Sinclair Meadows Community Village

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InnovateUK project number	450099
Project author	National Energy Foundation for the Three Rivers Housing Association
Report date	2014
[1]InnovateUK Evaluator	N/A

No of dwellings[2]	**Location**	**Type**	**Constructed**
1 dwelling, 1 flat	South Shields	Terraced houses and flats	2012
[2]Areas	**Construction form**	**Space heating targets**	**Certification level**
107 m² and 66.5 m²	Timber frame, hemp insulation	Dwelling: 8.3 kWh/m² per annum Flat: 6.4 kWh/m² per annum	Code for Sustainable Homes Level 6 (SAP 2005)

Background to evaluation

The BPE study assessed the performance of the Sinclair Meadows Carbon Negative social housing project in Tyne and Wear which intended to be a carbon neutral development. The development was designed as mixed-use, with twenty one dwellings including nine each of three-bed terraced houses and a three-storey apartment block containing twelve two-bed apartments/flats. The development incorporated a biomass-fuelled communal district heating system to provide space heating and hot water. In addition 85 kWp solar photovoltaic (PV) panels generated electricity. Rainwater was harvested for toilet flushing and gardening.

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

One terraced house and one flat were analysed. The predicted net carbon emissions were -6.26 $kgCO_2/m^2$ per annum for the house and -2.85 $kgCO_2/m^2$ per annum for the apartment. The designed heat loss parameter for the house and apartment was very low at and 0.51 W/m^2K and 0.59 W/m^2K respectively. The annual requirement for delivered heat energy for both dwelling types was dominated by that for domestic hot water, which accounted for around 80 per cent of the heat requirement. The net efficiency of the biomass-fuelled boiler was 82.2 per cent compared to the manufacturer's quoted efficiency of 93.6 per cent. The overall system efficiency for delivery of heat to the dwellings was 20.3 per cent. Measured temperatures indicated overheating in the bedrooms in both dwellings during the summer.

Occupant survey type	**Survey sample**	**Structured interviews**
BUS (domestic)	17 of 21 (81 % response rate)	Yes, various

Residents reported many positive experiences of their new homes and scores compared well against BUS benchmark datasets. Overall comfort, perceived health and needs met all scored in the 99th percentile. The flats performed much better in winter than during summer. While in the winter the residents appreciated the ability of the flats to retain heat, during warmer periods 80 per cent of residents said that dwellings were too hot in the summer, reportedly due to high levels of solar gain. Over a third of residents stated that they were unable to control cooling. **Users note: inappropriate use of histograms for reporting BUS data (page 62).**

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Executive Summary

In order to combat the threat of dangerous anthropogenic climate change, the UK government has a target of 80% carbon dioxide (CO_2) emission reduction by the year 2050 against 1990 levels. The UK emits 595.6mt of CO_2 equivalent per year and, of this 27% is due to the housing stock; hence a major reduction must be made in housing emissions, both operating and embodied.

By the year 2016, all new housing in the UK will legally be required to be zero carbon. However, the introduction of zero carbon homes is not enough; 66% of the housing stock to be occupied in the year 2050 is already built. In order to offset some of these emissions new homes should be “**carbon negative**” [that is the reduction of an entity’s carbon footprint to less than neutral]. The **Three Rivers Housing Association** innovative and ground-breaking **Sinclair Meadows Carbon Negative Community Village** project in South Shields, Tyne and Wear has gone beyond this.

The vision from the outset of the development project was to create a social housing development that would be the first in the UK to achieve carbon negativity. The Three Rivers Housing Association Sinclair Meadows development was designed as mixed-use, with twenty one dwellings including nine of, three-bed terraced houses and a 3-storey apartment block containing twelve of, two-bed apartment / flat dwellings.

The results from the Sinclair Meadows development show that a fabric first approach to building design and construction can result in significant reduction in energy demand for space heating compared to the existing building stock.

Through **innovative design, construction methods and renewable technology** the twelve apartments and nine houses in the scheme **exceed Level 6 of the Code for Sustainable Homes** and were designed as being **carbon negative**.

Sinclair Meadows incorporates a biomass-fuelled communal district heating system to provide space heating and hot water to the development. In addition and Solar Photovoltaic (PV) panels generate electricity for the homes whilst rainwater is harvested for toilet flushing and gardening. The project was listed in the **Top 50 Affordable Housing Development of 2013** by Inside Housing and has won several awards including; **Best New Affordable Housing Scheme** at the Housing Excellence Awards 2013 and the **Innovation Award** at both the North East and National Construction Excellent Awards 2013.

<u>Background to the study</u>

The Technology Strategy Board established a programme in 2010 for domestic and non-domestic projects to fund studies into the gap between the design intent of new and retrofit buildings and their performance in reality. These Building Performance Evaluation (BPE) studies aimed to increase understanding of the nature of the gap and how to close it. Three Rivers Housing Association made a successful bid to study the Sinclair Meadows Carbon Negative Community Village. This was a two year study which also benefitted from additional behavioural change research undertaken by Northumbria University's Sustainable Cities Research Institute. This report provides details of the Sinclair Meadows BPE study.

Section 1 – Introduction

Section 1 provides an introduction to the scope of the project, the expected results and includes a summary of the key facts, figures and findings. The results from the Sinclair Meadows development show that a **fabric first** approach to building design and construction can result in a **significant reduction in energy demand** for space heating compared to the building stock.

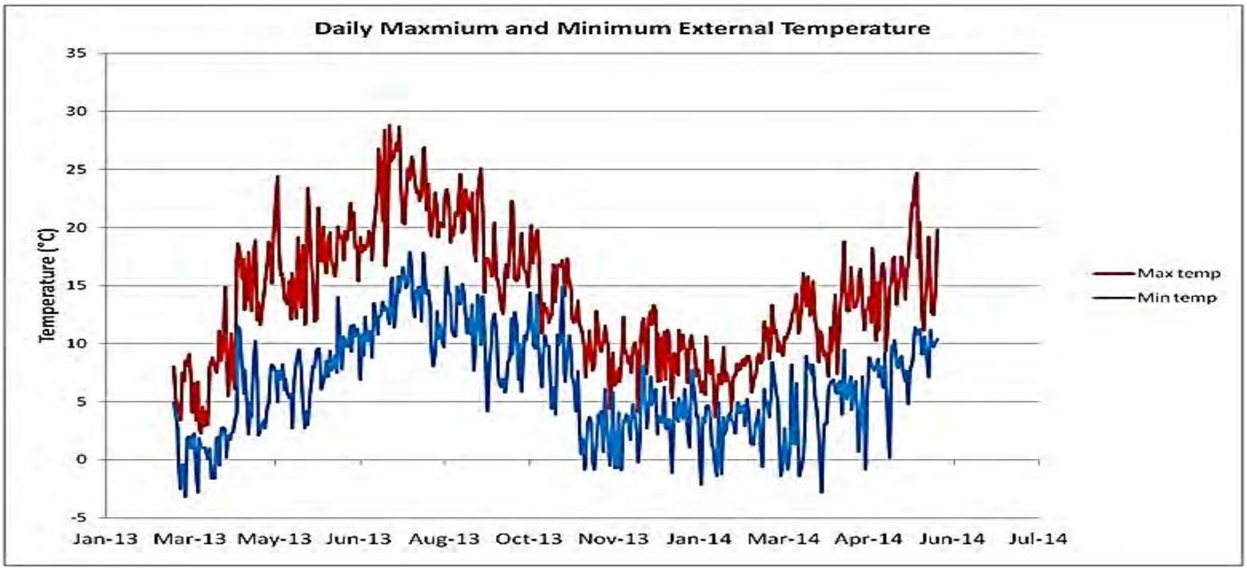
The overall predicted net carbon emissions were -2.85 $kgCO_2/m^2.a$ for the apartment and -6.26 $kgCO_2/m^2.a$ for the house and hence **the dwellings as designed in 2006 would even exceed the requirements of a zero carbon home built today**.

The designed emissions due to energy consumption for the dwellings were very low due to the low carbon intensity of **biomass heat,** with the overall emissions being dominated by the effect of the carbon offset from the **solar photovoltaic (PV) electrical generation** [which resulted in **negative overall emissions**].

The **designed heat loss parameter** for the house and apartment was **very low** at 0.59 W/m^2K and 0.51 W/m^2K respectively and it could be seen that the annual requirement for delivered heat energy for both dwelling types was dominated by that for domestic hot water, which accounted for around 80 per cent of the heat requirement.

The net efficiency of the biomass-fuelled boiler was 82.2 per cent compared to the manufacturers quoted boiler efficiency of 93.6 per cent. The overall system efficiency for delivery of heat to the dwellings was 20.3 per cent; and this was perhaps an **indication that the use of district heating for small scale low energy developments such as Sinclair Meadows may not be appropriate due to the lack of a sufficiently large heat demand to offset the system inefficiencies and distribution losses**. There is growing evidence that many other district heating developments are encountering similar performance issues.

The design data showed that there was **no significant tendency to overheat in the living rooms**: However, the measured temperatures did indicate overheating in the bedrooms in both dwellings during the summer. This may have been due in part to the **relatively high summer temperatures in the UK in 2013** when peak summer temperatures in the UK were around 28 °C.



Data from this study indicates that residents of Sinclair Meadows 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 Standard Assessment Procedure (SAP) if occupants of low energy buildings tend to live at higher temperatures than standard assumptions. The study however was unable to definitively determine what proportion of the higher temperature at Sinclair Meadows was due to active choices made by tenants with respect to heating and what proportion was down to other causes such as heat losses from the heat distribution system.

