therefore be mainly heated with adventitious heat gain across party elements and with gains arising from the communal heating distribution system.

Table 38 – Annual Communal Heat Input to Monitored Apartments (Feb-12 to Jan-13)

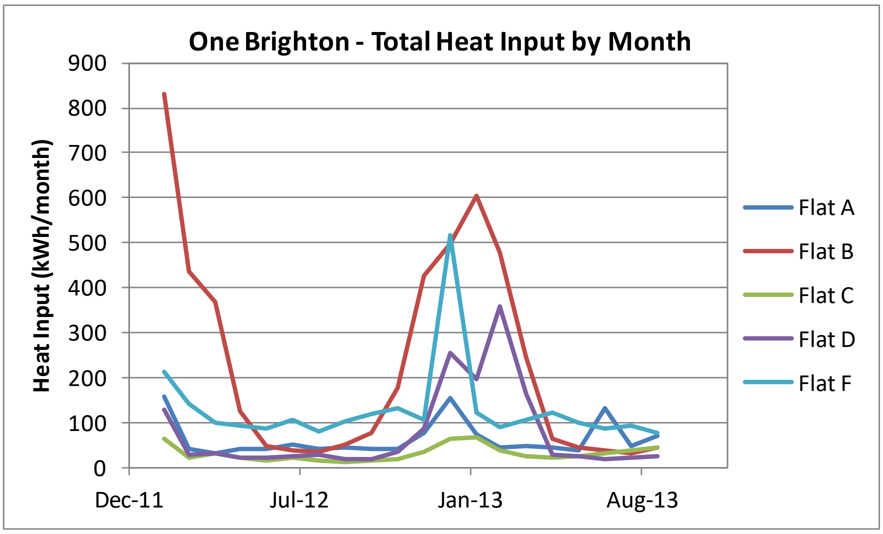
	A	B	C	D	F
Space Heat (kWh)	270	2614	117	408	590
Space Heat (kWh/m^2)	6.0	57.7	2.6	9.0	13.0
Hot Water (kWh)	497	499	216	294	1207
Hot Water (kWh/m^2)	11.0	11.0	4.8	6.5	26.6
Total Heat (kWh)	767	3113	333	702	1797
Hot Water (kWh/m^2)	16.9	68.7	7.4	15.5	39.7

Figure 53 – Annual Communal Heat Input to Monitored Apartments (Feb-12 to Jan-13)



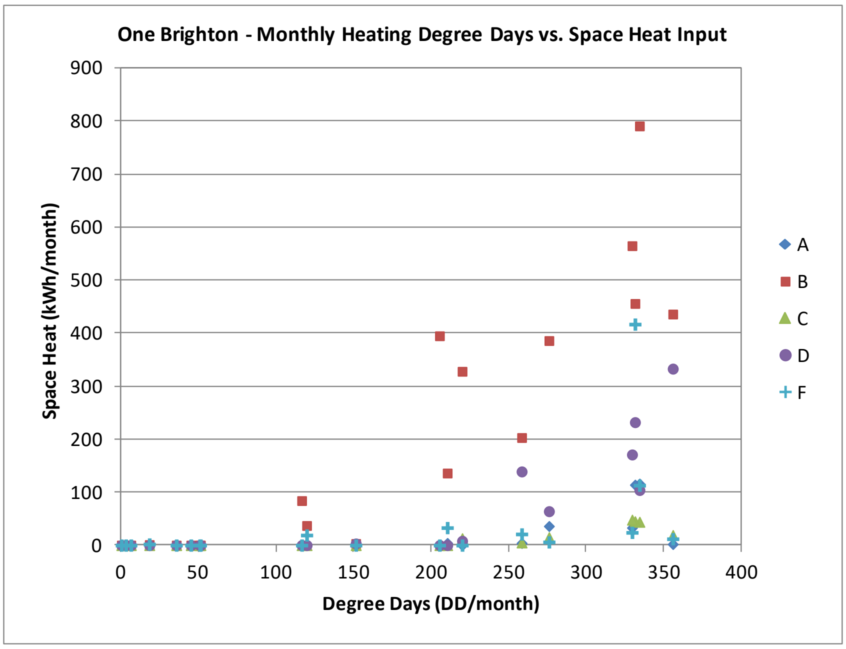
The graph in Figure 54 shows the monthly communal heat input to the apartments. The increase in heat demand in the winter months is clearly visible, even for the dwellings with very little overall heat demand. These results clearly demonstrate the variability in energy use that is possible, even with dwellings nominally of the same construction, floor area and occupancy.

Figure 54 – Monthly Communal Heat Input to Monitored Apartments



Normally, one would expect a reasonable correlation between external temperature and heat input. The graph in Figure 55 shows monthly heating degree days from the One Brighton weather station (at 15.5° base temperature) versus the monthly heat input. It can be seen that, for dwellings B and D, the heat input increases as the heat demand increases. However, there is very little correlation for heat demand and space heat for dwellings A, C and F.

Figure 55 – Monthly Heating Degree Days versus Space Heating Input



There are currently no databases of typical communal heat energy use for the UK against which to compare the results from One Brighton. Instead, data for typical gas consumption given in the DECC NEED database (DECC 2013a) are used as a comparator. The NEED dataset gives the median gas consumption for a purpose built flat of 50 m^2 or less as 6,400 kWh in 2011, and 7,100 kWh in both 2010 and 2009. The heat consumption levels of the five monitored apartments at 333 kW to 3,113 kWh are significantly less than this, even after allowing for factors to account for the efficiency of a gas boiler and differences in weather.

The energy use for domestic hot water for the five monitored apartments was very variable, and ranged from 216 kWh/a for dwelling C to 1,207 kWh/a for dwelling F. In all five cases, the DHW energy was significantly below that assumed in the SAP calculation (The SAP worksheet for dwelling F gives 2343 kWh/a as the heat energy requirement to satisfy the predicted DHW demand and 2894 kWh/a as the energy requirement after allowing for the efficiency of heat delivery). This sort of variation in DHW energy use is to be expected as it is dominated by user behaviour.

7.10 Monitored Dwelling Total Energy Consumption

The bar chart in Figure 56 shows the total energy input to the monitored apartments split by electricity and communal heat for the period February 2012 to January 2013. With the exception of apartment B, energy use is dominated by electricity. The data in

Table 39 give the annual total energy use for years at the start, middle and end of the monitoring period. These data show that the annual energy use was relatively constant over the 20 months.

Figure 56 – Annual Total Energy Use for Monitored Apartments Feb-12 to Jan-13

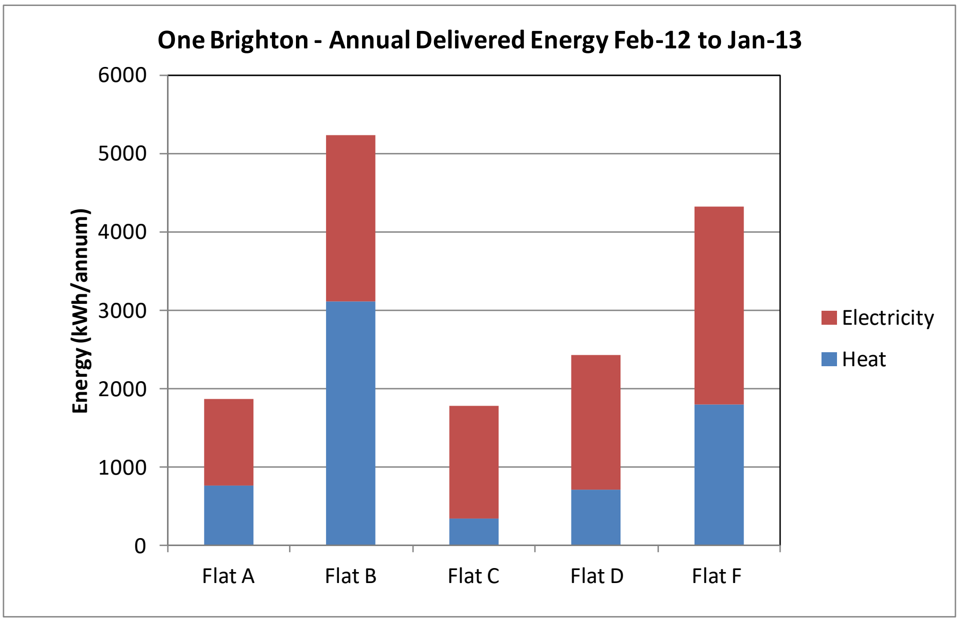


Table 39 – Total Energy Use for Monitored Apartments Feb-12 to Jan-13, Jun-12 to May-13, Oct-12 to Sep-13

	A	B	C	D	F
Total Energy Use Feb-12 to Jan-13 (kWh)	1874	5231	1776	2421	4323
Total Energy Use Feb-12 to Jan-13 (kWh/m^2)	41.4	115.5	39.2	53.4	95.4
Total Energy Use Jun-12 to May-13 (kWh)	1789	4836	1768	3035	4250
Total Energy Use Jun-12 to May-13 (kWh/m^2)	39.5	106.8	39.0	67.0	93.8
Total Energy Use Oct-12 to Sep-13 (kWh)	1998	4852	1865	3016	4402
Total Energy Use Oct-12 to Sep-13 (kWh/m^2)	44.1	107.1	41.2	66.6	97.2

7.11 Overall Development Dwelling Electricity Consumption

The energy data supplied by the ESCo were used to calculate the average annual electricity consumption for the 172 dwellings on the One Brighton development over the monitoring period as shown in Table 40. There was a wide variation in use with the lowest consumption being only 58 kWh/annum and the highest 7,840 kWh/annum.

Table 40 – Total Annual Electricity Consumption for all 172 One Brighton Dwellings

Period	**Total (kWh)**	**Mean (kWh)**	**Std.Dev. (kWh)**	**Max (kWh)**	**Min (kWh)**
Feb-12 to Jan-13	426218	2478	1095	7652	387
Mar-12 to Feb-13	423397	2462	1088	7840	299
Apr-12 to Mar-13	428801	2493	1109	7836	223
May-12 to Apr-13	429485	2497	1101	7384	190
Jun-12 to May-13	428150	2489	1095	6962	128
Jul-12 to Jun-13	426797	2481	1089	6492	86
Aug-12 to Jul-13	425904	2476	1076	5991	58
Sep-12 to Aug-13	425432	2473	1071	5569	74
Oct-12 to Sep-13	425549	2474	1071	5503	144
Annual Mean (kWh)	**426637**	**2480**	**1069**	**6776**	**177**

The histogram in Figure 57 shows the frequency distribution of electricity use for the 172 One Brighton dwellings based on the average annual consumption for each dwelling over the monitoring period. The data appear normally distributed and are skewed to the top end of the distribution. The descriptive statistics for the average annual consumption data are given in Table 41. The mean annual electricity consumption per dwelling was 2,480 kWh/annum with a standard deviation of 1,069 kWh. The median annual electricity consumption was 2,312 kWh. The positions of the five monitored dwellings on the distribution are shown by red letters. Dwellings A, C and D are in the bottom half of the distribution, whilst dwelling B and F are towards the middle of the distribution. The average floor area for the 172 dwellings at One Brighton is 54.0 m^2, so the normalised mean electricity use was 45.9 kWh/m^2 per annum and the normalised median was 42.8 kWh/m^2 per annum. The median annual electricity consumption for all 172 dwellings (2,312 kWh) is comparable to the median of 2,500 kWh for purpose built apartments in the NEED database (DECC 2013a).

Figure 57 – Frequency Distribution of Mean Annual Electricity per Apartment (Feb-12 to Sep-13)

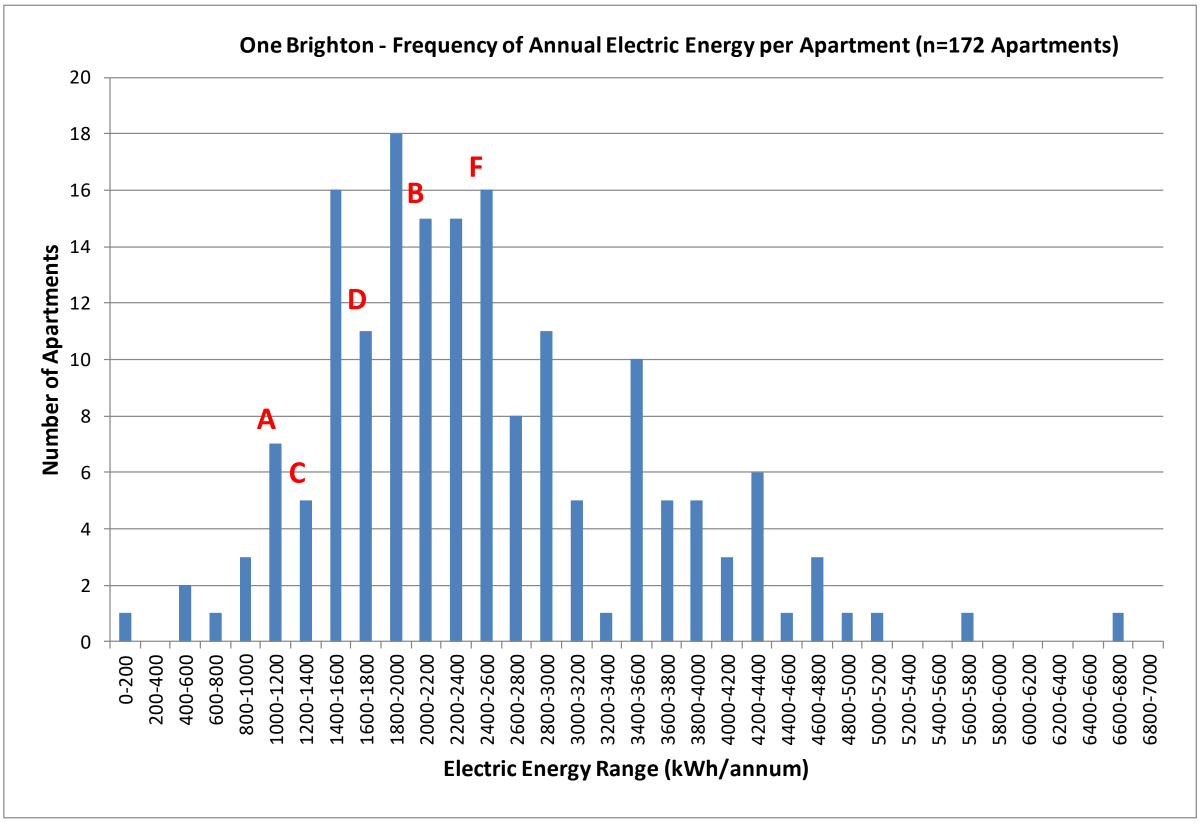
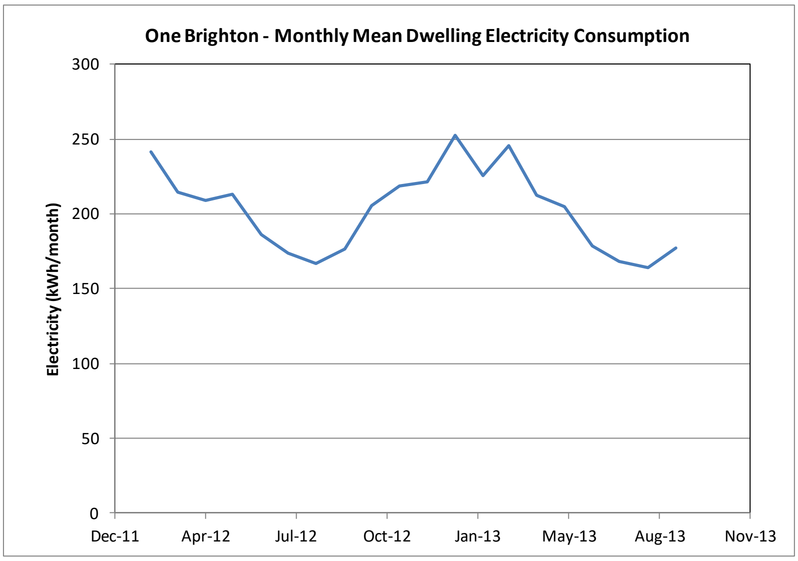


Table 41 – Descriptive Statistics for Mean Annual Electricity Consumption for All 172 One Brighton Dwellings

Statistical Parameter	Value
Mean	2480
Standard Error	81.5
Median	2312
Standard Deviation	1069
Kurtosis	1.09
Skewness	0.87
Range	6600
Minimum	176.5
Maximum	6776

The mean monthly electricity consumption for the One Brighton dwellings over the monitoring period is shown in Figure 58. It can be seen that the mean electricity use peaks in the winter at around 250 kWh, with a minimum in summer of around 165 kWh. The difference will be due to additional lighting in winter and the MVHR fan in heating mode.