It is recognised that at the time of construction, Building Regulations compliance was achieved. Flow measurements during the study, of the Mechanical Ventilation and Heat Recovery (MVHR) systems in two occupied dwellings on the development have shown that the systems would not meet the ventilation requirements of Part F 2006; however due to the length of time that had elapsed between initial commissioning and the BPE performance tests, it is unknown whether this was related to the commissioning process, problems with reliability of the MVHR system, a gradual deterioration in performance, as a result of occupant behaviour or some combination of factors. This will require further investigation. Issues associated with poor performance of MVHR systems has emerged as a key theme across a range of the BPE projects.

Section 2 - Design and Construction

Section 2 describes the BPE project up to pre-commissioning. It provides detail on the building type, form and materials and detailed any discrepancies between the design and Standard Assessment Procedure (SAP) methodology. From the start of the project, the emphasis was placed on the quality of the building fabric, especially on air tightness and heat loss. The principal adopted was that by starting with a *high quality* building fabric would mean less energy required to heat/cool the buildings during occupancy. This approach was reflected in the stretching of design targets for thermal performance and air permeability of the dwellings.

Natural materials were specified wherever possible [notably timber frame, hemp insulation, lime render, sustainable timber, etc.] and hence all dwellings were constructed using a combination of NBT Pavatherm-Plus, PavaFlex insulation, Scottish Larch Timber Cladding and NBT Diffutherm with Baumit lime render.

Design targets for thermal performance required insulation levels to be in **excess of 2010 Building Regulations** minima **by 15 per cent**; with proposed external wall U-value of 0.21 W/m^{2}K and triple glazed window; with proposed U-value of 0.7 W/m^{2}K. Ground floor cassettes comprised Lewis® and screed composite floor; with a proposed U-value of 0.1 W/m^{2}K. Roofs were clad with cedar shingles with a proposed U-value 0.09 W/m^{2}K.

The houses on the development were built in accordance with the requirements of Part L1a 2006. All SAP calculations provided had therefore been carried out with SAP 2005. CfSH assessments were completed using the NHER software version of the Code compatible with SAP 2005. The **design air permeability** for the development was **2.5 $m^3/h.m^2$**. The **measured values of air permeability** given in the Part L1a checklists were given as **1.62 $m^3/h.m^2$ for the monitored apartment and 1.64 $m^3/h.m^2$ for the monitored house;** showing both compliance with the design target and being **significantly better than the Part L1a 2006 default limit of 10 $m^3/h.m^2$**. The heat loss calculations used in SAP 2005 meant that party walls between dwellings were assumed to have zero heat loss and hence were not taken into account.

Section 3 - Design and delivery team review

Section 3 details the key findings from the design and delivery team walkthrough; where the purpose was to provide an opportunity for core members of the team to visit the completed development and discuss the delivery process.

Sinclair Meadows was **felt by the design and delivery team to have been a success and the team were proud to be part of it**. It was agreed by all participants that there had been reasonably good co-operation during the project that had been enhanced through the use of weekly on site meetings. The participants enjoyed the design and delivery feedback process; which they perceived as having been useful and productive. **There was a general consensus that all would be interested in taking part in similar processes in the future.**

Achieving CfSH6 and being carbon negative was seen as challenging as CfSH included features that were not specifically related to energy consumption; although it was **widely acknowledged** by the team **that the support provided by the Code Assessor was extremely beneficial to the success of the project**.

There are a number of areas where design team members have learnt from their experience on the project and would, given the choice, do things differently in the future including the use of many new technologies. The project applied a number of new systems and technologies which had not previously been well tested in the UK. This presented challenges 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 design of CfSH timber framed buildings.

Section 4 – Fabric Testing

Section 4 provided detail of fabric testing undertaken as part of the mandatory elements of the BPE programme, including the onsite testing of:

- Thermal transmittance
- Thermographic imaging
- Airtightness and air permeability measurement

In-situ thermal transmittance (U-value) heat flux data showed that the **thermal performance of the external walls exceeded the design U-values**. The evidence from the **thermal imaging surveys** indicated that the residents of both the apartment and the house were opening windows even when the external temperatures were cold. This however was contrary to the advice given to the residents to close windows during the heating season in order to maintain the effective operation of the MVHR system.

Thermographic imaging showed that there were **no indications of any significant thermal anomalies** in either the external walls or ground floor and those walls had been well constructed without any major gaps in the insulation layer. A problem observed with the fitting of mineral wool insulation at the eaves in cold roof construction is common across the industry.

The **measured air permeability values** of the Sinclair Meadows dwellings were **all less than the design target** of 2.5 $m^3/h.m^2$ @50Pa with a mean of 1.6 $m^3/h.m^2$ @50Pa **and significantly better than the regulatory maximum air permeability** in Part L 2006 is 10 $m^3/h.m^2$ @50PaA

Section 5 – What the occupants think

Section 5 provides details about the occupant surveys using standardised housing questionnaire Building Use Survey (BUS) methodology.

The results from the BUS study confirmed by Phase 1 of the behavioural change research, suggested that the **new tenants of Sinclair Meadows were largely willing to engage with carbon-negative lifestyles and become part of new type of community.** Despite some initial teething problems, most residents were very pleased with their new homes (in the words of one person, ***'I feel like I've won the lottery!'***), and appeared to be willing to enter into the ethos of the development.

While most tenants already displayed at least some pro-environmental attitudes and beliefs, there were areas for potential improvement in their habits and everyday behaviours, e.g. reducing the amount of time spent in the shower, reducing packaging waste, and re-using items. Tenants identified a number of areas in which they would have liked more information and support; with the most common ones being advice about how the heating system and boiler worked, composting, bin use and recycling on site, problems with toilets, and information about how Individual Appliance Monitors (IAMs) and energy monitors worked. Ensuring that people get the information and support they require, and managing potential problem issues such as onsite car parking, was identified as being a potential challenge in the coming months and years.

A community development training programme developed and provided by external consultants, as well as efforts by Three Rivers Housing Association staff to address tenants' concerns and needs, has had a vital role in ensuring that the new community settled in and problems were dealt with.

Section 6 – Services and systems

Section 6 covers the installation and commissioning checks of services and systems, together with services performance checks and evaluation.

The total predicted annual output for the overall 85 kWpeak array based on the inputs to the SAP 2005 assessments for the dwellings was 70,845 kWh.a. The measured output from the array was therefore higher than the predication.

The overall system efficiency for delivery of heat to the dwellings was 20.3 per cent. This is perhaps an indication that the use of district heating for small scale low energy developments such as Sinclair Meadows may be inappropriate due to the lack of a sufficiently large heat demand to offset the system inefficiencies and distribution losses. Recent research carried out by the National Energy Foundation on a number of district heating schemes in London found similarly poor system efficiencies. This is an area that requires further industry research.

The design, installation and operation of the MVHR systems at Sinclair Meadows presented numerous problems with issues surrounding the location and fitment of the units giving rise to installation and access issues together with difficulties with both maintenance and operation. It should be noted that many of these problems have also emerged at other BPE projects which have investigated MVHR systems. One of the consequences of this has been that the Technology Strategy Board has commissioned a separate Meta-study into MVHR.

Section 7 – Monitoring Data

Section 7 provides a summary of the method adopted to monitor the properties during the study. It also includes the conclusions and key findings and provides a summary break down of where energy was being generated and consumed on site.

Information on internal conditions including temperatures, relative humidity and carbon dioxide emissions, disaggregated energy consumption and external weather for the two test houses, was collected by wireless monitoring system installed by the main contractor on behalf of the housing association. A second set of energy data for all twenty one dwellings on the development was also collected. A final set of data including the weights of biomass-fuel and dates of deliveries, was provided by the housing association from their financial records.

A fundamental part of the BPE programme is the continuous and ongoing analysis of the monitored data; the highlighting of any issues encountered to the relevant programme coordinators; and the speedy resolution of any identified problems. Analysis of the monitored data at Sinclair Meadows showed that not all of the BPE data gathering methodology worked as predicted and that this shortcoming affected both the robustness and quality of some of the extracted data. It was 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.

Section 8 – Post construction review

Section 8 summarises the conclusions and key findings of a post construction project review attended by members of the project team. The **unique nature of this project** required an intensive research and development phase and this was felt to be a **positive learning experience** by all involved.

This was an innovate project, drawing together elements which many of the project team had never worked with before, as such the research and development phase was a long process.

There were some difficulties in translating the unique design concept of this project to a completed building and that was at times challenging. However, it was acknowledged by the team that this transition is always difficult and the team have learnt from their experiences of delivering the innovative elements of this project. A valuable method of identifying and resolving issues resulting from this transition was the weekly technical meetings carried out on site involving the full project team. **Regular technical meetings have now been adopted on all development projects.**

Section 9 – Key messages for the client, owner and occupier

Section 9 summarises and discusses the key messages for the client, owner and occupier. It focuses on the main findings from the BPE study and highlights the key messages for wider communication. To summarise, **overall satisfaction at the site appears to be quite high, with residents reporting many positive experiences of their new homes and scores comparing well with benchmark datasets**.

All residents felt that their needs were being met, and the majority are comfortable in their new home. Additionally it is evident that the **significant majority of respondents of the BUS** do believe that living in the new development has **changed their lifestyle**; with a **large number of positive comments** relating to the ways in which residents have embraced those changes, in terms of diet, leisure, travel and work.

There are also key messages for all parties about the design, installation and operation of MVHR systems and around overheating. The efficiency of biomass fired district heating systems is a further key area of consideration for clients and owners.

Section 10 – Key lessons for industry

Section 10 summarises and discusses the wider lessons for the industry, including clients, other developers, funders, insurance bodies, skills and training groups, construction team, designers and supply chain members. It aims to provide insights which others can learn from and use to improve future performance.

Sinclair Meadows is an innovative and leading edge development. Academic research has shown that even low-energy buildings, carefully built to perform well, rarely perform to expectations, either in use, or in the fabric alone. Only a systematic evaluation of the performance of buildings can aid in the diagnosis of the reason or reasons for this, and, assuming that remedies can be applied, can evaluate the effectiveness of the remedies. During the course of this project it is clear that **all of those involved learned an enormous amount** and there were a **whole range of positive learnings** (e.g. the Clerk of Works success together with the design and delivery team engagement).

This section also includes wider learning associated with the following: improving the Building Performance Evaluation Methodology; the benefits of the Fabric First Approach; issues associated with SAP calculations; considerations and issues associated with the actual performance and carbon emissions from community heating; commissioning of MVHR systems; designing for overheating and internal air quality.

1 Introduction and overview

1.1 Introduction

In order to combat the threat of dangerous anthropogenic climate change, the UK government has a target of 80% carbon dioxide (CO_2) emission reduction by the year 2050 against 1990 levels. The UK emits 595.6mt of CO_2 equivalent per year and, of this 27% is due to the housing stock; hence a major reduction must be made in housing emissions, both operating and embodied.

By the year 2016, all new housing in the UK will legally be required to be zero carbon. However, the introduction of zero carbon homes is not enough; 66% of the housing stock to be occupied in the year 2050 is already built. In order to offset some of these emissions new homes should be “carbon negative” [that is the reduction of an entity’s carbon footprint to less than neutral].

This report details the findings of a Technology Strategy Board Phase 2 Building Performance Evaluation (BPE) project that investigated the design and construction, post construction and in-use performance of dwellings of the Three Rivers Housing Association innovative and ground-breaking Sinclair Meadows Carbon Negative Community Village in South Shields, Tyne and Wear.

Figure 1 - Sinclair Meadows Architects Images

The £3.8m Sinclair Meadows development was designed as the first carbon negative social housing development in the UK and was developed as an exemplar and sustainable affordable housing community for social housing provider Three Rivers Housing Association.

The vision from the outset of the development project was to create a social housing development that would be the first in the UK to achieve carbon negativity. All partners investigated the Renewable Energy (RE) technologies and design approaches that would achieve best practice around energy and sustainability performance without impacting the usability of the homes.

Additionally a Low and Zero Carbon (LZC) feasibility assessment was carried out prior to development commencement to determine the most appropriate energy strategy for the site. The strategy that incorporated biomass-fuelled communal heating and hot water generation and solar photovoltaic (PV) electricity generation was chosen for the development.

The Sinclair Meadows development was designed as mixed-use, with 21 dwellings including 9 of, 3-bed terraced houses (approx. total floor area 963 m^2) and a 3-storey apartment block containing 12 of, 2-bed apartment / flat dwellings (approx. total floor area 798 m^2), see Figure 1 - Sinclair Meadows Architects Images.

The development was designed and constructed to exceed the government's Carbon Zero definition by approx. 19-20 per cent [as set out in Part L (1A) Building Regulations (2010)] and the CfSH Level 6 [CfSH6] by approx. 15 per cent [through a combination of advanced building fabric design and the inclusion and use of a number of LZC and RE technologies].

Figure 2 shows an aerial photograph of the development. A significant design concept was to maximise natural heat and light available from the sun. Using a staggered housing layout it was possible to capture solar gain through south facing glazed areas. All of the main habitable rooms were built south facing and the houses fitted together in such a way that the north facing aspect of each property was minimised, specifically to minimise heat loss. Additionally all south facing aspects roofs had solar photovoltaic (PV) panels installed on them [with the designed total output of the overall solar PV array being 85 kWpeak; with a gross area of about 700m^2].

Figure 2 - Aerial view of Sinclair Meadows development

Construction was completed in July 2012 with first occupancy in September 2012.

Rainwater harvesting systems on the properties provide water for toilet flushing and for gardening. The project consists of a “no-car” resident scheme [although there is on-site vehicle parking for visitors or disabled residents] and subsequently residents were expected to travel sustainably [including the use of both public transport and cycling]. To that end cycling storage has been provided for all dwellings. Composting and “home growing” facilities were also provided.

The dwellings on the development were built in accordance with the requirements of Part L1a 2006. The Thermal Mass Parameters (TMPs) used in the design assessment were consistent with the low thermal mass of the timber frame construction on the development. Heating and hot water were provided by a centralised district community heating system linked to a biomass-fuelled Hargassner pellet boiler, coupled to a large water accumulator with electric immersion-heater back-up.

All dwellings were constructed using a combination of NBT Pavatherm-Plus, PavaFlex insulation, Scottish Larch Timber Cladding, and NBT Diffutherm with Baumit lime render. Design targets for thermal performance required insulation levels to be in excess of 2010 Building Regulations minima by about 15 per cent; with proposed external wall U-value of 0.21 W/m^{2}K and triple glazed window U-value of 0.70 W/m^{2}K. Ground floor cassettes comprised Lewis® and screed composite floor; with proposed U-value 0.10 W/m^{2}K. Roofs were clad with cedar shingles; with proposed U-value 0.09 W/m^{2}K (see Table 1 - Summary designed building fabric U-values).

Table 1 - Summary designed building fabric U-values

Design Element	Design U-value
Walls	0.14 W/m^{2}K
Floor	0.10 W/m^{2}K
Windows	0.70 W/m^{2}K
Roof	0.09 W/m^{2}K

The design target for air permeability was 2.5 m^3/h.m^2@50pa [Part L1a 2006 default limit 10 m^3/h.m^2@50pa].

The UK has a higher rate of owner occupancy than the European average, which has a tendency to lead towards a culture of domestic self-sufficiency with lower collective provision of district heating systems. Biomass-fuelled district heating systems can however provide low carbon intensity heat at higher efficiency, reliability and lower cost than that for single dwellings; however, there are considerable challenges in their effective design, application and use, particularly with regards to meeting peak load demands; ensuring responsiveness to changes in demand; and minimising waste heat production during periods of lower capacity (e.g. in summer months).

A typical district heating installation consists of a highly insulated "heat main" of ***flow*** and ***return*** pipes distributing hot water (or steam) past all buildings which might be connected. A junction point allows easy connection to each building, from which hot water can be taken from the heat main to a heat exchanger (heat interface unit - HIU) within each property. The heating circuit within the building is thus isolated from the heat main. Temperature measurement of the flow and return lines, plus a flow meter [i.e. together forming a “heat meter”], allow the actual heat usage within each property to be measured and the delivered heat billed for accordingly. Remote meter reading by router modem, secure web interface or “drive-by” are all possible, as are remote diagnostics to ensure reliable continuous operation.

Figure 3 and Figure 4 show the completed development; with Figure 3 showing the 3-bed houses [view from west] and Figure 4 showing the 2-bed apartment blocks [view from south side]; also visible is solar PV arrays mounted to the roof of the apartment blocks].

Figure 5 shows the biomass-fuelled boiler plant room [view from north side].

Figure 3 - West/front side of the 9, 3-bed terraced houses at Sinclair Meadows

Figure 4 - South side of 3-storey apartment block comprising 12 of, 2-bedroom flats at Sinclair Meadows

Figure 5 – Biomass-fuelled boiler plant room at Sinclair Meadows

1.2 Building Performance Evaluation project

This Technology Strategy Board funded Building Performance Evaluation (BPE) project was a 2-year monitoring study focussed on the operational performance and efficiency of a communal based biomass-fuelled wood pellet district heating scheme together with an in-depth and detailed monitoring and analysis of 1 of, 3-bed house and 1 of, 2-bed apartment/flat property. Additionally Three Rivers Housing Association and the Technology Strategy Board were keen to explore whether such small-scale district heating systems for a "domestic-only" development was the most efficient approach for future such developments through investigating the following points (Table 2):

Table 2 – Building Performance Evaluation

1) The heating and hot water demands of dwellings compared to designed [i.e. Standard Assessment Procedure (SAP) calculation and SAP review];

2) The annual heating, hot water and electrical energy consumption pattern of individual homes and the district heating system;

3) Differences/similarities in heating, hot water and electricity demands of individual dwellings when compared with occupancy levels, external/internal temperatures and appliances;

4) Energy-use behaviours of tenants, and in particular

a) satisfaction with heating/hot water provision on site, and

b) the need for electric backup sources during the monitoring period;

5) The efficiency and running costs of the district heating scheme;

6) The maintenance and fuel supplier issues related to the technology and fuel type;

7) The knowledge gap between the design and practical implementation of district heating and high fabric efficiency dwellings for the design team, contractors and tenants; and

8) The potential impact of the planned Three Rivers Housing Association tenant engagement activity through a 12-month Community Development Programme to provide training and support to occupants.

1.2.1 Identifying codes

In order to maintain the anonymity of the residents, the monitored dwellings have been given the identifying codes "**dwelling or House A**" (for the house) and "**dwelling or Apartment B**" (for the apartment/flat).

The monitoring of the properties included:

- *1 house and 1 apartment:*
  - Comprising detailed sub metering of electricity, mechanical ventilation and heat recovery [MVHR] use, water consumption, space heating, carbon dioxide (CO_2) levels, hot water & internal/external temperatures.
- *All properties:*
  - Comprising additional space heating, electricity, water & temperature data collection for all dwellings through existing energy data collection [via an embedded energy metering system].

There are two types of apartment dwelling at Sinclair Meadows; with one being slightly bigger [including bigger bedroom and living space] positioned in the middle of the apartment block. The design features of all the houses are largely the same, with the notable exception of the end property to the south of the development; which has two extra windows and a greater area of exposed external wall. Figure 6 is the drawing of the apartment elevations. Figure 7 is the drawing of the houses elevations.