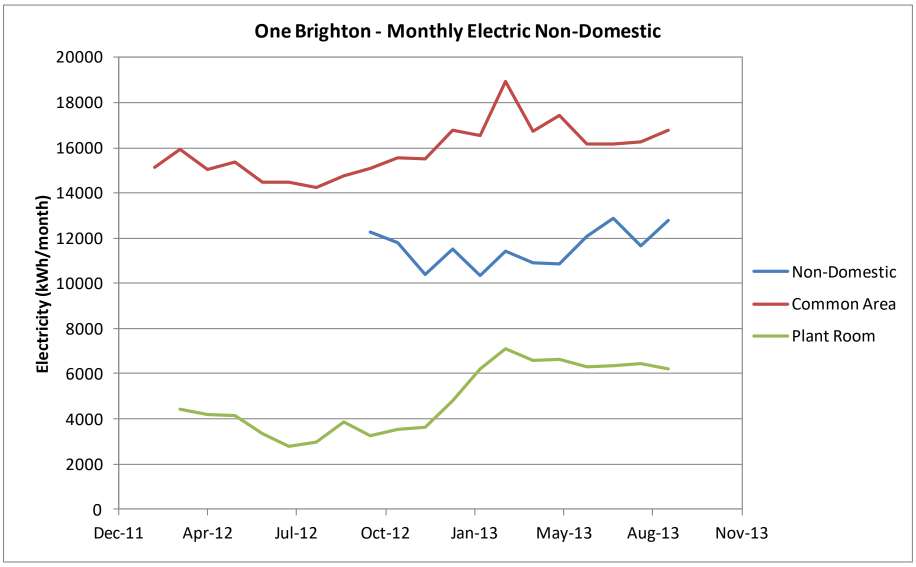
Figure 58 – Monthly Electricity Consumption for all 172 One Brighton Dwellings



7.12 Non-Domestic, Common Area and Plant Room Electricity Use

The electricity consumption data for the non-domestic areas, common areas and the plant room at One Brighton were analysed using data provided by the ESCo. The monthly consumption levels for each category over the monitoring period are shown in Figure 59. The electricity consumption for common areas was of the order 14,000 to 16,000 kWh per month, with the average annual consumption over the monitoring period being 190,159 kWh per annum. This electricity use will be related to factors such as lighting in corridors and lobby areas, lifts and security systems. This can be mostly attributable to the requirements of the dwellings rather than the non-domestic offices, and would be equivalent to 1,106 kWh per annum per dwelling. The residents and companies occupying the non-domestic properties will be paying for this common area electricity in the annual service charges levied by the management company. The electricity consumption for the non-domestic properties on the ground floor (offices and community cafe) was of the order 11,500 kWh/month, with an annual consumption of 138,975 kWh/a (67.5 kWh/m^2.a) for the period October 2012 to September 2013. The electricity consumed by the plant room was of the order 5,000 kWh per month. The average annual plant room electricity use was 56,874 kWh. The plant room electricity use will mostly be related to the energy for the communal heating system pumps, fans and controls, although a small proportion will have been used for the building cold water system. The data shows an increase in plant room electricity use in February 2012 from 4,000 kWh per month to around 6,000 kWh per month. The reason for this increase is unknown, but is likely to be related to a change in the plant room components or system settings, and should be investigated by the ESCo maintenance team.

Figure 59 – Monthly Non-domestic Electricity Consumption at One Brighton



7.13 Overall Development Dwelling Heat Consumption

The energy data supplied by the ESCo were used to calculate the average annual communal heat consumption for the 172 dwellings on the One Brighton development over the monitoring period are given in Table 42.

Table 42 – Total Annual Heat Consumption for all 172 One Brighton Dwellings

Period	Total (kWh)	Mean (kWh)	Std.Dev. (kWh)	Max (kWh)	Min (kWh)
Feb-12 to Jan-13	292939	1703	1126	5610	5
Mar-12 to Feb-13	288077	1675	1100	5401	5
Apr-12 to Mar-13	302988	1762	1174	5819	5
May-12 to Apr-13	311459	1811	1236	6730	0
Jun-12 to May-13	315536	1835	1289	7506	0
Jul-12 to Jun-13	318005	1849	1311	7783	0
Aug-12 to Jul-13	318393	1851	1311	7868	0
Sep-12 to Aug-13	319240	1856	1313	7872	0
Oct-12 to Sep-13	319293	1856	1308	7821	0
Annual Mean (kWh)	**309548**	**1800**	**1210**	**6683**	**10**

The histogram in Figure 60 shows the frequency distribution of communal heat use for the 172 One Brighton dwellings based on the average annual consumption for each dwelling over the monitoring period. The distribution is highly skewed towards the top end. The positions of the five monitored dwellings on the distribution are shown by red letters.

Figure 60 – Frequency Distribution of Mean Annual Communal Heat per Apartment (Feb-12 to Sep-13)

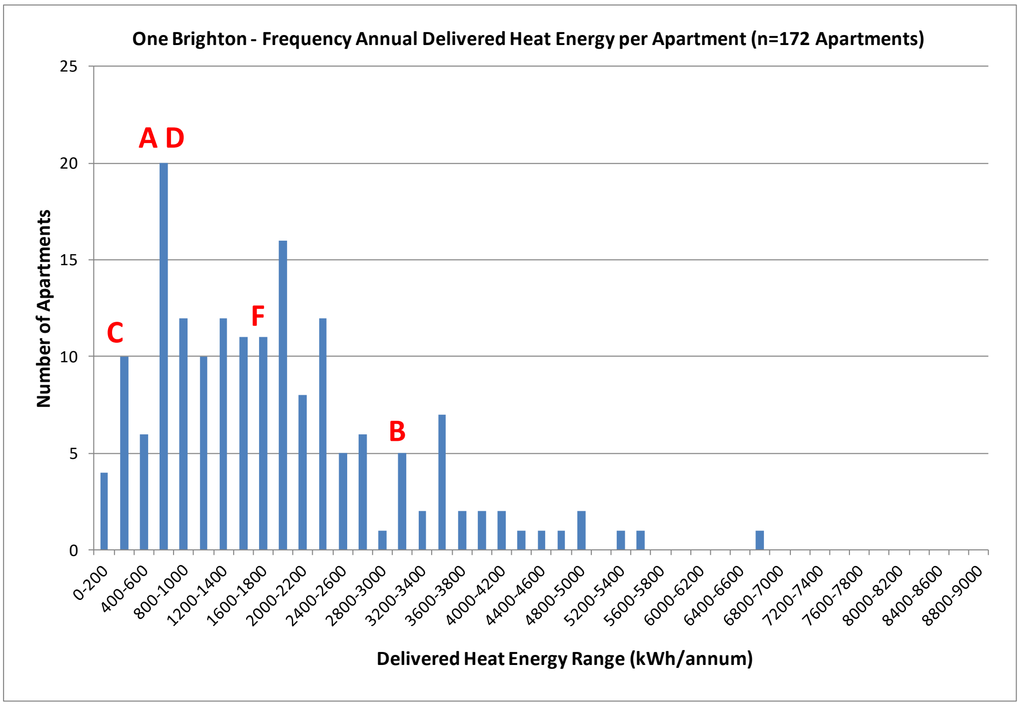


Table 43 – Descriptive Statistics for Mean Annual Heat Consumption for All 172 One Brighton Dwellings

Statistical Parameter	Value
Mean	1799.7
Standard Error	92.3
Median	1632.1
Standard Deviation	1210.0
Kurtosis	1.46
Skewness	1.12
Range	6672.7
Minimum	10.1
Maximum	6682.8

The descriptive statistics for the mean annual heat consumption for each dwelling over the period February 2012 to September 2013 are given in Table 43. The mean communal heat input was 1,780 kWh with a standard deviation of 1,210 kWh. The maximum heat input was 6,682 kWh. The annual gas consumption data in the NEED database (DECC 2013a) for a purpose built apartment gives the median in 2011 as 6,400 kWh and 7,100 kWh in 2010. These gas data can be compared with the median communal heat input from One Brighton over the monitoring period of 1,632 kWh, and indicate that the heating and hot water energy requirements at One Brighton are around 25% of the UK norm for purpose built apartments. The graph in Figure 61 shows the combined daily heat input to the One Brighton dwellings. The highest heat demand was in February 2012 at around 2,100 kWh/day. The graph in Figure 62 shows the combined monthly heat input to dwellings, with a winter maximum of 40,000 kWh.

Using the average floor area for all One Brighton dwellings of 54.0 m^2 gives the normalised mean delivered heat use of 33.3 kWh/m^2 per annum, with a normalised median of 33.2 kWh/m^2 per annum. These results are significantly better than the original design performance target for the development of less than 75 $kWh/m^2.a$ for combined space heating and hot water demand.

Figure 61 – Daily Combined Heat Input to Dwelling over Monitoring Period (Feb-12 to Sep-13)

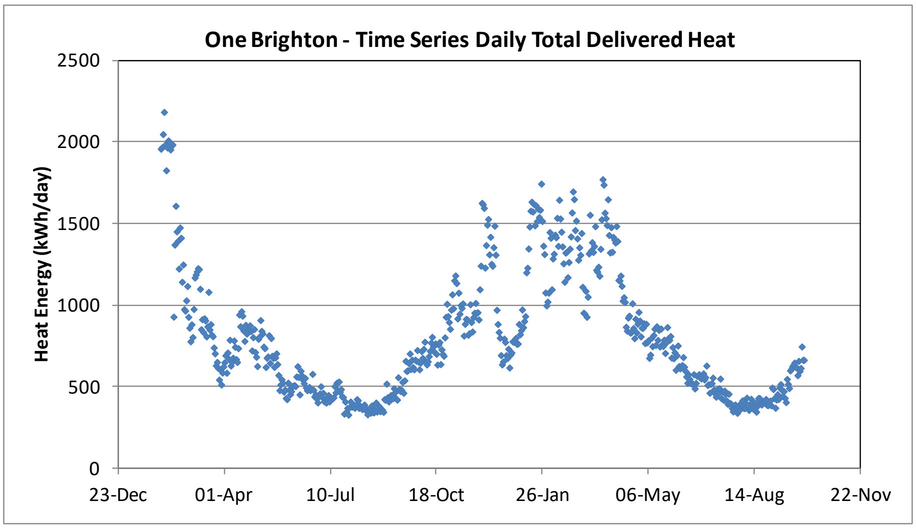
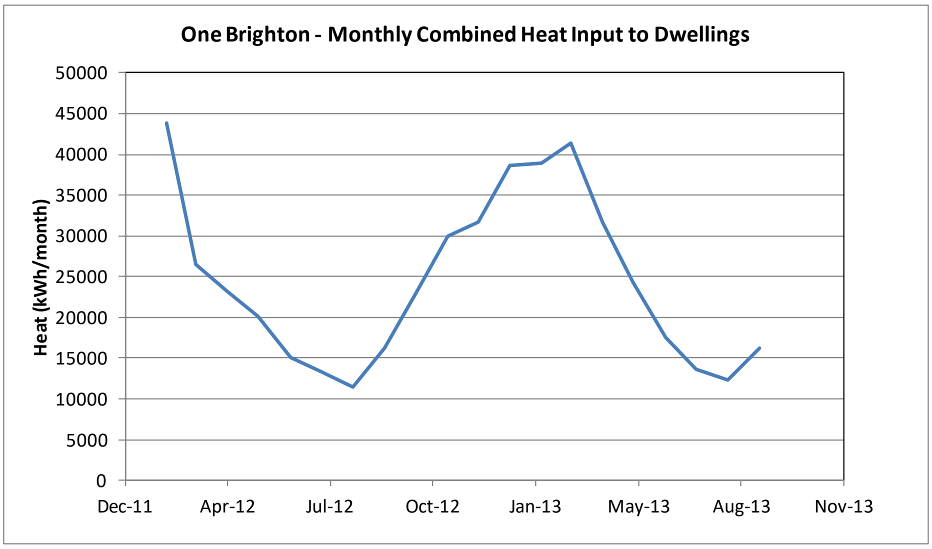


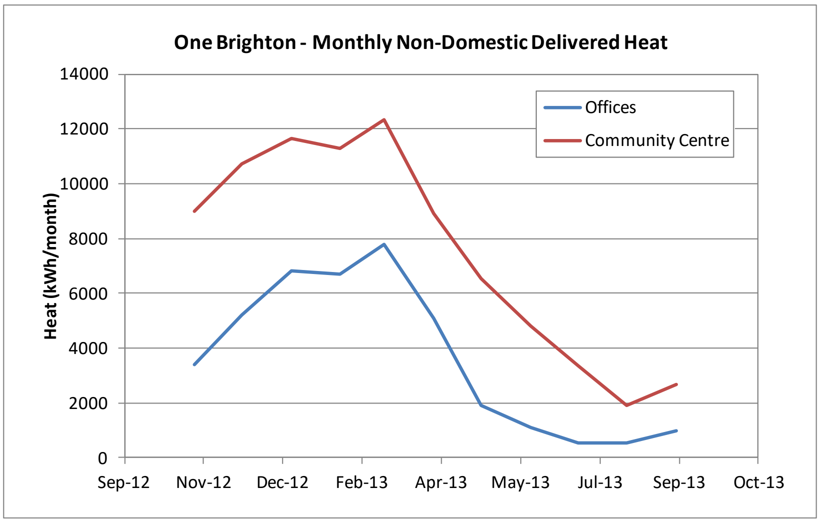
Figure 62 – Monthly Combined Heat Input to Dwellings over Monitoring Period (Feb-12 to Sep-13)



7.14 Non-domestic Heat Consumption

The monthly heat delivered to the offices and community centre at One Brighton for the period November 2012 to September 2013 is shown in Figure 63. The monthly trends for the community centre and offices are very similar, indicating that the way that heat is controlled in the spaces is also similar. The maximum combined non-domestic heat demand in the winter is around 20,000 kWh/month, which is around half of the maximum combined monthly heat input to the One Brighton dwellings. The monthly minimum heat input to the non-domestic properties in summer is only 3,000 kWh/month compared to a summer base load for the One Brighton dwellings of around 12,000 kWh/month. This shows that hot water demand for the non-domestic properties is, as expected, less significant than that of the dwellings. Total delivered heat to non-domestic areas was 131,162 kWh/a (63.7 kWh/m^2.a).