Figure 6 – Drawing of Apartments Elevations

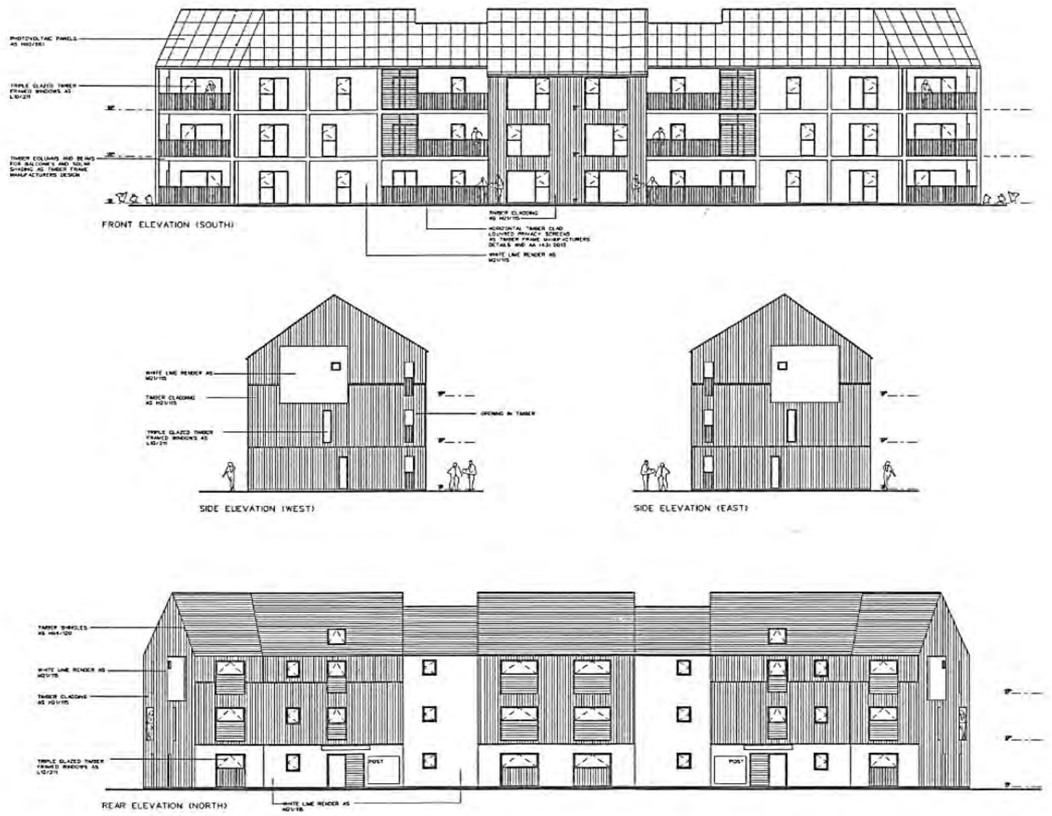


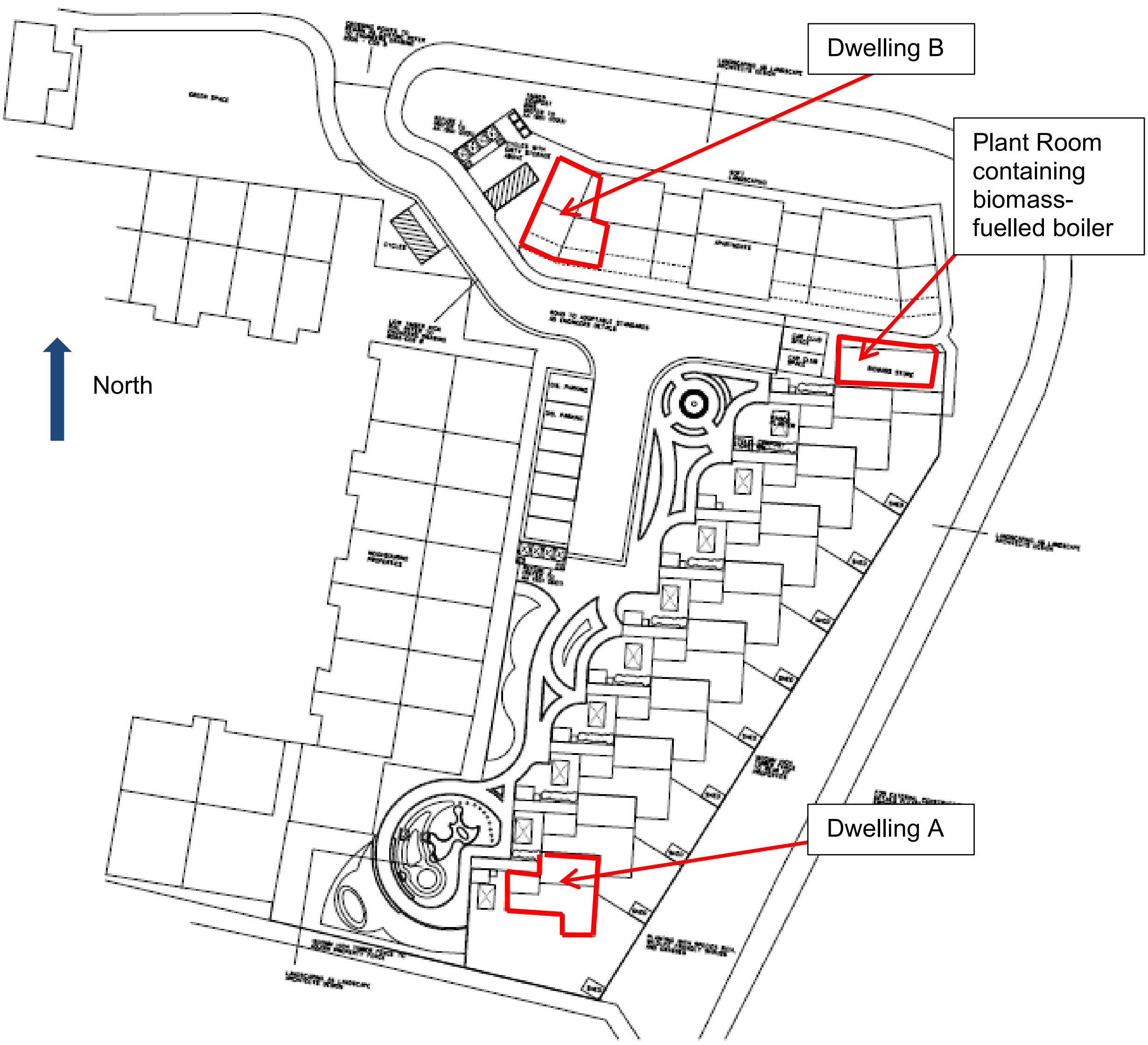
Figure 7 – Drawing of Houses Elevations

The houses have a sunspace area on both lower and upper floors. In the original design, this sunspace didn't have a ceiling between the two floors, but due to building regulations relating to fire risk, this was deemed necessary. The sunspace was designed with double-doors which, in the event of fire would act as a thermal barrier between the space and the rest of the property.

The design of Sinclair Meadows development was such that all roofs were facing in a southerly direction with all homes having east; south and west aspects (Figure 8). The biomass-fuel boiler plant room was located to the north of the terrace row of houses.

The apartments were designed so that the main living spaces were on the south side of the apartment block and kitchens and bathrooms faced north and west. As well as maximising solar gain, this layout also provided additional natural surveillance within the development itself. Additionally northern elevations have been minimised.

Figure 8 - Site Plan (March 2011) showing the properties monitored under the BPE programme and the location of the biomass-fuelled boiler, pellet store and plant room



The orientation and exposure of the two monitored dwellings are summarised in Table 3 – Orientation and Exposure of Monitored Dwellings.

Table 3 – Orientation and Exposure of Monitored Dwellings

Dwelling Code	No of Floors	Orientation of Main Glazed Facade	Fully Exposed Elements	Elements Exposed to Heated Common Spaces	Party Elements
Dwelling A	2	South/South West Azimuth ≈ 268°	5 external walls, floor	2 walls	Ceiling, 1 party wall
Dwelling B	1	South Azimuth ≈ 178°	7 external walls, floor, ceiling	None	1 party wall

Figure 9 is a representative ground floor plan drawing of dwelling A. Figure 10 is a representative first floor plan drawing of the dwelling A. Figure 11 is the plan drawing of dwelling B.

All drawings are dated 10th September 2010 and were subject to subsequent change during the construction phase of the project development.

Figure 9 – Ground Floor Plan Drawing of Representative House

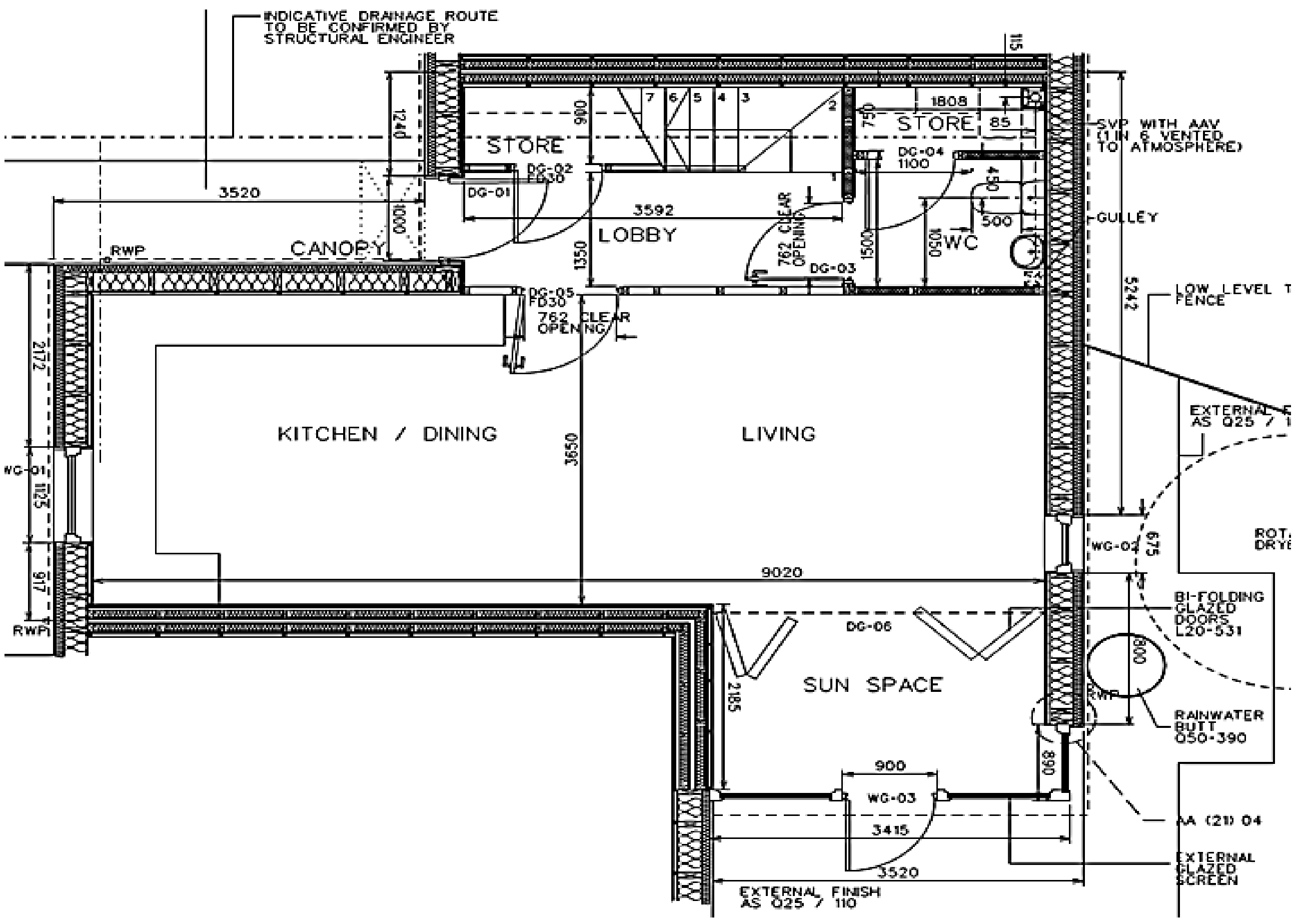


Figure 10 – First Floor Plan Drawing of Representative House

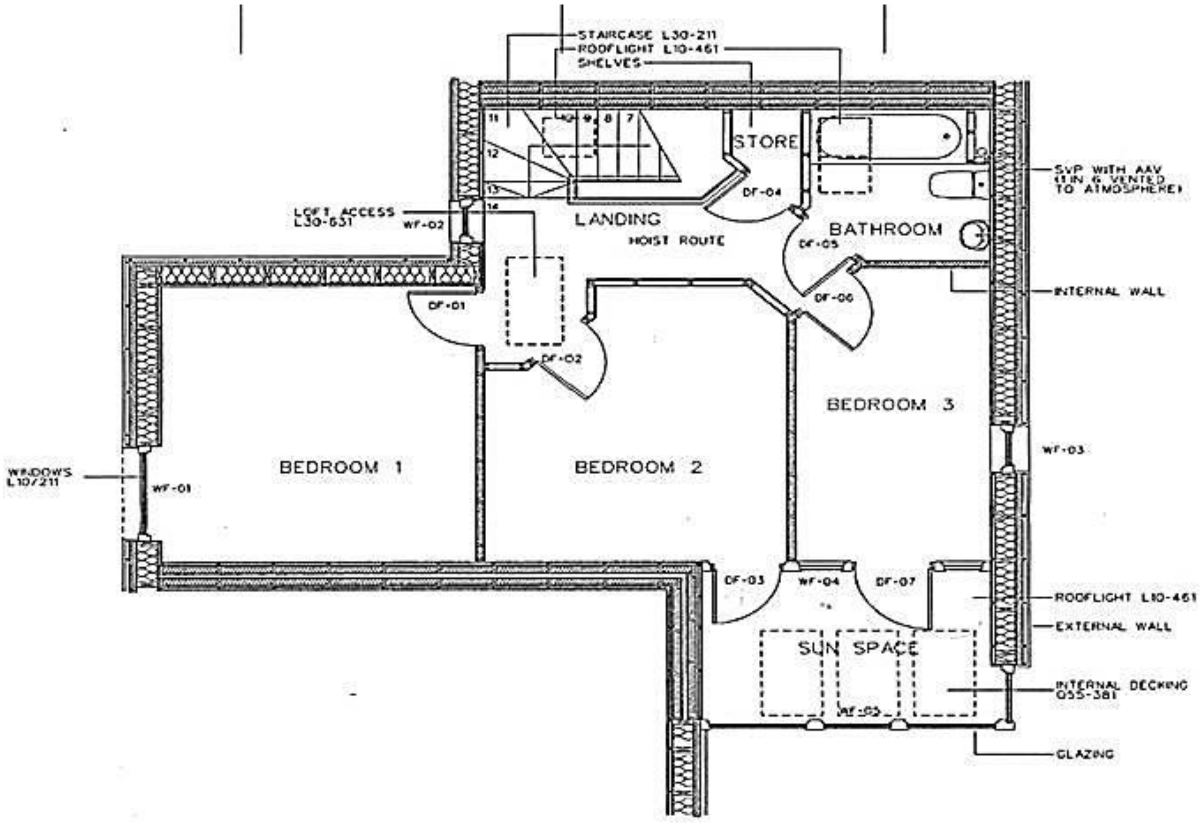


Figure 11 – Plan Drawing of Representative Apartment

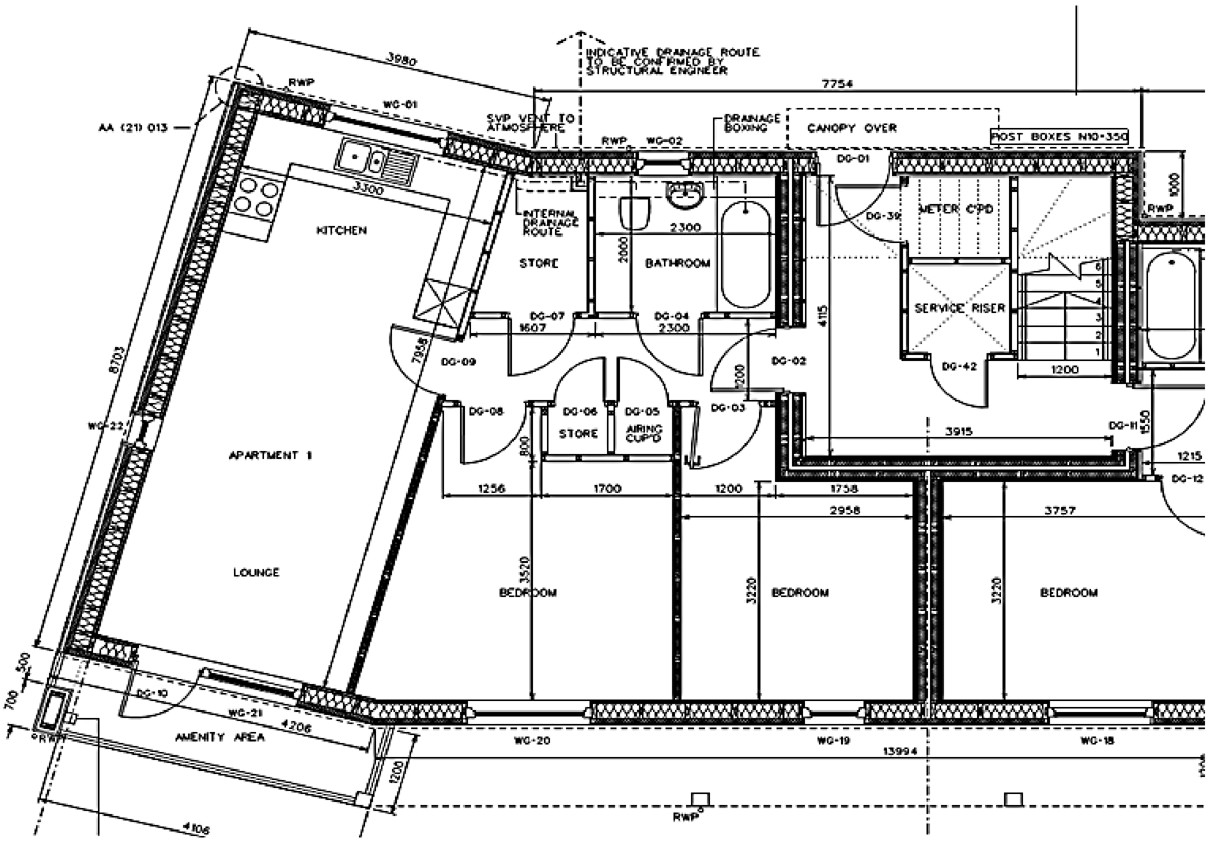


Table 4 gives the comparison of gross floor area (m^2) from Standard Assessment Procedure (SAP) 2005 methodology with final values determined from construction drawings (see Section 11.2 - Construction Drawings, page 123).