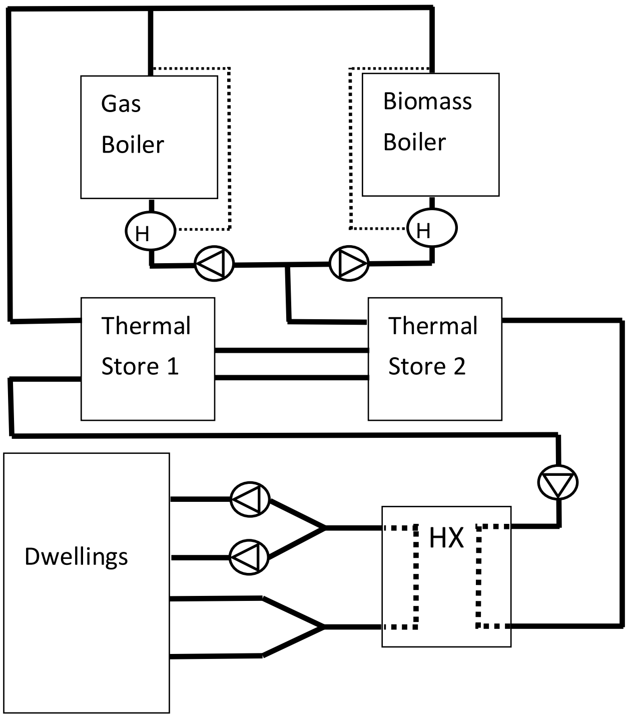
Figure 63 – Monthly Delivered Heat to Non-Domestic Properties for Period Nov-12 to Sep-13



7.15 Performance of Communal Heating System

The heat output of the communal heating system was monitored by the ESCo using heat meters located on the biomass boiler and gas boiler as shown by the schematic of the plant room in Figure 64. These data were supplied to the research team as daily meter readings along with daily gas meter readings. There was no heat meter on the total output from the plant room after the heat exchanger that hydraulically separates the plant room from the DH network, so it was not possible to determine system losses arising from within the plant room. The ESCo also supplied data on the quantity of biomass wood pellet deliveries for the 12-month period June 2012 to May 2013.

Figure 64 – Schematic of One Brighton Communal Heating Plant Room



The data in Table 44 show the heat output and gas boiler efficiency for the periods February 2012 to August 2013, which covers most of the monitoring period. Readings were also provided by the ESCo for a slightly longer period from September 2011, giving two years worth of performance data for the communal heating plant. It can be seen that the plant output is actually dominated by heat provided by the gas backup boiler, with heat from biomass only accounting for 27.8% of total heat output over the monitoring period. The design and regulatory expectation was that 100% of heat should have been provided by the biomass boiler, with the gas backup only being used for shutdowns due to maintenance or equipment faults. Clearly, there have been significant issues with the reliability of the biomass boiler, although the exact nature of these reliability problems is unknown.

The measured efficiency of the gas boiler was very good, with an overall efficiency of 86.1% over the monitoring period. This compares very favourably to the manufacturer's quoted efficiency of 84.2% for the installed Ideal Viceroy GT 400 boiler.

Table 44 – Heat Output from Communal Heating Plant from Sep-11 to Aug-13

Period	Gas Used (kWh)	Gas Heat Out (kWh)	Biomass Heat Out (kWh)	Total Heat Out (kWh)	Gas Boiler Efficiency (%)	Heat from Biomass (%)
Feb-12 to Aug-13	1314709	1132430	583530	1715960	86.1	34.0
Sep-11 to Aug-13	1807866	1557820	601120	2158940	86.2	27.8

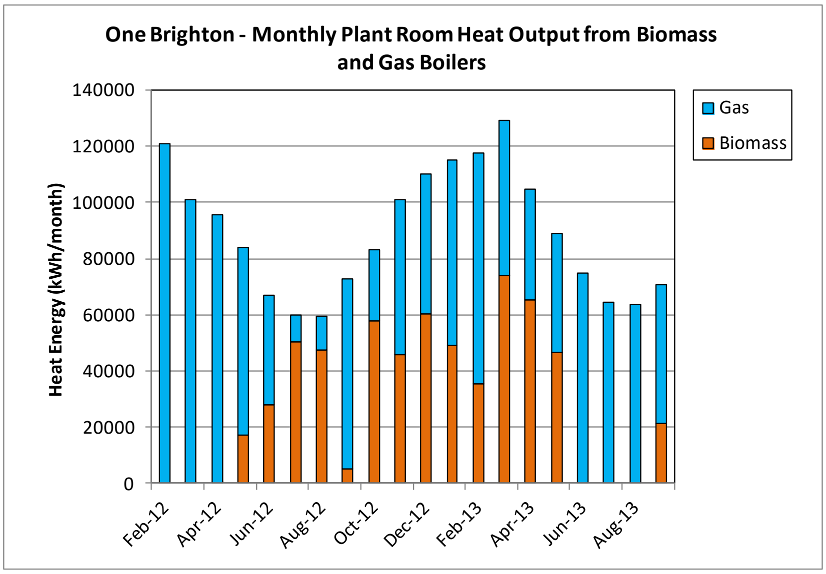
The data in Table 45 show the calculated fuel input and heat output from the biomass boiler for the period June 2012 to May 2013. The weight of wood pellet biomass was converted to the biomass energy content using a net calorific value of 4.8 kWh/kg (17.3 GJ/tonne) as quoted by the supplier of the wood pellets. This calorific value is consistent with the nominal value for wood pellets given by the Biomass Energy Centre (Biomass Energy Centre 2013). Our estimate of the overall efficiency of the biomass boiler over the period was 69.6%, although there will be some uncertainty around this value as the exact mass of fuel used in the boiler is unlikely to match that delivered. The manufacturer of the installed Binder RRK 400-600 biomass boiler does not provide data on expected efficiency, so it is not possible to compare the measured efficiency with manufacturer's data. The efficiency for the communal biomass boiler used in the as-built SAP calculation was 85%, which is much higher than the measured 69.6%.

Table 45 – Efficiency of Biomass Boiler for Period Jun-12 to May-13

Period	Total Wood Pellet Deliveries (tonnes)	Biomass Used (kWh)	Biomass Heat Output (kWh)	Biomass Efficiency (%)
Jun-12 to May-13	169.34	812832	565970	69.6

The graph in Figure 65 shows the overall monthly heat output from the communal heating systems, and the split between the gas and biomass boilers. It can be seen that the summer base demand is around 60,000 kWh/month, which is equivalent to a load of around 81 kW. The peak demand in the winter is approximately twice this at 120,000 kWh/month, which is equivalent to a load of around 162 kW. It can be seen that the biomass boiler was only operating for 14 months out of the 20 month monitoring period.

Figure 65 – Monthly Heat Output from Biomass and Gas Boilers Feb-12 to Sep-13



The heat losses attributable to system effects in the plant room and from the distribution network were calculated from the difference between the combined heat output from the boilers and the heat delivered to both domestic and non-domestic properties at One Brighton. The results in Table 46 show the calculated distribution and plant room system losses for the period November 2012 to August 2013 for which a full set of comparable dwelling, non-domestic and plant room data were available. The distribution/system losses were calculated to be 58.8% (79 kW), which is equivalent to a distribution efficiency of 41.2%. The research team were not provided with any design calculations for the expected system losses or distribution losses from the communal heating network, so it is not possible to compare these results with the designer’s assumptions. The assumption in the SAP 2005 calculations for One Brighton was for a distribution efficiency of 95%. This is the default value for community heating as given in Table 12c of SAP 2005 (BRE 2008) which lists the distribution loss factor as 1.05 for community heating systems with ”modern pre-insulated piping” and variable flow. Actual losses were therefore eight times those assumed in the as-built SAP calculations. The situation would not have been any better with the latest version of SAP (SAP 2012) as, although there are improved algorithms to calculate predicted distribution heat loss based on the length of network and heat loss characteristics of the pipework, this requirement does not apply to networks where the only dwellings connected to the network are apartments (BRE 2013).

Table 46 – Calculation of Distribution Losses for Period Nov-12 to Aug-13

Period	Gas Heat Out (kWh)	Biomass Heat Out (kWh)	Total Heat Out (kWh)	Non-Dom Heat In (kWh)	Dwelling Heat In (kWh)	Total Heat In (kWh)	Distribution/ System Losses (%)
Nov-12 to Aug-13	593810	376940	970750	119528	280054	399582	58.8

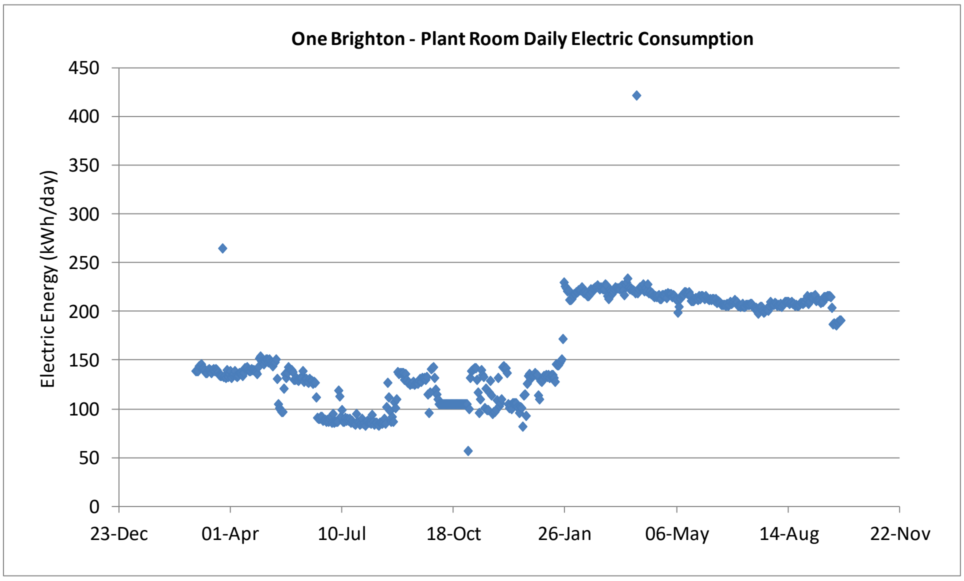
It was not possible to separate out what proportion of the measured distribution losses occurred within the plant room from that which was attributable to losses from the pipes of the district heating network in the apartment blocks. This would have required additional heat meters on the district heating pipework to the two apartment blocks. These would need to be located immediately after the plant room heat exchanger. Losses arising from the heating network would have the potential to provide useful gains during the heating season by reducing heat loss from the dwellings to the nominally unheated communal spaces. However, in the summer, heat losses from the district heating pipework would contribute to the overheating potential of the dwellings. If it assumed that 50% of the distribution losses might contribute to either winter gains or summer overheating in dwellings, this would equate to around 300 W per apartment in the winter and 150 W per apartment in the summer.

The parasitic energy use of the One Brighton plant room for the period November 2012 to August 2013 is given in Table 47. The plant room electricity use over this period equates to 211 kWh/day, which is equivalent to 8.8 kW. The plant room parasitic electricity use for this period was 5.9% as a proportion of total heat output and 14.4% as a proportion of total delivered heat. The plant room electricity use was lower in the early stages of the monitoring period at around 120 kWh/day (see Figure 66). The average plant room electricity use over the whole monitoring period was 160 kWh/day, which would give the parasitic electricity use as 4.5% as a proportion of heat output and 11% as a proportion of delivered heat.

Table 47 – Plant Room Parasitic Electrical Energy

Period	Plant Room Electricity (tonnes)	Total heat output from plant room (kWh)	Total heat delivered (kWh)	Parasitic Electricity as % of Heat Output (%)	Parasitic Electricity as % of Delivered Heat (%)
Nov-12 to Aug-13	57618	970570	399582	5.9	14.4

Figure 66 – Plant Room Daily Electricity Consumption



Comment from Communal Heating designer

Gabriel Gallagher from Sustainable Energy Ltd was sent these findings and provided the following comment below. He has been involved with the communal heating system at One Brighton since Practical Completion, but did not have any involvement with the original design, construction, or commissioning. According to the managing ESCo, he was brought in when it was realised there was a problem with the operation and efficiency of the biomass boiler that was found from reconciling ESCo billing data with energy costs and design parameters. He has designed and overseen some modifications to the system to try to improve its efficiency subsequent to Practical Completion.

"The results on biomass boiler availability and efficiency have not changed significantly over the period since installation. There are a number of reasons, but essentially as you point out it is not meeting design conditions.

I conducted heat loss calculations for the full distribution network around the site and concluded that the total pipework network losses should be (at a flow temp of 77'C and a return of 70'C):

Pipe losses	*23.56*	*kW*
Valve losses	*1.02*	*kW*
Heat loss from ACC tanks	*2.39*	*kW*
Heat loss from HX	*1.00*	*kW*
TOTAL losses	***28***	***kW***
Hours per year	*8760*	
kWh per annum	***206,427***	

This is much less than the approximate 570,000 kWh losses from the period you have measured. This raises a question as to the accuracy of the heat meters in the heat interface units. I was surprised by the figure of mean annual heat demand per apartment of 1799 kWh. I know you stated that this was 25% of other apartments; but even heating 40litres of hot water per day would be about half that figure. Meaning averaged over 200 days and 8 hours per day the mean heat input would be 0.6 kW. So either there is an issue with metering, or apartments are gaining significant input from the risers and horizontal pipe runs through the building."

7.16 Overall Development Energy Use and Carbon Emissions

In order to calculate the carbon emission factor for delivered heat for the development, the carbon emissions factors for the fuels used were taken from SAP 2012 (BRE 2013), as these will be most representative of the monitoring period (see Table 48). The assumptions used in the carbon emission calculations for the various system efficiencies are given in Table 49.

Table 48 – SAP 2012 Carbon Emission Factors (BRE 2013)

Fuel	**Carbon Emission Factor (kgCO_2/kWh)**
Electricity from grid	0.522
Natural gas from grid	0.212
Biomass wood pellets	0.039

Table 49 – Assumptions used in Calculation of Development Carbon Emission Factor for Delivered Heat

Factor	Design Assumption in SAP	Measured Value
Heat from Biomass Boiler (%)	100	34.0
Biomass Boiler Efficiency (%)	85	69.6
Heat from Gas Boilers (%)	0	66.0
Gas Boiler Efficiency (%)	n/a	86.1
Distribution Efficiency (%)	95	41.2
Parasitic Plant Room Electric (% of delivered heat)	0	11.0

Using the design assumptions given in the SAP calculations for the One Brighton dwelling, the calculated carbon emission factor for delivered heat is given in Table 50. This is compared to the carbon emission factor calculated using the measured values. It can be seen that the measured carbon emission factor for delivered heat at 0.50 $kgCO_2/kWh$ is ten times the 0.05 $kgCO_2/kWh$ calculated using the design assumptions. The carbon intensity of heat delivered by individual gas condensing boilers in each apartment would be expected to be of the order 0.24 $kgCO_2/kWh$ (allowing for a system efficiency of the gas boiler of 87%) and is therefore half the measured emissions of the communal system at One Brighton.

Table 50 – Carbon Emission Factor for Delivered Heat

Carbon Emission Factor	Using Design Assumptions in SAP Calculation ($kgCO_2/kWh$)	Using Measured Values ($kgCO_2/kWh$)
Carbon emission factor due to boilers and distribution (%)	0.05	0.44
Carbon emission factor due to plant room electricity (%)	-	0.06
Total carbon emission factor for delivered heat (%)	0.05	0.50

The graph in Figure 67 shows the monthly delivered energy use for the whole One Brighton development over the period October 2012 to September 2013. The energy consumption is split by end use and includes the offset electricity use based on the predicted energy generated by the photovoltaic panels. The maximum monthly energy use was in March 2013 at just over 140,000 kWh, with the minimum in August 2013 at around 80,000 kWh. The annual energy use for the period October 2012 to September 2013 is given in Table 51. Total delivered energy was 1,290,638 kWh. Energy use was dominated by that for the dwellings, with delivered heat to dwellings at 24.7% of total energy use and electricity use within dwellings at 33.0% of total energy use. It is interesting to note that the electricity used for common areas was 15.3% of total energy use. SAP calculations currently take no account of energy used in common areas, and these results suggest that SAP may therefore be missing a significant area of energy consumption in apartment blocks.

Figure 67 – Monthly Delivered Energy Use for One Brighton Development for Period Oct-12 to Sep-13

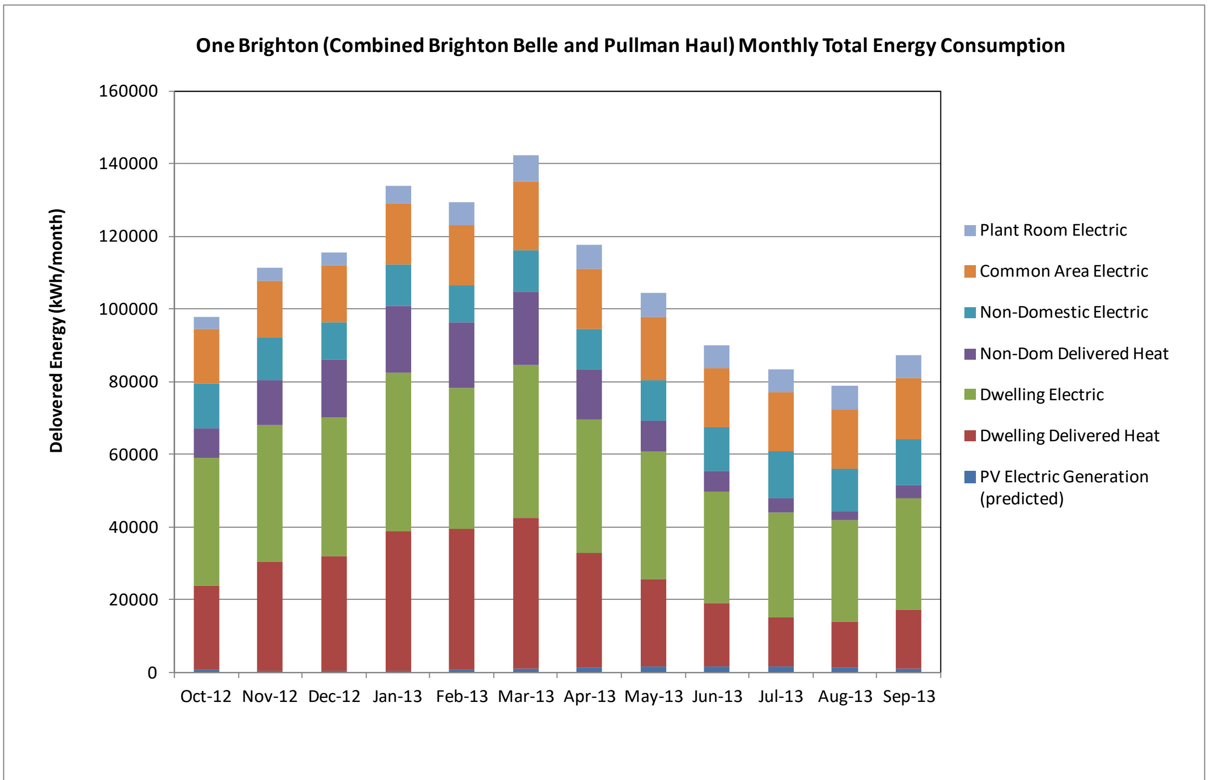


Table 51 – Annual Energy Use for One Brighton Development for Period Oct-12 to Sep-13

	Plant Room Electric	Common Electric	Non-Dom Electric	Non-Dom Heat	Dwelling Electric	Dwelling Heat	Electric Offset by PV	Total Energy
kWh/a	67072	197893	138975	131162	425549	319293	10694	1290638
kWh/m².a	-	-	67.5	63.7	45.8	34.4	-	-
%	5.2	15.3	10.8	10.2	33.0	24.7	0.8	100

The graph in Figure 68 shows the monthly carbon emissions for the whole of the One Brighton development over the period October 2012 to September 2013, with the carbon emissions split by end use. The emissions related to electricity offset by the photovoltaic panels are assumed to be zero. For the purpose of this comparison, the calculations use the measured carbon emission factor of 0.44 $kgCO_2$/kWh for delivered heat excluding the contribution from the plant room electricity, which is treated separately here. Monthly carbon emissions peaked in March 2013 at 69 tonnes CO_2, with a minimum of 39 tonnes of CO_2 in August. The annual carbon emissions for the period October 2102 to September 2013 are given in Table 52. Total measured carbon emissions were 632 tonnes of CO_2 per annum. The amount of carbon offset by the photovoltaic panels would be of the order 5.6 tonnes of CO_2 per annum, which is less than 1% of overall emissions. It is interesting to compare the actual emissions from the development (632 tCO_2/a) with the design expectation for emissions of around 250 tCO_2/a given in the One Brighton sustainability action plan (Bioregional Quintain 2007).

Figure 68 – Measured Monthly Carbon Emissions for One Brighton Development for Period Oct-12 to Sep-13

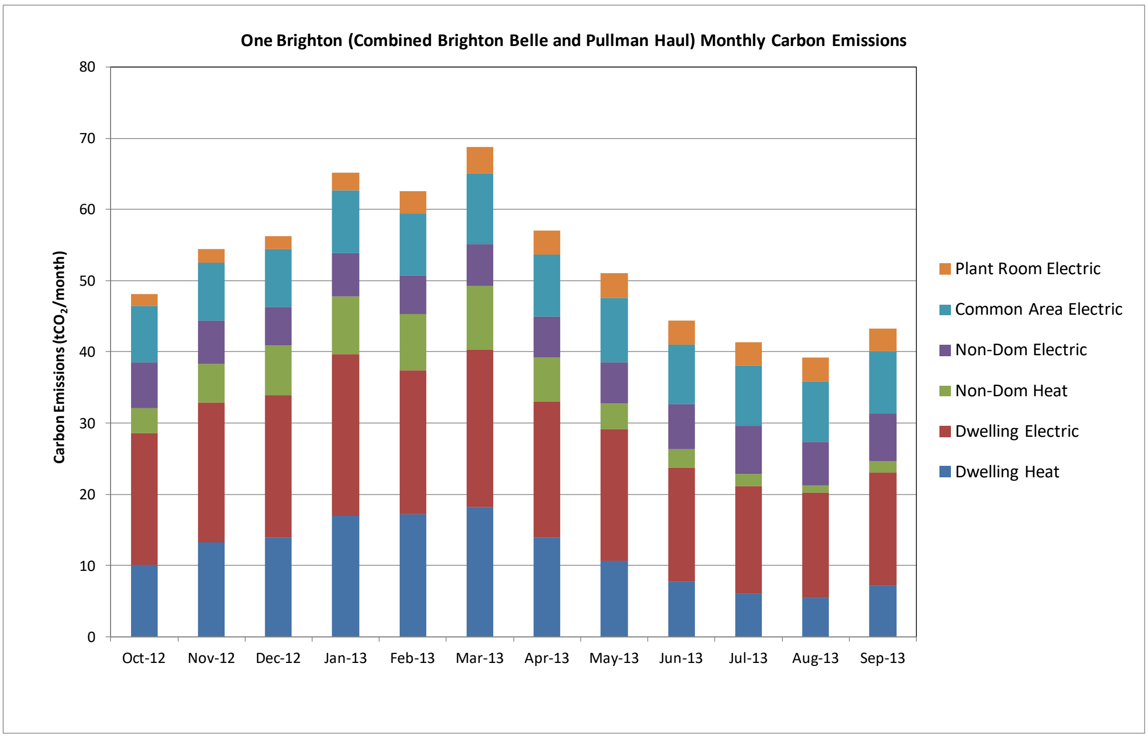


Table 52 – Measured Annual Carbon Emissions for One Brighton Development for Period Oct-12 to Sep-13

	Plant Room Electric	Common Electric	Non-Dom Electric	Non-Dom Heat (excl. plant elec.)	Dwelling Electric	Dwelling Heat (excl. plant elec.)	Total Carbon Emissions
tCO_2/a	35.0	103.3	72.5	57.8	222.1	140.7	631.5
kgCO2/m2.a	-	-	35.2	28.1	23.9	15.2	-
%	5.5	16.4	11.5	9.2	35.2	22.3	100

The measured annual carbon emissions for the dwellings at One Brighton for the period October 2012 to September 2013 are given in Table 53. Total emissions, including that for delivered heat, delivered electricity and the electricity use in the common area, were 485 tonnes of CO_2 per annum, which is an average of 2.82 tonnes of CO_2 per dwelling. The average floor area for the 172 One Brighton dwellings is 54.0 m^2, which would give average carbon emissions per dwelling of 52.2 $kgCO_2/m^2.a$, including the contribution of common area electricity. Excluding the contribution of the common areas, the average carbon emissions per dwelling were 41.0 $kgCO_2/m^2.a$. The calculated dwelling emission rates given in the provided as-built SAP calculations were 9.72 $kgCO_2/m^2.a$ for dwelling F and 9.41 $kgCO_2/m^2.a$ for the Coheating test apartment, although these values only include regulated emissions and would not therefore include emissions for plug-in appliances.

Table 53 – Measured Annual Carbon Emissions for One Brighton Dwellings for Period Oct-12 to Sep-13

	Carbon Emission for All Dwellings (tCO_2/annum)	**Carbon Emissions per Dwelling (tCO_2/annum)**	**Carbon Emissions per Dwelling ($kgCO_2/m^2$.annum)**
Dwelling Heat (including plant room electric)	159.0	0.92	17.1
Dwelling Electricity	222.1	1.29	23.9
Common Area Electricity	103.3	0.60	11.1
Total Energy for Dwellings	484.5	2.82	52.2

In order to estimate the typical actual regulated energy use of the apartments at One Brighton, the measured data on electricity use for appliances in the five monitored apartments were used to account for unregulated electricity. The mean electricity use in the five apartments for unregulated electricity was 12.8 $kgCO_2/m^2.a$. Subtracting this from the average carbon emissions per dwelling for delivered heat and electricity (41.0 $kgCO_2/m^2.a$) gives an average empirical value for regulated emissions for the One Brighton apartments of 28.2 $kgCO_2/m^2.a$. This is around 30% higher than the Part L 2006 compliant TER of 20.8 $kgCO_2/m^2.a$ for apartment A given in the regulatory checklist (see Table 4).

7.17 Monitored Dwelling Carbon Emissions

The annual carbon emissions for delivered energy for the monitored dwellings for the periods February 2012 to January 2013 and October 2012 to September 2013 are given in Table 54 and Table 55 respectively.

Table 54 – Monitored Dwelling Carbon Emissions for Delivered Energy for Period Feb-12 to Jan-13

	Flat A	Flat B	Flat C	Flat D	Flat F	Mean One Brighton
Delivered Heat (tCO_2/a)	0.38	1.56	0.17	0.35	0.90	0.85
Delivered Electric (tCO_2/a)	0.58	1.11	0.75	0.90	1.32	1.29
Total Delivered Energy (tCO_2/a)	0.96	2.66	0.92	1.25	2.22	2.14
Total Delivered Energy ($kgCO_2/m^2.a$)	21.36	59.16	20.44	27.74	49.27	39.63

Table 55 – Monitored Dwelling Carbon Emissions for Delivered Energy for Period Oct-12 to Sep-13

	Flat A	Flat B	Flat C	Flat D	Flat F	Mean One Brighton
Delivered Heat (tCO_2/a)	0.41	1.36	0.21	0.62	0.83	0.93
Delivered Electric (tCO_2/a)	0.62	1.11	0.76	0.93	1.43	1.29
Total Delivered Energy (tCO_2/a)	1.03	2.47	0.96	1.55	2.26	2.22
Total Delivered Energy ($kgCO_2/m^2.a$)	22.78	54.95	21.43	34.38	50.25	41.11

It can be seen that carbon emissions for delivered energy were relatively stable for each dwelling over the monitoring period and ranged from around 21 $kgCO_2/m^2.a$ for dwellings A and C, to between 50 and 60 $kgCO_2/m^2.a$ for dwellings B and F. The mean carbon emissions for delivered energy for all One Brighton dwellings was of the order 41 $kgCO_2/m^2.a$, which is in the middle of the range for the monitored dwellings. The bar chart in Figure 69 shows the carbon emissions for the monitored dwellings in tCO2/a for the period February 2012 to January 2013, split in terms of delivered heat, regulated and unregulated electricity and the apportioned energy relating to electricity use in common areas. The bar chart in Figure 70 shows the same data but as $kgCO_2/m^2.a$. The common area electricity was apportioned by dwelling gross floor area, with a calculated emission factor of 10.2 $kgCO_2/m^2.a$ (this assumes that all common area electricity is attributable to the dwellings only). It should be noted that the scope of SAP explicitly excludes energy use in common areas, and it is assumed that these will be assessed using the procedures for non-domestic buildings.

Figure 69 – Monitored Dwelling Carbon Emissions (tCO_2/a) for All Energy for Period Feb-12 to Jan-13