Table 4 – Comparison of Gross Floor Area from SAP Worksheet with Values Calculated from Drawings

	Dwelling A	Dwelling B
Gross Floor Area (m^2) from SAP Worksheet	107.12	66.51
Gross Floor Area (m^2) Calculated from Drawings	107.26	66.45

The key dimensions of the two monitored dwellings are summarised in Table 5.

Table 5 – Dimensions of Monitored Dwellings

Dwelling Code	Floor Area (m^2)	Internal Volume (m^3)	Room Height (m)	Envelope Area (m^2)	Glazed Area (m^2)	External Wall Area (m^2)	Total Exposed Area (m^2)
Dwelling A	107.1	279	2.5	350	22.2	115.3	243.9
Dwelling B	66.5	166	2.5	220	12.8	66.5	129.7

The fabric, ventilation and total heat loss coefficients for the two monitored dwellings are given in Table 6. The overall heat loss parameter for the house and apartment was very low at 0.59 W/m^2K and 0.51 W/m^2K respectively.

Table 6 – Predicted SAP 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)	Heat Loss Parameter (W/m^2K)
Dwelling A	47.6	15.2	62.8	0.59
Dwelling B	25.0	9.0	34.0	0.51

1.3 Expected Results

The SAP outputs for useful energy requirement for space heating and domestic hot water (DHW) are given in Table 7. It can be seen that the annual requirement for delivered heat energy for both dwelling types is dominated by that for domestic hot water; which accounts for around 80 per cent of the heat requirement.

In both cases, the space heating requirement is less than 1000 kWh. This very low space heating requirement is mainly a result of the very low designed heat loss from the building fabric.

Table 7 – SAP Annual Useful Energy Requirement for Heat

Heat Energy	Dwelling A	Dwelling B
Heat for DHW (kWh)	3312.9	2696.6
Heat for Space Heating (kWh)	894.5	428.5
All Heat (kWh)	**4207.4**	**3125.1**

The SAP outputs for annual energy consumption and energy production are given in Table 8. These values take into account the assumptions for boiler efficiency [given as 92.1 per cent in the SAP 2005 worksheet] and distribution losses from the district heating system [where the distribution loss factor given as 1.05 in the SAP 2005 worksheet].

Table 8 – SAP Annual Energy Consumption and Energy Production

Energy Type	Dwelling A	Dwelling B
All Heat (kWh)	4796.7	3562.8
Lighting (kWh)	481.0	306.6
Pumps & Fans (kWh)	194.1	115.9
Solar PV Produced (kWh)	4158.8	2581.7

The SAP outputs for carbon emissions are given in Table 9. The designed emissions due to energy consumption for the dwelling are very low due to the low carbon intensity of biomass heat [given as 0.025 $kgCO_2/kWh$ in SAP 2005]. However the overall emissions are dominated by the effect of the carbon offset from the solar PV generation; which result in negative overall emissions: This being a key part of the overall design strategy for a CfSH6 dwelling necessary to offset the nominal electricity use for appliances and cooking in the dwellings.

Table 9 – SAP Annual Carbon Emissions

Energy Type	Dwelling A	Dwelling B
All Heat ($kgCO_2$.a)	119.9	89.1
Lighting ($kgCO_2$.a)	203.0	129.4
Pumps & Fans ($kgCO_2$.a)	81.9	48.9
Solar PV Electricity Exported	-2362.2	-1466.4
Total Emissions ($kgCO_2$.a)	**-1957.4**	**-1199.0**

The specific design performance targets for the Sinclair Meadows development are given in Table 10 and Table 11. The Target Emissions Rate (TER) and Dwelling Emission Rate (DER) from SAP 2005 and Part L checklist are given in Table 10. The calculated DERs are of the order -18 $kgCO_2/m^2$.a for both dwelling types and easily exceeds the target emissions rate of around 23 $kgCO_2/m^2$.a [i.e. as would be expected for CfSH6 compliant dwellings].

Table 10 – Target Emission Rate and Dwelling Emission Rate from SAP Assessment and Part L checklist

	Dwelling A	Dwelling B
Target Emission Rate, TER ($kgCO_2/m^2$.a)	23.31	23.97
Dwelling Emission Rate, DER ($kgCO_2/m^2$.a)	-18.27	-18.03

The total predicted DERs from the CfSH assessment are given in Table 11. The overall predicted net carbon emissions are -6.26 $kgCO_2/m^2$.a dwelling A and -2.85 $kgCO_2/m^2$.a dwelling B. The dwellings as designed therefore exceed the requirements of a zero carbon home.

Table 11 – Dwelling Emission Rate from CfSH

	Dwelling A	Dwelling B
Dwelling Emission Rate, DER ($kgCO_2/m^2$.a)	-16.91	-16.67
Net CO_2 Emissions ($kgCO_2/m^2$.a)	-6.26	-2.85

The Part L1 checklists for the apartment and house both state that there is no significant overheating risk in the summer. The parameters given for these assessments are summarised in Table 12. The assessments both assume the SAP default shading factors for dark curtains.

Table 12 – Assumptions used in SAP Overheating Risk Assessment

	Region	Thermal Mass Parameter (W/m²K)	Hot Weather Ventilation Rate (h^{-1})	Blinds/Curtains
Dwelling A	Borders	5.30	4.00	Dark curtain or roller blind
Dwelling B	Borders	4.53	6.00	Dark curtain or roller blind

The hot weather ventilation rate for the house is given as 4.0 h^{-1} [which is consistent with that given in SAP 2005 appendix P for a two storey dwelling with windows; open half the time and with cross ventilation]. The ventilation rate for ground floor apartment is given as 6.0 h^{-1}, however this value is only applicable for ground floor apartments where there is secure night time purge ventilation provided to at least two sides of the dwelling.

The monthly maximum and minimum internal temperatures in the monitored dwellings are shown by the graph in Figure 12. This shows that peak internal temperatures ranged from 25°C in winter to 35°C in summer.

Figure 12 – Monthly Maximum and Minimum Temperature in House A and Flat B

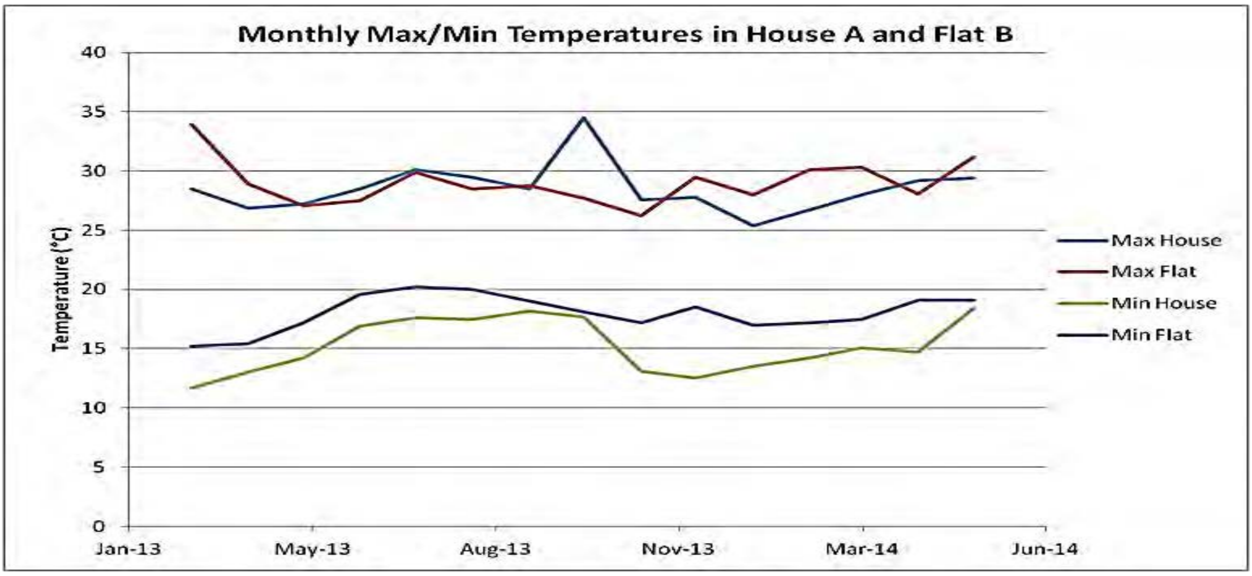
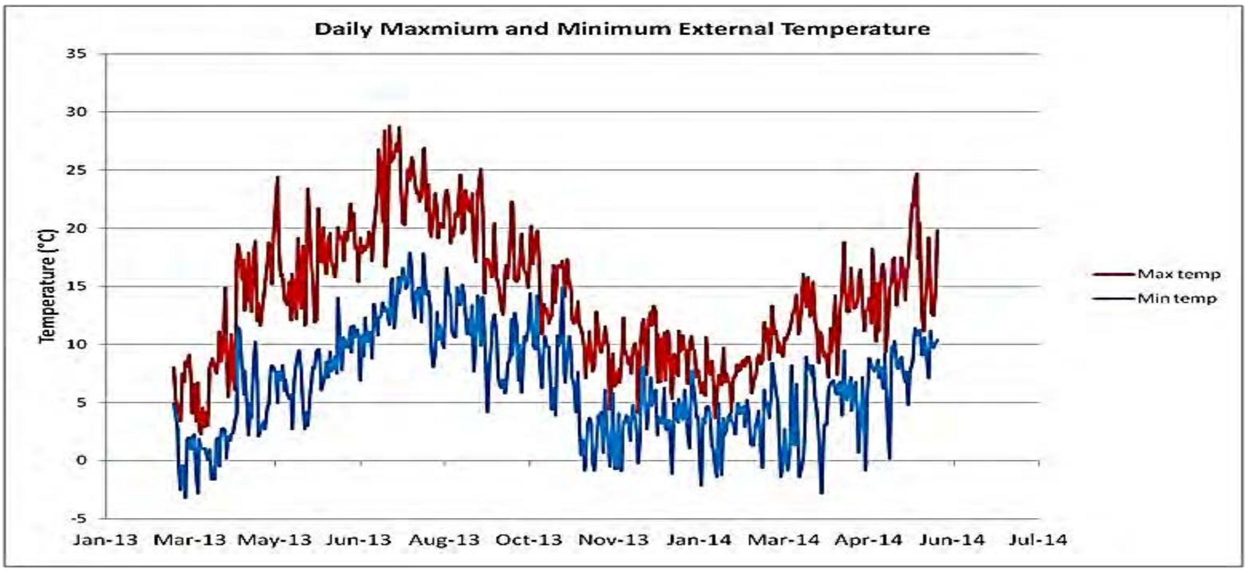


Figure 13 – Daily Maximum and Minimum External Temperature during Monitoring Period



The daily maximum and minimum external temperatures over the monitoring period are shown in Figure 13. The peak summer temperatures occurred during the monitoring period [July 2013] at around 28°C. Minimum winter temperatures were around -3°C. The relatively high maximum external temperatures for the period can therefore be considered as contributing to summer overheating.