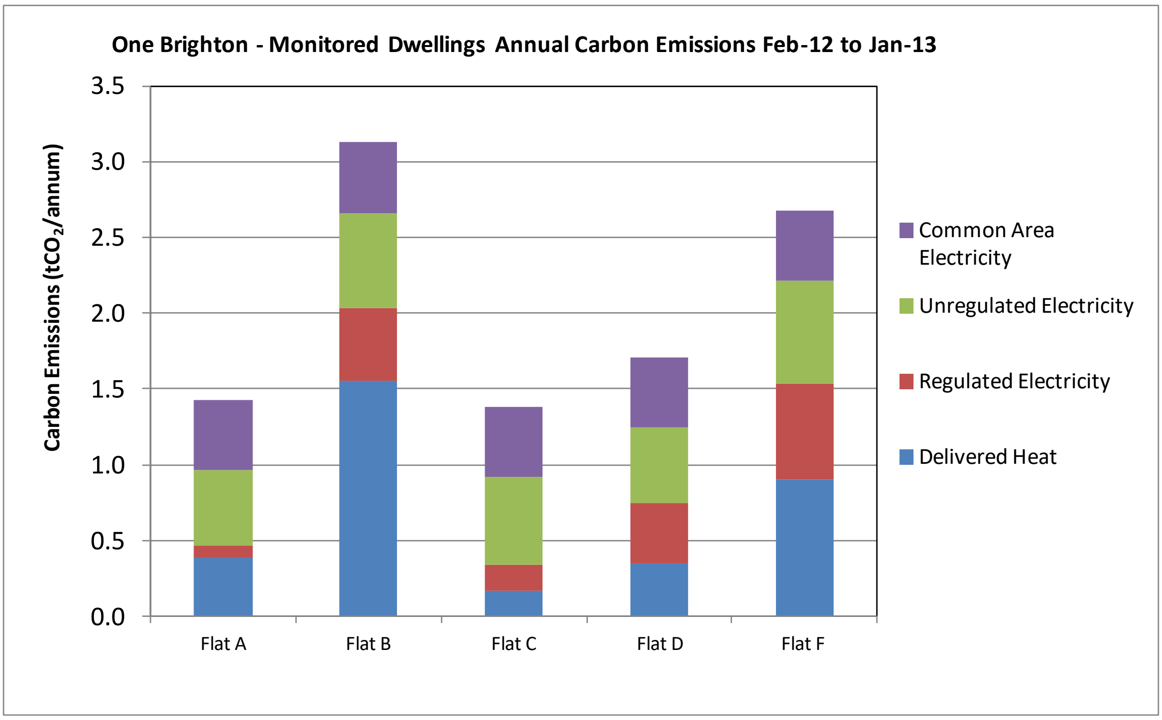
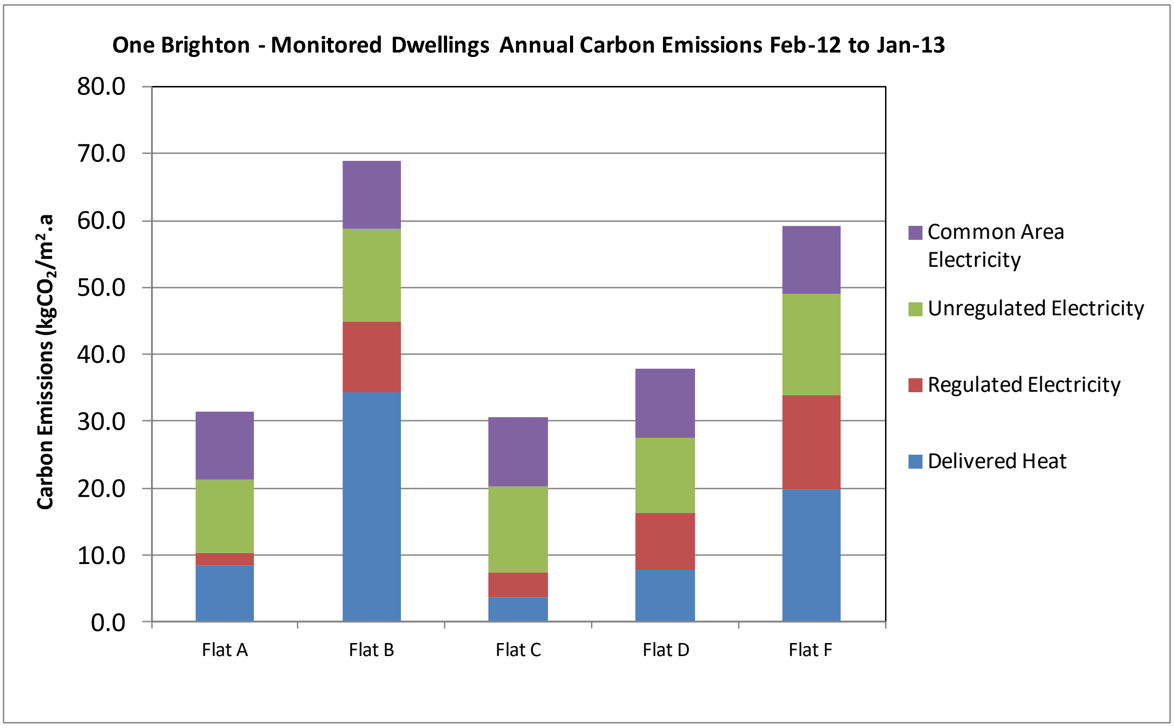


Figure 70 - Monitored Dwelling Carbon Emissions ($kgCO_2/m^2.a$) for All Energy for Period Feb-12 to Jan-13



In Table 56, it can be seen that the carbon emissions for regulated energy (delivered heat, lighting, fans and pumps) ranged from between 7.5 $kgCO_2/m^2.a$ for dwelling C up to 45.2 $kgCO_2/m^2.a$ for dwelling B. These values can be directly compared to the value of 9.7 $kgCO_2/m^2.a$ given as the dwelling emission rate in the as-built SAP calculation for dwelling

F. Even allowing for differences in heat demand due to the actual weather and occupancy, the measured carbon emission rates for dwellings D, B and F are significantly higher than that calculated in SAP. This is mostly a direct effect of the high carbon intensity of delivered heat as measured compared to that assumed in SAP. The overall carbon emissions of the monitored apartments will include the emissions due to regulated energy, un-regulated appliance energy and energy relating to the common areas. Taking all these factors into account gives a range of carbon emissions for the period of between 30.7 $kgCO_2/m^2.a$ for dwelling C up to 69.4 $kgCO_2/m^2.a$ for dwelling B. In absolute terms, this is between 1.38 tonnes of CO_2 per annum for dwelling C up to 3.12 tonnes of CO_2 per annum for dwelling B. There is clearly a considerable mismatch between the stated aspirational carbon performance of One Brighton as a zero carbon development in design terms, and that of the development as it is actually performing.

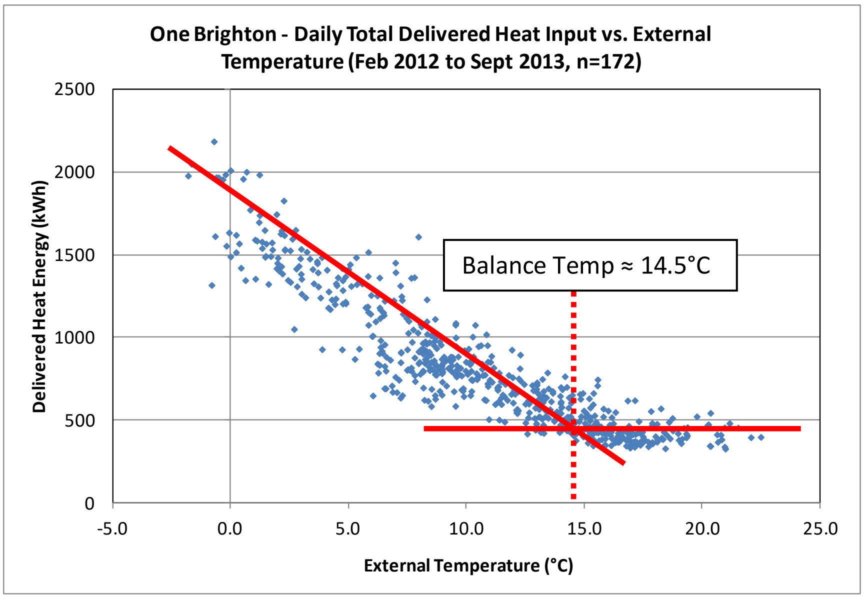
Table 56 – Monitored Dwellings Carbon Emissions for All Energy for Period Feb-12 to Jan-13

	Flat A	**Flat B**	**Flat C**	**Flat D**	**Flat F**
Carbon Emissions for Regulated Delivered Heat (tCO_2/a)	0.38	1.56	0.17	0.35	0.90
Carbon Emissions for Regulated Electric (tCO_2/a)	0.09	0.48	0.17	0.39	0.64
Carbon Emissions for Un-regulated Electric (tCO_2/a)	0.49	0.63	0.58	0.50	0.68
Carbon Emissions for Common Area Electric (tCO_2/a)	0.46	0.46	0.46	0.46	0.46
Carbon Emissions for Regulated Energy (tCO_2/a)	0.47	2.03	0.34	0.74	1.53
Carbon Emissions for Regulated Energy ($kgCO_2/m^2.a$)	10.42	45.20	7.46	16.53	34.09
Carbon Emissions for All Energy (tCO_2/a)	1.42	3.12	1.38	1.71	2.68
Carbon Emissions for All Energy ($kgCO_2/m^2.a$)	31.60	69.40	30.68	37.98	59.51

7.18 Average Dwelling Heat Loss Coefficient

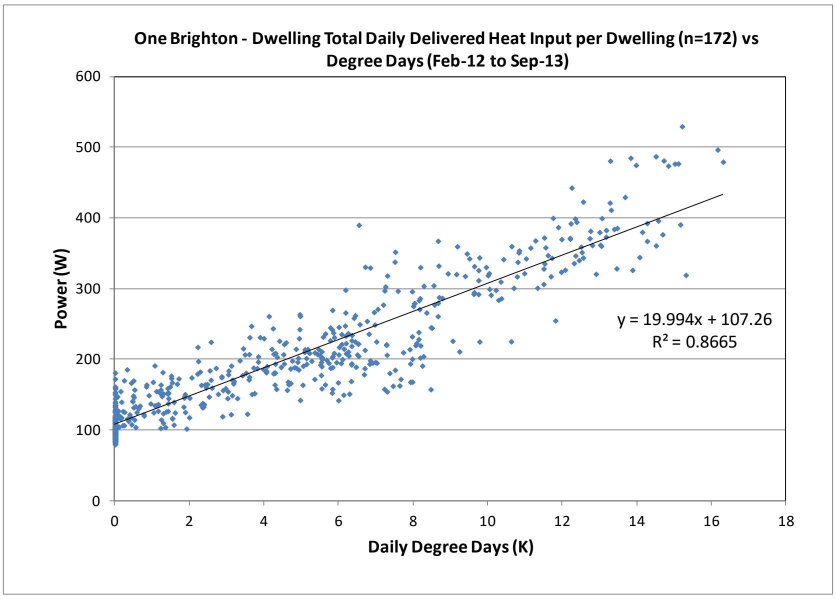
A plot of total daily heat input to the One Brighton dwellings versus mean external temperature over the monitoring period is shown in Figure 71. The average balance temperature for all dwellings can be approximated from the data by determining the crossing point between a fitted line for the heating response and the average summer base load for hot water. This gives a balance temperature of the order of 14.5°C.

Figure 71 – Plot of Total Daily Heat Input to One Brighton Dwellings vs. External Temperature



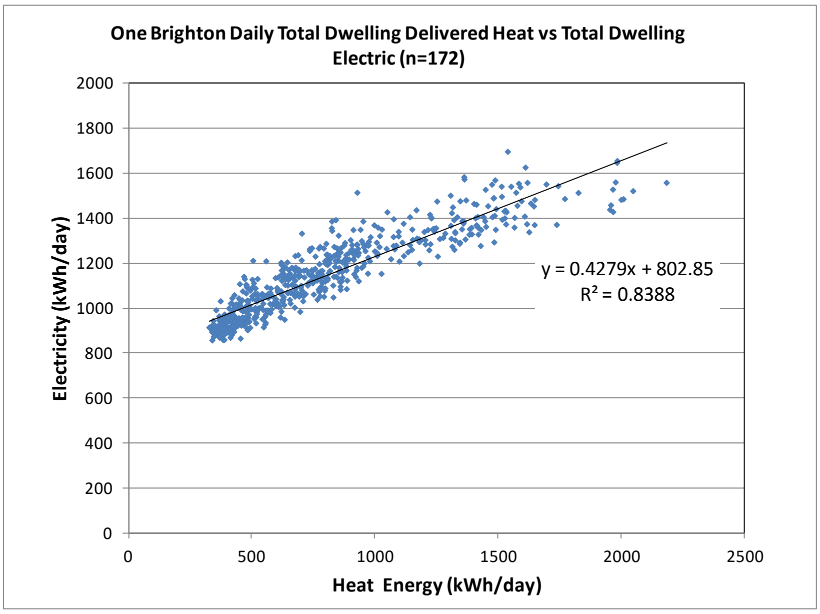
Using the balance temperature of 14.5°C, the space heat demand in heating degree days for each day of the monitoring period can be calculated as the difference between the balance temperature and the mean external temperature. The daily degree days in Kelvin can then be plotted against total dwelling heat input in Watts as shown in Figure 72. The slope of the fitted line at 20.0 W/K is the apparent mean heat loss coefficient with respect to communal heat input only. The intercept at 107 W is the mean daily demand per dwelling for hot water.

Figure 72 – Mean Dwelling Daily Heat Input vs. Daily Degree Days at 14.5°C Base



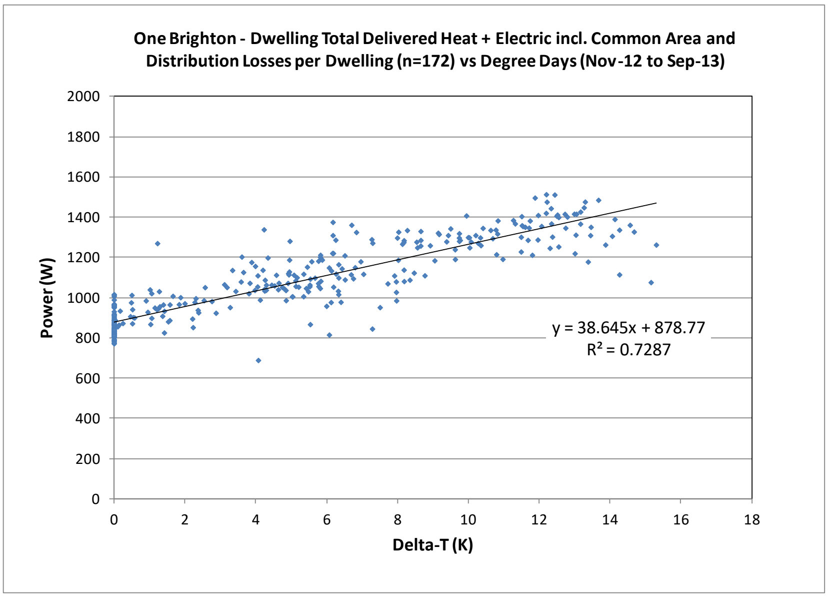
The apparent heat loss coefficient calculated by the relationship between communal heating input and external temperature in Figure 72 will not give a true indication of heat loss from the dwellings. This is because the calculation does not take into account differences in gains over the year from electricity use in the dwelling, communal electricity and losses from the district heating system. There is a strong linear relationship between communal heat input and dwelling electricity use as illustrated by the graph in Figure 73 showing that electricity is likely to have an impact on the calculated heat loss coefficient.

Figure 73 – Daily Total Communal Heat Input to Dwellings vs. Total Dwelling Electricity Consumption



The graph in Figure 74 shows the daily degree days plotted against the maximum potential energy input to the dwelling including delivered heat, electricity and distribution losses. The slope of the fitted line gives the heat loss coefficient as 38.6 W/K. The mean heat loss coefficient for the One Brighton dwellings will therefore lie between 20 and 39 W/K.

Figure 74 – Daily Total Energy (Dwelling Delivered Communal Heat, Dwelling Electricity, Distribution Losses, Common Area Electricity) vs. Daily Degree Days at 14.5°C Base



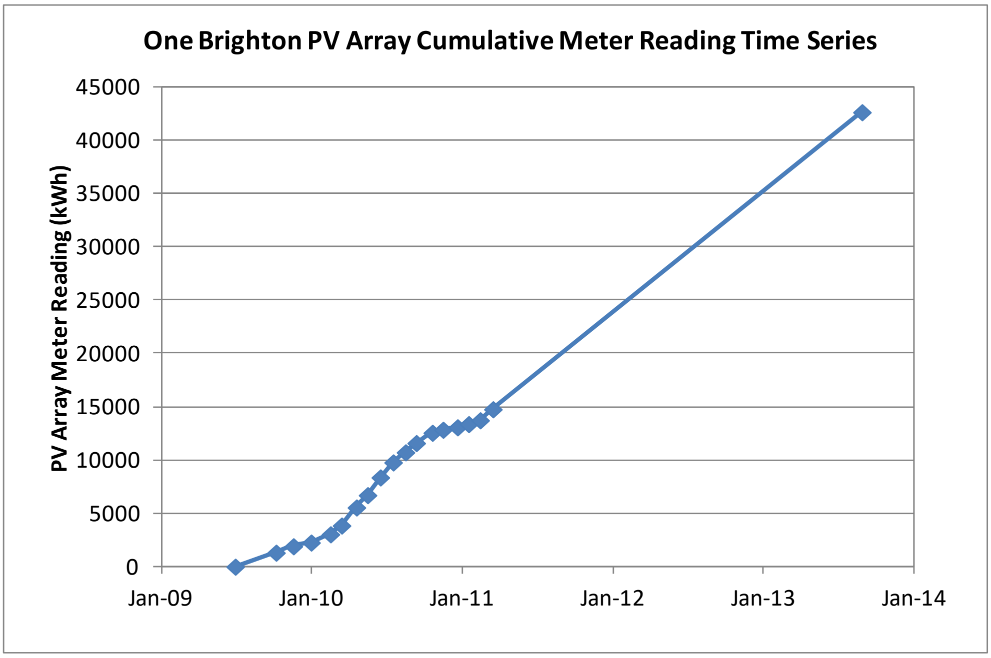
7.19 Performance of Photovoltaic Panels

The photovoltaic (PV) panel array at One Brighton consists of 52 Sharp NU 180 modules. These are fitted to the roof of the Pullman Haul building (see Figure 75), and are oriented due south with a tilt angle of 45°. The modules are monocrystalline silicon with a nominal output of 180 Wp per module, giving a total design output for the array of 9.36 kWp. The panels are all 1.318 m x 0.994 m in size, giving a total area for the array of 68.1 m^2. The panels are linked to the private wire system for the development via three Fronius IG30 inverters, with 3 kWh meters recording the output from the array. The kWh meters were not connected to any datalogging devices, so the performance of the system has been assessed using a series of monthly manual meter readings taken in the early years of the development (October 2009 to April 2011), together with final manual readings taken in September 2013.

Figure 75 – PV Array on Roof of Pullman Haul Building at One Brighton

The meter reading data will give the long term performance for the array over a period of four years between July 2009 and September 2013 as shown by the graph in Figure 76. The mean annual yield of the PV array over this period was 10,252 kWh/a. The expected yield for the PV array at One Brighton was calculated using the algorithms given in Appendix M of SAP 2012 (BRE 2013). The SAP algorithm uses regional data for typical solar radiation, together with the characteristics of the array in terms of peak output, tilt angle, orientation and overshading. For the purposes of the calculation, it was assumed that there was little or no overshading. The SAP algorithm gives a predicted annual output for the array of 10,694 kWh/a based on data for the South East region. This is reasonably consistent with the measured long term average, indicating that the panels are performing well. It should also be pointed out that the output from the PV array will all be consumed by the base electrical load of the buildings, with none being exported to the grid.

Figure 76 – Time Series Plot of Cumulative PV Array kWh Meter Readings



7.20 Performance of MVHR System

The performance of the MVHR systems was assessed using the measured temperature of the air in the supply and extract ducts. The graphs in Figure 77 and Figure 78 show the monthly mean temperature for the MVHR supply and extract ducts for all five monitored dwellings. Winter time supply temperatures were between 15 and 35° higher than the external temperature, with the highest mean supply temperatures in dwelling B at 40°C. The highest mean extract temperatures were in summer for dwelling F at around 30°C.

Figure 77 – Monthly Mean MVHR Supply Air Temperature for Period Feb-12 to Sep-13

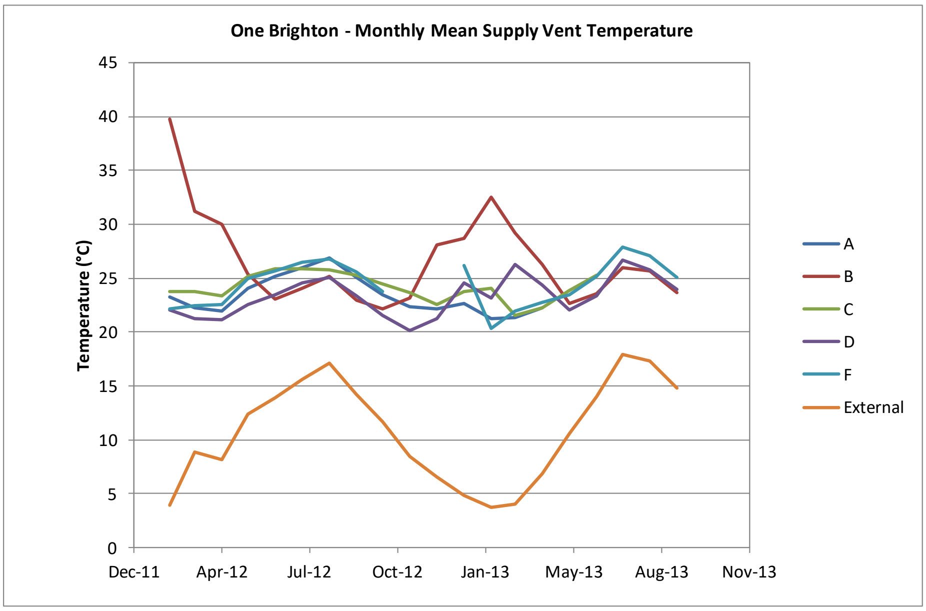
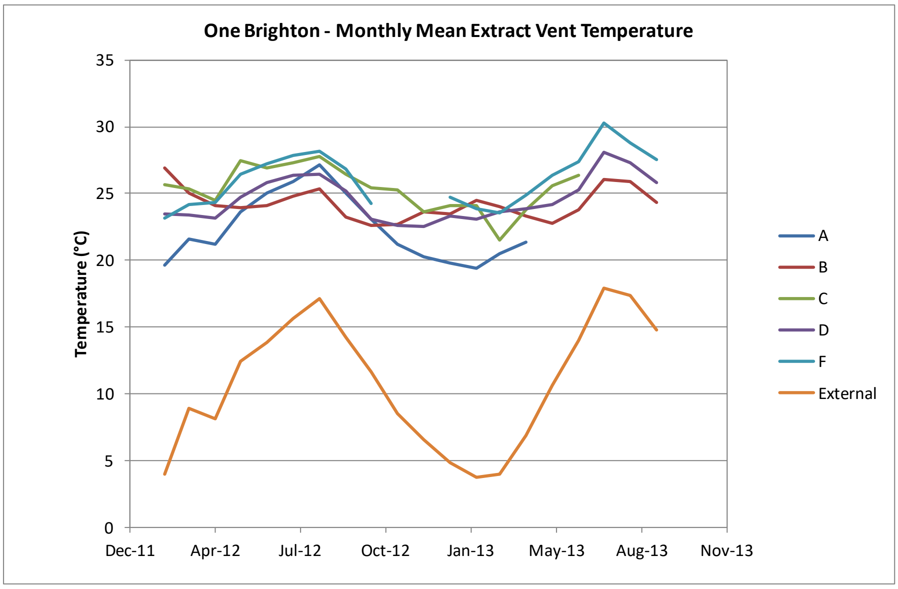
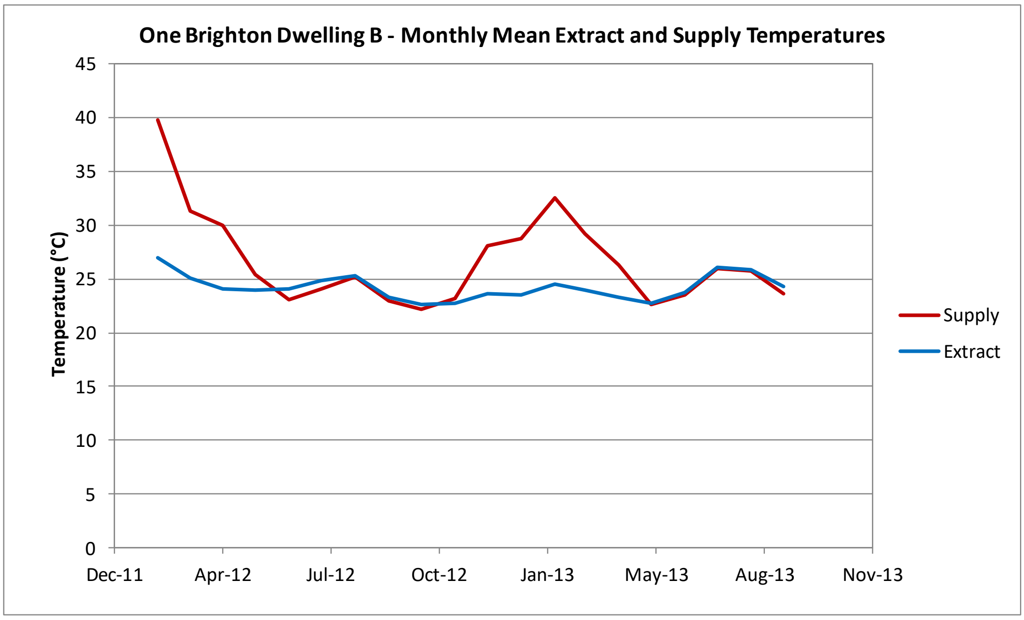


Figure 78 – Monthly Mean MVHR Extract Air Temperature for Period Feb-12 to Sep-13



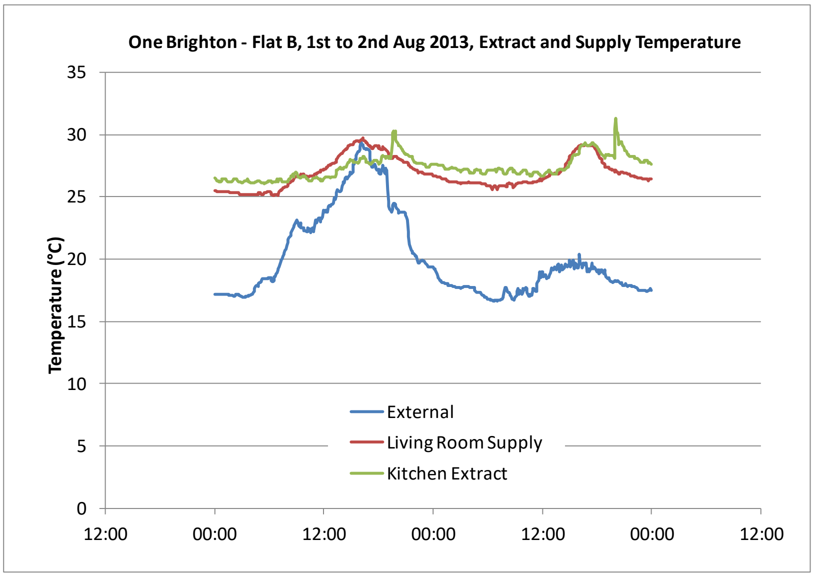
A comparison of monthly mean extract and supply temperatures is shown in Figure 79 for dwelling B. It can be seen that in winter, the supply temperature is higher than the extract temperature, with the maximum difference occurring in February 2012 at 13°C. These data show that the MVHR fan is operational in dwelling B and that the heater matrix is supplying heat to the incoming air. Conversely, in summer, there is very little difference between extract and supply temperatures indicating that the MVHR fan is operational with the heater matrix off, but that the automatic summer bypass is not functioning as expected. Under normal operation, the supply air would be expected to be less than the extract air due to the effect of free overnight cooling with external air.

Figure 79 – Dwelling B Monthly Mean Supply and Extract Temperatures



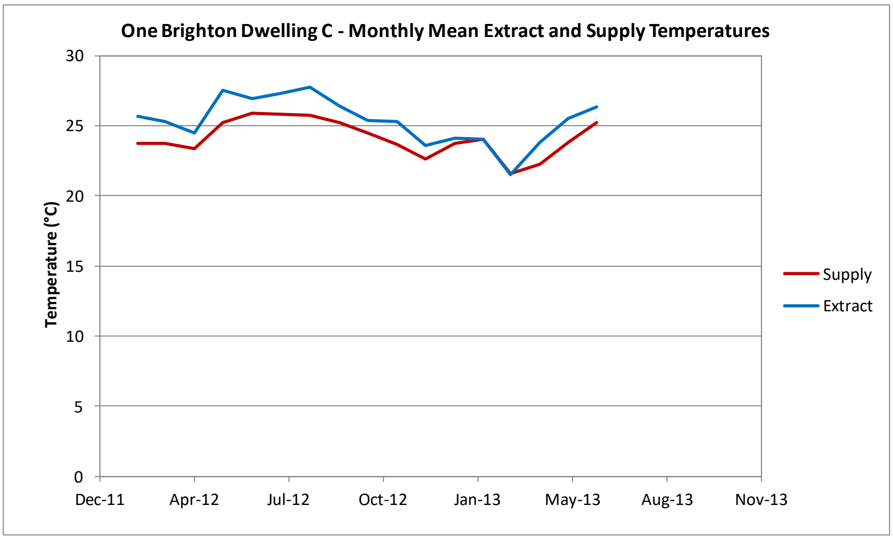
The graph in Figure 80 shows the 5-minute temperature data for the living room supply and kitchen extract in dwelling C for the 1st August 2013, when the external temperature peaked at 29°C. It can be seen that, when the external temperature dropped to around 17°C overnight, the supply temperature remained high, indicating that the automatic summer bypass dampers in the MVHR unit are not operating to take advantage of free-cooling. The operation of the MVHR system should be checked by the building manager.

Figure 80 – Dwelling B 5 minute Extract and Supply Temperatures for 1st to 2nd August 2013



A comparison of monthly mean extract and supply temperatures is shown in Figure 81 for dwelling C. It can be seen that, in winter, the supply temperature is generally lower than the extract temperature. These data indicate that the MVHR unit and heater matrix are likely to be turned off, which is consistent with the low measured energy consumption of the MVHR unit in dwelling C (see Table 37).

Figure 81 – Dwelling C Monthly Mean Supply and Extract Temperatures



The efficiency of the MVHR heat exchanger is determined by the formula in Equation 1.

Equation 1

$$\eta = [m_s.(T_s - T_o)]/[m_e.(T_e - T_0)]$$

η = heat exchanger efficiency
m_s = flow rate of supply air
m_e = flow rate of extract air
T_s = temperature of supply air (after heat exchanger)
T_e = temperature of extract air (before heat exchanger)
T_0 = temperature of incoming outside air (before heat changer)

The apparent efficiencies of the MVHR heat exchangers in the monitored houses were calculated using Equation 1, with the assumption that supply and extract flow rates were the same. The data in Table 57 show the mean monthly apparent heat exchanger efficiencies for the period February 2012 to August 2012. In the case of dwellings A and C, these data are meaningless due to the fact that the MHVR fan is probably switched off for most of the year. For dwelling B, the values of apparent exchanger efficiency are greater than 1.0 in the winter, which is a result of the heater matrix in operation. The spring and autumn data for dwellings D and F are likely to be representative of the real efficiency of the heat exchanger, for periods when the space heating is known to be off. This gives a range of efficiency of the order 0.80 to 0.90 (data in bold in Table 57). This is higher than the manufacturer's quoted efficiency of 0.70.

Table 57 – Apparent Heat Exchanger Efficiencies for Monitored Dwellings

Month	Flat A	Flat B	Flat C	Flat D	Flat F
Feb-12	1.23	1.56	0.91	0.93	0.94
Mar-12	1.06	1.38	0.90	0.85	0.89
Apr-12	1.06	1.37	0.93	0.86	0.89
May-12	1.04	1.13	0.85	**0.82**	**0.90**
Jun-12	1.01	0.90	0.92	**0.80**	**0.88**
Jul-12	1.00	0.92	0.87	0.83	0.89
Aug-12	0.98	0.98	0.81	0.85	0.87
Sep-13	1.00	0.97	0.90	**0.83**	**0.90**

It would seem unlikely that a heat exchanger will perform better than the manufacturer's specification under normal conditions. It can therefore be concluded that the performance of the system is being affected by the temperature of the incoming air. Examination of the MVHR systems has shown that there were long runs of un-insulated duct work between the air intake and the MVHR unit. There is also a possibility of the exhaust air being re-circulated back into the air intake. These factors will mean that the temperature of the intake air will likely be raised above the external air temperature before the incoming air reaches the MVHR heat exchanger. Part of the problem here is that the set-up of the monitoring equipment used to measure the air flow temperatures was not ideal. A better monitoring solution would have been to have temperature sensors positioned in all 4 ducts leading to the MVHR heat exchanger. These sensors would need to have been located as close as possible to the MVHR unit to eliminate the effects of increased air intake temperature or heating of the supply air by the heater matrix. However, such an approach to the measurement of heat exchanger efficiency is not always possible due to limitations on access to the MVHR unit and ducting, and the need to create holes in the ducts for the sensors.