The total predicted annual delivered heat energy requirement for all 21 dwellings on the development is 75426 kWh.a [data taken from SAP 2005 worksheets]. The total thermal heat energy output from the energy centre including expected distribution losses is calculated at 110,904 kWh.a. On this basis the expected distribution loss due to the external pipework is calculated to be about 32 per cent and the distribution loss factor would be 1.47. This is considerably higher than the distribution loss factor of 1.05 assumed in SAP 2005. The effect of a higher distribution loss factor on the overall carbon emissions from the dwellings is small, as the carbon intensity of biomass-fuelled derived heat is relatively low. However, it will increase the unit cost of delivering heat.

The assumed dwelling electrical energy use in SAP2005 and National Energy Efficiency Database (NEED) (DECC 2013a) are given in Table 13. The assumed electrical energy use in SAP2005 calculation is 2814 kWh.a, and 3722 kWh.a for an apartment and house respectively. The NEED database (DEC2013a) gives the median electrical energy use for a purpose-built housing association apartment as 2300 kWh.a in 2011 and for a 2 bedroom dwelling with 2 adults, as 3100 kWh.a. The NEED database (DEC2013a) gives the median electrical energy use for an end terrace housing association dwelling as 3300 kWh.a in 2011 and for a three bedroom dwelling with 2 adults as 3700 kWh.a.

Table 13 – Dwelling Electrical Energy Use used in SAP2005 and NEED database (DECC 2013a)

	SAP2005 Electrical Energy used (kWh.a)	NEED database (DECC 2013a), Energy use, Median (kWh.a)	NEED database (DEC 2013a), Energy use, for 2 bed dwelling with 2 adults (kWh.a)
Dwelling A	3722	3300	3700
Dwelling B	2814	2300	3100

The assumed dwelling heat energy delivered in SAP2005 and NEED database (DECC 2013a) are given in Table 14. The assumed heat energy delivered in SAP2005 calculation is 3125 kWh.a, and 4207 kWh.a for an apartment and house respectively. The NEED database (DEC2013a) gives the median heat energy delivered for a purpose-built housing association apartment as 6900 kWh.a in 2011 and for a 2 bedroom dwelling with 2 adults as 10900 kWh.a. The NEED database (DEC2013a) gives the median heat energy delivered for an end terrace housing association dwelling as 11500 kWh.a in 2011 and for a three bedroom dwelling with 2 adults as 13800 kWh.a.

Table 14 – Dwelling Heat Energy delivered in SAP2005 and NEED database (DECC 2013a)

	SAP2005 Heat Energy delivered (kWh.a)	NEED database (DECC 2013a), Heat delivered, Median (kWh.a)	NEED database (DEC 2013a), Heat delivered use, for 2 bed dwelling with 2 adults (kWh.a)
Dwelling A	4207*	11500	13800
Dwelling B	3125*	6900	10900

* Note: SAP2005 heat energy delivered for apartment (3125 kWh.a) comprised 428 kWh.a space heating, and 2697 kWh.a domestic hot water (DWH). Heat energy delivered for house (4207 kWh.a) comprised 894 kWh.a space heating and 3313 kWh.a DWH.

The analysis for the development shows that the mean electrical energy use for all 21 dwellings is 2929 kWh.a [comprised 2346 kWh.a apartments and 3511 kWh.a houses]. The mean heat energy delivered is 2753 kWh.a [comprised 2586 kWh.a apartments and 2919 kWh.a houses] (Table 15).

Table 15 – Mean Electricity Energy Used and Mean Heat Energy Delivered

	Electrical energy used, (kWh.a)	Heat energy delivered, Mean (kWh.a)
Dwelling A	3511	2919
Dwelling B	2346	2586
Mean (kWh.a)	2929	2753

Figure 14 shows the Solar PV array at the development. The total predicted annual output of the overall 85 kWpeak solar PV array [comprising 302 panels; @ 281 Wpeak per panel] based on the inputs to the SAP2005 assessments for the dwellings was 70845 kWh.a. The analysis for the development shows that the mean output of the array was 79594 kWh.a for the period 1/12/12 – 31/5/14 [comprised of approx. 51 per cent electrical energy generated from the array located on the apartments and approx. 49 per cent from the houses] (Table 16).

Figure 14 – Solar PV Array

Table 16 - Total Annual Output from PV Arrays

Period	Total PV Output Use (kWh.a)	Total PV Output from Apartment Array (kWh.a)	Total PV Output from House Arrays (kWh.a)
1/12/12 to 30/11/13	86059	40299	45760
1/1/13 to 31/12/14	86731	40429	46302
1/2/13 to 31/1/14	87594	40702	46892
1/3/13 to 28/2/14	72964	40914	32050
1/4/13 to 31/3/14	75062	41709	33353
1/5/13 to 30/4/14	74153	40881	33272
1/6/13 to 31/5/14	74597	40652	33945
Mean (kWh.a)	**79594**	**40798**	**38796**
Percentage split		**51**	**49**

It should be noted however that SAP is relatively conservative in its calculation of solar PV performance, and the SAP algorithm applies a factor of 80 per cent to account for the system efficiency. By comparison the measured data from Sinclair Meadows indicate that the solar PV system efficiency factor is of the order 90 per cent or better.

Figure 15 shows the Hargassner Wood Pellet Boiler / Plant Room at the development. The overall performance of the district heating system was assessed using ESCo data and biomass-fuel delivery data for the period 25th March 2013 to the 24th March 2014. This period was chosen to match with biomass-fuel deliveries that took place on both these dates and therefore minimises any potential variability caused by the periodic nature of the deliveries.

Figure 15 – Hargassner Wood Pellet Boiler / Plant Room

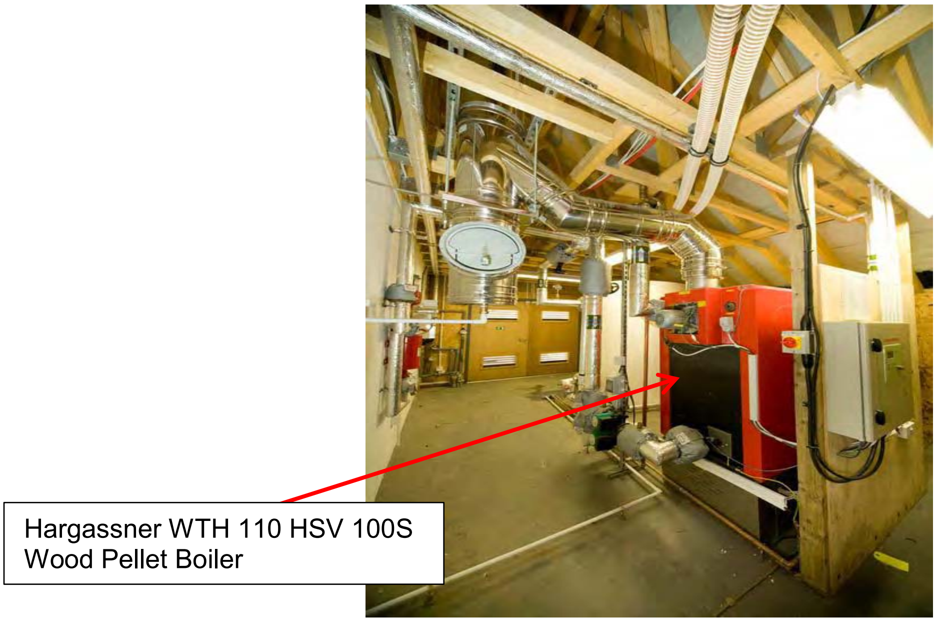


Figure 16 – Hargassner Wood Pellet Boiler

The distribution efficiency of the heat via the district heating system was only 26 per cent (Table 17). This compares to the assumption used in the SAP calculation of 95 per cent [although it should be noted that the SAP2005 protocol is based on a nominal figure for distribution efficiency and does not require detailed calculation of pipe losses]. An assessment of the actual losses from the communal system was carried out based on manufacturers' data and observations of the installed system.