7.21 Energy Costs

All energy to One Brighton is supplied by the One Brighton Energy Services Company (OBES). The annual cost of energy for One Brighton residents for 2012 was 5.20 p/kWh for delivered heat and 9.06 p/kWh of electricity. OBES also charge an annual service charge based on the size of the apartment which covers the cost of management and maintenance of the communal heating network. This includes the cost of maintaining and replacing the heat interface units in the apartments. The annual OBES service charge for the monitored apartments for 2012 was £1.45 per day, giving a total charge of £530 per annum. The total energy costs for 2012 for the monitored apartments are given in Table 58, with an average total bill of £799 (based on measured data for the period February 2012 to January 2013).

Table 58 – Annual Energy Costs for Monitored Apartments for 2012 (base on data for Feb-12 to Jan-13)

	Dwelling A	**Dwelling B**	**Dwelling C**	**Dwelling D**	**Dwelling F**
Electricity (£/a)	£100.25	£191.81	£130.68	£155.67	£228.75
Heat (£/a)	£39.88	£161.88	£17.32	£36.50	£93.44
Standing Charge (£/a)	£530.09	£530.09	£530.09	£530.09	£530.09
VAT at 5% (£/a)	£33.51	£44.19	£33.90	£36.11	£42.61
Total (£/a)	£703.73	£927.96	£711.99	£758.38	£894.90

Total energy costs for the monitored apartments ranged from a low of £704 for dwelling A to a high of £928 for dwelling B. These compare to the average annual energy costs for a typical UK dwelling with gas and standard electricity of £1,279 (see Table 59, DECC 2013b). The direct energy costs for the monitored One Brighton apartments are therefore around 40% cheaper than the average UK gas-heated dwelling. However, this comparison does not take into account of the fact that the One Brighton energy costs also allow for the maintenance and replacement of the HIU. After including a nominal cost of £250 per annum for gas boiler maintenance and replacement, this increases the annual costs for a typical UK gas-heated dwelling to £1,529. This gives a more realistic difference in energy costs between the monitored One Brighton dwellings and a typical UK gas-heated dwelling of the order 50% lower.

Table 59 – Average UK Domestic Gas and Standard Electricity Bill for 2012 (DECC 2013b)

	UK Average Bill (£/a)
Standard Electricity	£479.00
Gas	£800.00
Total	£1,279.00

7.22 Conclusions and key findings for this section

The median annual consumption of delivered heat energy for the One Brighton dwellings over the monitoring period of February 2012 to September 2103 was 1,632 kWh. This compares to the median annual gas consumption for purpose built apartments in the UK of between 7,100 kWh to 7,800 kWh for the years 2009 to 2011 (DECC 2013a). The median gas consumption of purpose built apartments constructed since 1999 ranged between 6,200 kWh and 6,600 kWh for the years 2009 to 2011 (DECC 2013a). The delivered energy consumption for heating and hot water for the One Brighton dwellings is therefore around 20% of that for a typical UK apartment. This demonstrates the impact of the high performance building fabric at One Brighton when compared to the building stock. The headline performance for delivered energy at One Brighton is however slightly flattering, as the heat energy consumption for the dwellings is partly offset by gains arising from losses from the distribution network and the electrical energy required to run the MVHR heating system. Calculations of the mean heat loss coefficient of the One Brighton dwellings indicate the maximum potential effect of the gains would be to double the heat loss compared to that calculated using delivered heat only. So the actual heat requirement of the average One Brighton dwelling is likely to be of the order 2,000 kWh after allowing for a factor to account for the usefulness of the gains. This is still well below the gas consumption of a typical UK apartment.

The heat energy consumption of the five monitored households was very different. Two of the dwellings had very low consumption with annual delivered heat in the range 700 to 800 kWh, split roughly evenly between heating and hot water. The highest consumption of the five monitored households was 3,100 kWh per annum, 2,600 kWh of which was for space heating. These compare to the median delivered heat consumption of the development of 1,632 kWh and the maximum of around 6,700 kWh. The mean internal temperatures for the five monitored dwellings in the heating season ranged from 20°C to 23°C, so it is clear that the dwellings with low heat input are not being under-heated. If anything, the internal winter temperatures are higher than those measured in recent studies of UK dwellings. The implication therefore is that there is a certain amount of heat sharing between adjacent apartments at One Brighton, with some dwellings being partly heated by gains across party elements. This sort of variation is typical in apartment blocks.

It is not known how representative the internal temperatures of the monitored dwellings are of the One Brighton development as a whole. However, the indications from this study are that residents of low energy dwellings are likely to live at higher temperatures in the heating season than existing models assume. For example, the assumption in SAP is that the mean internal temperature for the One Brighton dwellings is 19.5°C compared to the measured average for the monitored apartments of 21.7°C. There are implications for national energy policy and regulatory targets if occupants of low energy buildings tend to live at higher temperatures than modelled assumptions.

The median annual consumption of electricity for the One Brighton dwellings over the monitoring period of February 2012 to September 2103 was 2,312 kWh. This compares to the median electricity consumption for purpose built apartments in the UK of between 2,500 kWh for the years 2009 to 2011 (DECC 2013a). There is therefore not much difference in electricity consumption patterns between One Brighton and a typical apartment in the UK. This is perhaps to be expected as electricity use is to a large extent dominated by appliance use and user behaviour rather than the attributes of the dwelling.

Analysis of the electricity use in the monitored dwellings showed that, for the three households that used the MVHR system as designed, around 40% of total electricity use was for the MVHR system, with annual electricity for the MVHR system ranging from 635 kWh to 854 kWh. This high level of electricity use is a result of the high flow rates needed to run the MVHR system in heating mode coupled with very poor specific fan power of between 3.5 W/l/s to 6 W/l/s. Two of the monitored households had the MVHR system switched off for the majority of the time, but even then the standby electricity use for the MVHR unit was of the order 140 kWh per annum. It is likely that the dwellings at One Brighton would have been better served in energy use terms if heating had been provided using a traditional wet heating system with radiators in combination with a more conventional MVHR system, or a continuous mechanical extract (MEV) system. Where the supply chain lacks experience, the simplification that would result from decoupling heating and ventilation might well improve overall performance.

Electricity use for fixed lighting in the monitored apartments ranged from a low of 22 kWh per annum (0.5 kWh/m^2.a) to 364 kWh per annum (8.0 kWh/m^2.a). The DOMEARM benchmark for typical UK dwelling lighting energy use is 8.3 kWh/m^2.a and that for Code 4 and Code 6 dwellings is 5.5 kWh/m^2.a. So lighting use at One Brighton varies from the UK norm to less than that for a Code 6 dwelling. However, it is known that the occupants of the dwellings with low energy use for fixed lighting at One Brighton actually used plug-in light fittings in preference to the fixed lighting. This demonstrates how difficult it can be to make sense of disaggregated electricity data without the right contextual information. It would only really be possible to make valid comparisons against benchmarks with sub-metered data from a much bigger sample of dwellings.

Measured carbon emissions for the One Brighton development were significantly higher than expected in terms of the design calculations. Annual emissions from the whole development including both domestic and non-domestic areas were of the order 630 tCO_2/a, which is around 2 ½ times the design expectation for emissions of 250 tCO_2/a given in the One Brighton sustainability action plan (Bioregional Quintain 2007). The main reason behind this discrepancy is that the carbon emission factor for delivered heat was of the order 0.5 $kgCO_2$/kWh, which is 10x the 0.05 $kgCO_2$/kWh assumed in the design calculations. Underlying the high carbon emission factor is the excessive use of the more carbon intensive gas boiler rather than the biomass boiler to provide heat to the communal heating system. Over the monitoring period the biomass boiler was utilised for only 34% of heat output from the communal plant. In addition, the efficiency of the biomass boiler when it was operating was only 70% compared to the 85% assumed in the energy calculations, and the distribution losses were relatively high at 59%.

Carbon emissions for regulated energy from the monitored dwellings ranged from 8 $kgCO_2/m^2$.a to 45 $kgCO_2/m^2$.a. This compares to a calculated dwelling emission rate of around 10 $kgCO_2/m^2$.a given in the as-built SAP calculation. Overall carbon emissions for the monitored dwellings including un-regulated electricity use for appliances and apportioned common area electricity were between 31 $kgCO_2/m^2$.a and 69 $kgCO_2/m^2$.a. This compares to the original design target for the development of 25 $kgCO_2/m^2$ per annum (Table 1). In absolute terms, the measured emissions are between 1.4 tonnes of CO_2 per annum and 3.1 tonnes of CO_2 per annum. There is clearly a considerable mismatch between the stated aspirational carbon performance of One Brighton as a zero carbon development in design terms, and that of the development as it is actually performing.

Summertime overheating was found to be a significant issue for the dwellings at One Brighton. The annual overheating rates in the bedrooms of the monitored dwellings went from 4% of hours to 29% of hours during which the temperature exceeded 26°C. This compares to the maximum 1% of time above 26°C recommended by CIBSE (CIBSE 2006). The differences in overheating rates between dwellings suggest occupants are using different ventilation strategies.

Measurements of relative humidity and carbon dioxide concentration indicate that the internal air of the monitored One Brighton dwellings varied from satisfactory to poor. We note that scientific understanding of indoor air pollution and particularly of CO_2 is ongoing. Mean monthly CO_2 levels in the bedrooms were above 800 ppm in four out of the five dwellings during the winter. In one of the dwellings, CO_2 concentration exceeded 1000 ppm for 50% of the time in December, January and February – but the ventilation system for this dwelling appeared to have been switched off for most or all of this period. Average CO_2 concentration over the whole year ranged from 575 ppm to 831 ppm. It two of the dwellings, relative humidity fell below the CIBSE recommended 40%RH threshold for between 30% and 40% of the year. The underlying causes of the poor air quality are unknown, but are likely to be related to high internal temperatures, combined with the fresh air provided by the ventilation system, and occupant behaviour. It is recommended that further investigations are carried out to determine the causes of poor air quality and to investigate measures to improve performance.

The performance of the roof-mounted photovoltaic array was within expectations, with electricity generation averaging 10,252 kWh per annum over a four year period. Total electricity consumption for the One Brighton development over the monitoring period was 840,183 kWh per annum, including that for domestic and non-domestic use. Electricity generated by the PV array therefore offset a relatively modest 1.3% of the total electricity demand. This compares to the aspirational design target of 5% of electricity demand.

8 Key messages for the client, owner and occupier

Technology Strategy Board guidance on section requirements:	This section should investigate the main findings and draw out the key messages for communication to the client / developer and the building owner / occupier. Drawing from the findings of the rest of the report, specifically required are: a summary of points raised in discussion with team members; recommendations for improving pre and post handover processes; a summary of lessons learned: things to do, things to avoid, and things requiring further attention/study. Try to use layman's terms where possible so that the messages are understood correctly and so are more likely to be acted upon.

8.1 Summer Overheating

Measurements showed that summer overheating in the bedrooms of the monitored dwellings at One Brighton is an issue. This was unexpected as the installed MVHR systems were equipped with a high flow rate free-cooling mode which, in combination with an automatic summer bypass, exposed thermal mass and night purging, should have been able to provide sufficient cooling to minimise the overheating risk. The exact causes of the overheating at One Brighton are not fully understood. However, it is known that issues with the MVHR system will have reduced the potential of the ventilation system to minimise overheating. Overheating will also be related to occupant behaviour (e.g. window opening, incidental gains from appliance use and the use of curtains for shading) and gains arising from losses from the communal heating pipework. It is recommended that further work be carried out to assess the incidence of overheating in other dwellings on the development and to check the operation of controls for the summer bypass mechanism. It is also suggested that residents be provided with additional advice on simple measures that can be implemented to reduce overheating potential.

In our view, One Brighton would be at risk of serious overheating in a heat wave such as occurred in August 2003. We would suggest that the current landlord prepare a plan to deal with such an eventuality. Technical solutions to addressing the problem might range from turning off the communal heating in severe heat waves, to the installation of external blinds or other forms of shading. However, as the joint venture company formed by the two developers of One Brighton has been dissolved following project completion, it is unclear as to who would take responsibility for this.

8.2 MVHR installations

The MVHR systems in the studied apartments at One Brighton were found to be poorly functioning and with a range of system issues evident. The residents also complained about the usability of the controls and that it was difficult to change the MVHR filters. The impact of all these issues will be to reduce the efficiency of the system, both in terms of the effectiveness of the heat exchanger and in the ability of the system to deliver heat in the winter and provide free-cooling in the summer. It is recommended that inspections of all the MVHR systems at One Brighton are carried out as a matter of urgency. These inspections should include measurements of MVHR flow rates and checks of the condition of ducting, duct connections, air valves, controls and MVHR filters. Where necessary, flow rates would be adjusted so that they match the design values. Residents should be provided with better information and support in the effective operation of the MVHR systems. This may include for example advice on the frequency of filter changes and cleaning of air valves. Some issues were directly related to the design of the system and would be difficult to rectify without physical changes to the installation. For example, in the monitored dwellings, the kitchen air valve is located too close to the cooker hob. However, it would be disruptive and costly to move the valve to a better location, so a better option may be to improve the performance of the re-circulating hob extractor.

8.3 MVHR maintenance

Dirty filters and air valves were found to significantly reduce air flow, especially for the extract sides, for which the filters were more clogged. Regular maintenance of these systems is absolutely vital to their proper operation. As such it is imperative that emphasis is placed during the design and construction process to make access for maintenance as easy for the occupant as possible. Occupants also need greater system feedback – for example something similar to a ‘check engine’ light on the main controller could possibly be effective to alert occupants that filters need changing.

More effective maintenance contracts need to be explored further. Residents were offered filter changing services but were still found to be unsatisfied with this aspect of the system. It may be advantageous in future designs to enable access to the system from within a communal area.

8.4 Reliability of Biomass Boiler

The plant room monitoring data showed that the contribution of the biomass boiler to overall communal heat output was around 30%, with the remainder being provided by the back-up gas-fired boiler. This had a significant impact on the carbon emissions related to heat delivered by the communal heating network. It is known that some of the early issues with the biomass boiler related to the wood chip fuel used initially. To address these problems, the fuel was switched to wood pellets shortly after the development was complete. However, despite these changes, there have continued to be reliability issues with the biomass boiler. If the development is to meet its environmental targets in terms of carbon emissions, it is critical that these problems are resolved.

8.5 Energy Costs and Service Charges

Many residents in interviews and BUS survey responses expressed concerns about the cost of delivered energy, standing charges and service charges. Comparisons of average energy costs at One Brighton show that typical annual energy bills were actually around half of that for a typical gas-heated dwelling in the UK after taking into account the costs of boiler replacement and maintenance. Issues around costs at One Brighton may therefore be related more to expectation and a lack of understanding as to what the various charges relate to. It is therefore suggested that the ESCo, social landlord and building management company could do more to explain to the residents what is included in their bills.

8.6 Measured Performance versus Design Expectation

The measured performance of the One Brighton dwellings showed that they compared favourably with the design target in terms of delivered heat energy. The mean delivered communal heat to all One Brighton dwellings for the year October 2012 to September 2013 was 34.4 kWh/m^2.a versus the design target for space heating and domestic hot water of 75 kWh/m^2.a. The mean electrical consumption for the One Brighton dwellings (excluding communal areas) was 45.8 kWh/m^2.a, which is just above the design target of 45 kWh/m^2.a. In carbon terms, the measured performance of the dwellings was much higher than the design target. The measured carbon emissions for delivered heat and electricity were 41.0 $kgCO_2/m^2$.a compared to the design maximum of 25 $kgCO_2/m^2$.a.

In order to identify ways of reducing carbon emissions, it is recommended that further research and measurements be carried out to investigate the factors relating to the performance of the communal heating system. This could include for example a more detailed assessment of losses from the DH network and efficiency of the biomass boiler.

8.7 Developer's Perspective: BQL

The following text was provided by one of the developers, BQL:

Prior to commencement of construction, BQL was a founder member of the Good Homes Alliance, and this project met its aspirations to develop a formalised knowledge management process in the business. The idea was that BQL and other developer members would monitor the energy and environmental performance in use of the projects. At One Brighton, through the TSB project, this has happened in a very in-depth and meaningful way.

In overall terms, given the scale of the development and the level of innovation, it has proven to be a successful project that is liked by a number of the occupiers. However, it is important that we learn from projects such as this.

The following are some of the key lessons:

- *The D&B contractor was challenged by the level of innovation and technical challenge that the project entailed. It is understood that there are on-going discussions about aspects of the performance of some of the building services in this respect and in particular the MVHR system.* ***Innovation works, but the level of technical ability needs to rise to meet this challenge.***

- *The D&B form of contract that was used relied on the technical skill and ability of the design and build contractor. A conceptual design was inherited which was then developed in detail by them.* ***The use of D&B needs to be questioned in the future for projects of this nature where it may be much more appropriate to developed detailed designs with the contractor's input, but with design professionals who have proven experience and a sufficient skill set.***

- *The selection of a biomass boiler remains technically valid in relation to the wider One Planet Living zero carbon aspirations, albeit the experience of this technology has proven to be very challenging, and in hindsight it is unlikely that the same boiler would be used. The Austrian manufacturer refused to get involved in a dispute over the performance of its product (as between CNBQ and the UK distributor), and it is understood that there has been litigation on other projects. The issue does not remain fully resolved with considerable effort required on the part of the community ESCO to keep the boiler in use (difficulties include 2 call outs to the local fire brigade following smoke emissions from the wood store and then later the flue). Furthermore, the wood chip supply chain does not appear to have professionalised much in the 10 years since the project was conceived, and as a result of this (and other technical issues) wood pellets are now used.* ***Biomass boilers are OK in principle but extreme care needs to be taken in their selection and highly competent and experienced engineers appointed to design, install, commission and manage such systems. It remains a relatively brave technology choice.***

- *System heat loss assumptions made by the engineers in respect of the biomass communal heating system have proven to be considerably less than in reality. The community ESCO business model includes a high standing charge element, without which the financial model would have been compromised as a result.* ***Greater***

knowledge and capability needs to be developed across the UK to get communal heating systems to deliver on efficiencies and performance.

- *Likewise, the performance of the MVHR system has proven to be very challenging and there are ongoing issues with regard to the quality of the ductwork installation, difficulty of access to the filters and complaints from residents over comfort. Again, in hindsight it is questionable whether the same MVHR unit would be installed, and clearly there needs to be, with installations of this kind, much more effort with regard to design detailing, proper commissioning and site/quality inspections. This remains a difficult part of the project, but conceptually there is much to merit MVHR as a system in flatted urban projects.* ***MVHR remains a valid technology choice but much more effort needs to be taken with regard to unit selection, detailed design and installation of ductwork and connections, and controls. A change of mindset is required in the new homes market so that investment is made in training and skills development with the MVHR manufacturer taking a pivotal and ongoing supportive role throughout the process.***

- *BQL's knowledge management strategy and it's formulation with others of the GHA proved to be a sound move. The legacy of this and the extent of research that has followed into the building performance at One Brighton will be highly relevant and useful for future development projects. It was fortunate that there were a number of funders who proved to be very interested in supporting this research.* ***A shared industry resource such as the GHA remains essential in order that the industry can develop the level of technical competency that is required and that can be achieved through a collaborative learning process so that sustainable homes deliver the comfort, energy and carbon savings required.***

9 Wider Lessons

Technology Strategy Board guidance on section requirements:	This section should summarise the wider lessons for the industry, including, but not limited to clients, other developers, funders, insurance bodies, skills and training groups, construction team, designers and supply chain members to improve their future approaches to this kind of development. Provide a detailed insight in to the emerging lessons. What would you definitely do, not do, or do differently on a similar project. Include consideration of costs (what might you leave out and how would you make things cheaper); improvement of the design process (better informed design decisions, more professional input, etc.) and improvements of the construction process (reduce timescale, smooth operation, etc.). What lessons have been learned that will benefit the participants' businesses in terms of innovation, efficiency or increased opportunities? These lessons need to be disseminated through trade bodies, professional Institutions, representation on standards bodies, best practice clubs etc. Please detail how dissemination will be carried out for this project. As far as possible these lessons should be put in layman's terms to ensure effective communication with a broad industry audience.

9.1 Fabric First Building Design

The results from One Brighton show that a fabric first approach to building design can result in a significant reduction in energy demand for space heating compared to the building stock. The designed performance of the fabric at One Brighton would be slightly better than that which would be required to meet the expected minimum Fabric Energy Efficiency Standards (FEES) for zero carbon homes targets in 2016. The proposed FEES targets are 39 kWh/m^2.a for apartments/mid-terrace houses and 46 kWh/m^2.a for semi-detached/detached houses (Zero Carbon Hub 2009). One Brighton shows that a well specified fabric strategy is likely to be more deliverable in practice than many other low carbon technologies, and where it is successful, to substantially mitigate technical underperformance of other systems.

9.2 Errors in SAP Calculations

The evidence from One Brighton is that there can be significant errors in SAP inputs and inaccuracies in U-value calculations. This is perhaps unsurprising, as previous research carried out by the Energy Efficiency Partnership for Homes (Trinick, Elliott, Green, Shepherd and Orme 2009) showed that, in a sample of 82 SAP assessments, nearly all had some level of error, which in 20% of cases would have resulted in the assessment failing to meet the design target emissions. There are clearly still opportunities to improve the SAP assessment process and associated training, information and support for SAP assessors, Building Control Bodies, designers and housing developers. Problems around SAP are, to a large extent, systemic, and not the sole responsibility of house builders. The fact that these issues have emerged and have been documented in this project provides TSB and the project team with an opportunity to raise them with all relevant stakeholders.

9.3 Treatment of MVHR Heating in SAP

The dwellings at One Brighton use water to air heater exchangers integrated into the MVHR system to provide warm air heating. Similar systems are widely used in dwellings designed to Passivhaus standards where the heat demand is relatively low, and are likely to become more common place in the UK under more onerous energy performance requirements for new housing. However, SAP does not currently include options for MVHR heating. The consequence of this is that the SAP algorithms may underestimate ventilation heat loss in cases where MVHR flow rates in heating mode give air change rates that are significantly higher than the standard assumption (0.5 h^{-1}). It is therefore recommended that consideration be given to making MVHR heating an explicit option in the next revision of SAP.

9.4 Treatment of Common Area Energy Use in SAP and Part L

The existing protocols for the treatment of electricity use for common areas in the regulatory assessment of apartment blocks mean that this energy use is not included in the SAP assessment or the requirements of Part L1a. Instead, this energy use is considered as non-domestic and is taken into account under the requirements of Part L2a. In the case of One Brighton, the common areas are exclusively for the use of the residential part of the development, and it could be argued that Energy Performance Certificates should include some assessment of carbon emissions and service charges associated with common areas. This would give prospective purchasers and tenants better information when assessing the potential energy costs and environmental impact of living on the development. The measured data show that common area electricity accounts for 21% of total carbon emissions associated with the dwellings at One Brighton.

9.5 Treatment of Communal Heating Distribution Losses in SAP

The assumptions in SAP2005 for distribution losses from communal heating pipework may not be an accurate reflection for what is actually possible with these systems, with SAP significantly overestimating achievable efficiency. At One Brighton the distribution efficiency was calculated to be of 41.2%. The assumption in the SAP 2005 calculations for One Brighton was for a distribution efficiency of 95%, which is a default value for community heating in the software (for ”modern pre-insulated piping” and variable flow systems). Data for the performance of district heating systems in Denmark indicates that the average distribution loss from all Danish systems is much higher than this at around 20% (DEA 2007).

9.6 Coheating Test and In-situ U-value Measurements

The results for the One Brighton BPE project have clearly demonstrated the value of the Coheating test as a post-construction assessment tool, especially when combined with other techniques such as thermal imaging and in-situ U-value measurements. There are however experimental set-up issues which mean that testing of apartments can be much more complex than for houses. Whilst the widespread use of Coheating as a performance test method or compliance tool is clearly limited due to cost and practical constraints, there is clearly a place for some Coheating testing to check and verify performance. This could be perhaps at the level of research and development for new materials and products, when testing the performance of prototypes or on very large housing schemes where identical construction forms and methods are replicated on a large scale.

In-situ U-value measurements provide a simpler method of assessing fabric performance. The results from One Brighton show that this method can identify walls performing in accordance with design expectations from those containing significant thermal bridges.

9.7 Designing for Overheating

The risk of summer overheating is likely to increase in the future with the rises in seasonal atmospheric temperature that may result from climate change. The fact that some home owners at One Brighton are finding issues with high temperatures during the summer is therefore of concern, and indicates that current design methodologies for assessing overheating risk are not robust. A lack of data with respect to the extent and causes of the overheating issue at One Brighton makes it difficult to draw any firm conclusions other than to recommend that further national studies are required, especially with respect to the performance of apartments. This could include for example investigations of summer dwelling temperatures, the effect of gains from distribution losses, temperatures in common spaces and the ventilation strategies employed by householders. The Technology Strategy Board has funded some additional analysis of the overheating risk at One Brighton as part of the Design for Future Climate call, and the results of this work should be available soon.

9.8 Carbon Emissions from Community Heating

The results from One Brighton show that actual carbon emissions for delivered communal heat at 0.5 $kgCO_2/kWh$ were ten times that predicted, and twice that which would have been expected had the development used individual gas boilers to heat the apartments – though we note the significant technical difficulties that would have been faced in installing individual gas boilers at One Brighton. The factors giving rise to the high emissions were related mainly to the use of the backup communal gas boiler in preference to the main biomass boiler and high distribution losses. Many of the residents at One Brighton will have chosen to live there specifically because of the advertised environmental credentials of the development, and would be expected to be very disappointed with the actual performance of the communal heating system, especially as they have no choice in energy provider. There are clearly reputational risks associated with publishing data on performance, but in the view of the authors of this report, it is suggested that if annual emissions data were published by energy services companies, then this would help residents make informed decisions. A requirement to publish data may also provide the impetus for an ESCo to improve the performance of their systems.

At a national level, there are pressures to make more use of district heating, especially for large new housing developments. The success of such schemes in terms of reducing carbon emissions will depend to a large extent on the carbon intensity of delivered heat. The results from One Brighton show that communal heating systems do not always work as expected, and that emissions can be considerably higher than those calculated using design estimates. Further research is therefore required to better understand the mechanisms relating to the efficiency and effectiveness of community heating.

9.9 Commissioning of MVHR Systems

The indication from measurements of the performance of the MVHR systems at One Brighton was that it is likely that they had not been properly commissioned. However poor system maintenance can also greatly affect MVHR performance. The building regulations in force at the time did not require the builder or their sub-contractors to provide commissioning certificates for ventilation systems, and it is therefore unlikely that this issue would have been picked up during construction or at handover. The current building regulations however require installers of mechanical ventilation systems to comply with the guidance given in the Domestic Ventilation Compliance Guide (DCLG 2011c). The guide includes requirements for visual and functional checks of the installation, together with the measurement of air valve flow rates using a calibrated air flow recording device in accordance with approved procedures. A commissioning certificate must now be provided to the building control body. The effectiveness of this new compliance system in improving the performance of domestic ventilation systems will depend to a large extent on the use of a suitable Competent Person Scheme and rigorous oversight and monitoring of the process. It is suggested that the oversight regime should include some level of auditing and verification of test results.

The Domestic Ventilation Compliance Guide suggests the use of a vane anemometer and flow hood to measure air flow rates. Results from the One Brighton study indicate that a vane anemometer may not be accurate at high flow rates. It is recommended that further research is carried out to understand the variability in measurement for flow hoods with vane anemometers compared to other devices where the back pressure is minimised such as with a balanced balometer or when using a hot wire mesh device such at the Swema 125D flow capture hood. The main disadvantages of these other devices compared to a vane anemometer are that they are larger, heavier and more expensive.

9.10 Internal Temperature Set-points in Heating Season

Data from this study indicates that residents of low energy dwellings are likely to live at higher temperatures in the heating season than existing models assume. Similar findings were observed for low energy houses in Sweden, where measured data showed that residents lived at average internal temperatures of 23°C compared to the design assumption of 20°C (Wall 2006). There are implications for national energy policy, energy regulations and modelling tools such as SAP if occupants of low energy buildings tend to live at higher temperatures than standard assumptions. We are however currently unable to definitively determine what proportion of the higher temperature at One Brighton was due to active choices made by residents with respect to heating, and what proportion was down to other causes – in particular, to heat losses from the heat distribution system. The distinction between the two cases is crucial because the practical consequences are completely different.

9.11 Building Performance Evaluation Methodology

The scope of the Building Performance Evaluation (BPE) project at One Brighton was limited mostly to the measurement of post-construction performance. Consequently, it is not possible to relate the measured performance data to procurement, design or construction processes. A better understanding of the underlying process issues would require a model for building performance evaluation that is fully integrated into the design and construction process. A good example of this sort of extensive action research approach to performance evaluation in housing is the Stamford Brook project (Wingfield, Bell, Miles-Shenton, South and Lowe 2011).

Assessment of the data from One Brighton showed that not all of the monitoring methods worked as expected, and this affected the quality of some of the data. For example, the heat meters designed to measure the use of domestic hot water in the monitored dwellings had not been installed properly. This demonstrates the importance of robust procedures for the design, installation and commissioning of monitoring equipment (as well as a minimum level of technical competence in organisations responsible for conducting building performance evaluation). It is also clear than many installers and sub-contractors are still not familiar with the installation requirements of measuring devices such as heat meters, energy displays and sub-meters.

9.12 Internal Air Quality

The results of humidity and carbon dioxide measurements in the monitored dwellings at One Brighton indicate that the internal air quality ranged from satisfactory to poor. In two cases, this could be related to the fact that the residents were not using the mechanical ventilation system as intended. However, even where residents were using the mechanical ventilation system correctly, the air quality was still variable. There are lessons to be learned here both in terms of the information given to residents about their homes and also in understanding the limitations of mechanical ventilation systems. Further research is required, to understand the impact of occupant understanding and behaviour on air quality in mechanically ventilated airtight dwellings, to understand the role of communication between developers and occupants about ventilation systems, and to investigate the effect on air quality of factors relating to the design and installation of the ventilation system.

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11 Appendices

Technology Strategy Board guidance on section requirements:	The appendices are likely to include the following documents: • Details on commissioning of systems and technologies through appending of the document *BPE_Domestic_commissioning sheets.doc* • Initial energy consumption data and analysis (including demand profiles where available) • Further detail or attachment of anonymised documents • Additional photographs, drawings, and relevant schematics • Background relevant papers

11.1 List of Appendices

a. Arup BUS Survey Report

b. UCL MSc Dissertation by J Bainbridge based on Bus Survey: "*Do buildings that are built according to sustainability principles and to a high environmental standard deliver a sustainable living solution to their occupants?,* 2011, UCL

c. DOMEARM summary