Table 17 - District Heating System Calculated Efficiencies for Period 25/3/13 to 24/3/14

Efficiency of Biomass Boiler (%) (Based on net calorific value)	82.2
District Heating System Distribution Efficiency Biomass Heat Only (%)	26.2
District Heating System Distribution Efficiency All Heat (including buffer immersion heat) (%)	25.6
Parasitic Electricity as Function of Delivered Heat (%)	28.1
District Heating System Overall System Efficiency (%)	**20.3**

The net efficiency of the biomass-fuelled boiler was 82.2 per cent. This is based on the net calorific value for biomass-fuel wood pellets of 4,800 kWh/tonne [as specified by the biomass-fuel supplier (Verdo 2014)]. This compares to the manufacturers quoted boiler efficiency of 93.6 per cent. The reason for the under-performance of the boiler is unknown.

The parasitic electricity used to run the communal system (pumps, boiler controls, buffer tank immersion) was high at 28.1 per cent as a function of delivered heat. However this factor increases to as high as 40 per cent later in the monitoring period; where the use of immersion [electric] heat was higher due to the failure of the biomass-fuelled boiler in April 2014. The overall system efficiency for delivery of heat to the dwellings was 20.3 per cent.

Table 18 - Delivered Fuel Carbon Intensity Factors in SAP2005

Energy Source	SAP 2005 Carbon Intensity Factor ($kgCO_2/kWh$)
Electricity Imported from Grid	0.422
Electricity Exported to Grid	0.568
Mains Natural Gas	0.194
Biomass Wood Pellets	0.025

Carbon emissions for the development were calculated using the measured data for the period 25/3/13 to 24/3/14 (Table 18). The carbon intensities for delivered heat from the communal heating system were calculated using the measured system efficiencies as shown in Table 19. The overall carbon intensity of delivered heat was 0.328 $kgCO_2/kWh$ [i.e. when the effect of the parasitic plant room electricity use was included]. This is around seven times the predicted carbon intensity of 0.044 $kgCO_2/kWh$ calculated using the nominal SAP inputs of 93.6 per cent for boiler efficiency and 95 per cent distribution efficiency.

Table 19 - Measured Carbon Intensities for District Heating System

Energy Definition	Carbon Intensity ($kgCO_2/kWh$)
Delivered Heat (excluding communal system parasitic electricity for pumps, boiler controls and buffer immersion)	0.181
Parasitic Electricity for Communal System (at 28.1% of Heat)	0.147
Delivered Heat including Parasitic Electricity	0.328

The annual overall carbon emissions for the development were calculated for the period 25th March 2013 to the 24th March 2014 to coincide with the biomass-fuel delivery dates. The data used in the carbon calculation are given in Table 20. Total emissions from the development for the period were 10.3 tonnes of CO_2 per annum. This is equivalent to 5.65 $kgCO_2/m^2$.a based on the total floor area of the 21 dwellings at Sinclair Meadows of 1825 m^2.

Table 20 - Sinclair Meadows Annual Energy Data for Period 25/3/13 to 24/3/14

Energy Source	Annual Energy (kWh.a)	Carbon Emissions ($kgCO_2$.a)
Biomass-fuel Delivered	254976	9944.1
Electricity Used by Dwellings	60596	
Electricity Used by Communal Heating System	15466	
Electricity Generated by solar PV Arrays	75349	
Net Electricity Imported from Grid	713	372.1
Total Carbon Emissions		**10316**

This is perhaps an indication that the use of district heating for small scale low energy developments such as Sinclair Meadows may not be appropriate due to the lack of a sufficiently large heat demand to offset the system inefficiencies and distribution losses.

1.4 Conclusions and key findings for this section

The results from the Sinclair Meadows development show that a fabric first approach to building design and construction can result in significant reduction in energy demand for space heating compared to the building stock.

The designed performance of the fabric at Sinclair meadows would be significantly better than that which would be required to meet the government's carbon zero definition as set out L (1A) of the Building Regulations (2010) and the CfSH6.

The calculated DERs was of the order -18 $kgCO_2/m^2$.a for both dwelling types which easily exceeded the target emissions rate of around 23 $kgCO_2/m^2$.a. The overall predicted net carbon emissions were -2.85 $kgCO_2/m^2$.a for the apartment and -6.26 $kgCO_2/m^2$.a for the house and hence the dwellings as designed therefore exceeded the requirements of a zero carbon home.

The designed emissions due to energy consumption for the dwellings were very low due to the low carbon intensity of biomass heat with the overall emissions being dominated by the effect of the carbon offset from the solar PV generation [which resulted in negative overall emissions].

The designed heat loss parameter for the house and apartment was very low at 0.59 W/m^2K and 0.51 W/m^2K respectively and it could be seen that the annual requirement for delivered heat energy for both dwelling types was dominated by that for domestic hot water.

The effect of a higher distribution loss factor on the overall carbon emissions from the dwellings was small, as the carbon intensity of biomass-fuelled derived heat was relatively low. However, the net effect would be to increase the unit cost of delivering heat.

The net efficiency of the biomass-fuelled boiler was 82.2 per cent compared to the manufacturers quoted boiler efficiency of 93.6 per cent. The overall system efficiency for delivery of heat to the dwellings was 20.3 per cent; and this was perhaps an indication that the use of district heating for small scale low energy developments such as Sinclair Meadows is inappropriate due to the lack of a sufficiently large heat demand to offset the system inefficiencies and distribution losses.

The design data showed that there was no significant tendency to overheat in the living rooms: However, the measured temperatures did indicate overheating in the bedrooms in both dwellings during the summer however this may have been due in part to the relatively high summer temperatures in the UK in 2013.

Data from this study indicates that residents of low carbon energy efficiency 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 Sinclair Meadows was due to active choices made by tenants with respect to heating, and what proportion was down to other causes such as heat losses from the heat distribution system.

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 tenants concerning the function use and operation of ventilation systems; and to investigate the effect on air quality factors relating to the design, installation and operation of the ventilation system.

2 About the buildings: Design and construction audit, drawings & SAP calculation review

2.1 Detailed building description

See also Section 11.2 - Construction Drawings, pages 123 to 128. From the start of the project, the emphasis was placed on the quality of the building fabric, especially on airtightness and heat loss. The principal adopted was that by starting with a high quality building fabric would mean less energy required to heat/cool the buildings during occupancy.

2.1.1 Building materials

Natural materials have been specified wherever possible (timber frame, hemp insulation, lime render, sustainable timber, etc.) All dwellings were constructed using a combination of NBT Pavatherm-Plus, PavaFlex insulation, Scottish Larch Timber Cladding, and NBT Diffutherm with Baumit lime render. Design targets for thermal performance required insulation levels to be in excess of 2010 Building Regulations minima by 15 per cent; with proposed external wall U-value of 0.21 W/m^{2}K and triple glazed window; with proposed U-value of 0.7 W/m^{2}K. Ground floor cassettes comprised Lewis® and screed composite floor; with proposed U-value 0.1 W/m^{2}K. Roofs were clad with cedar shingles; with a proposed U-value 0.09 W/m^{2}K (Table 21).

Table 21 - Summary designed building fabric U-values

Design Element	Design U-value
Walls	0.14 W/m^{2}K
Floor	0.1 W/m^{2}K
Windows	0.7 W/m^{2}K
Roof	0.09 W/m^{2}K

The design target for air permeability was 2.5 m^3/h.m^2@50pa [Part L1a 2006 default limit 10 m^3/h.m^2@50pa].

2.2 Design & construction audit

2.2.1 Design intent

The final National Building Specification (NBS) was provided by the architect on 20 May 2011. The architect designed the floors, roofs, walls and windows to comply with the Green Guide Housing Specification and it was noted at the outset that any divergence from the original design specification may affect the CfSH rating. The design features of all houses are largely the same, with the notable exception of the end property to the south (dwelling A) of the development which has two extra windows and a greater area of exposed external wall. The dwellings have a sunspace on both lower and upper floors. In the original design, this sunspace didn't have a ceiling between the two floors, but due to building regulations relating to fire risk, this was deemed necessary. The sunspace was designed with double-doors which in the event of fire, would act as a thermal barrier between the space and the rest of the property.

The design uses carbon negative and natural materials as much as possible. The walls are constructed from 220mm timber stud filled with wood fibre insulation. The architect had originally considered using hemp insulation, but the intended supplier had stopped using this material prior to commencement of the build and so it was decided to use a wood fibre option instead.

The building contractor for the development undertook a Post Construction Carbon Review in August 2012; for which the outcome was summarised by the Design Team as:

> ***'…each Sinclair Meadows… …house exceeds the 2013 Zero Carbon definition by 10.66 Kg/CO_2/m^2 per year, or 16.96 tonnes of CO_2 will be offset by all the dwellings per year. In 2.8 years, the Sinclair Meadows… …homes will have offset 39.6 tonnes from the sites total construction CO_2…' [Consensus of Design Team View]***

2.2.2 In-use operation

The district heating system comprises a 100 kW biomass boiler and 24 kW electric immersions within the accumulator buffer vessel. The district heating pumps alternate on a 12 hourly switch over. The community district heating distribution is via two circuits of 63 mm Uponor Thermo Twin PE-Xa pipes, supplying the heat to apartments and houses retrospectively. The heating to each dwelling from the district distribution is via a heat exchanger in a packaged district heating interface unit (HIU), which includes a 120 litre mains pressure hot water cylinder and local backup immersion. District pumps are multi speed direct driven in duty and standby configuration with automatic 12 hourly switch-over for the main circulation pumps.

The heating system in the properties was sub-divided into two thermostatically controlled zones; one in the main living room and one in the corridor [in the houses], and in the apartments there was one in the living room and one in the main bedroom. DHW was at mains pressure with the temperature set to 65^{o}C.

In the event that the biomass-fuelled boiler failed there was an immersion heater fitted on the accumulator buffer vessel; which gave approx. ¼ output of the boiler and could run either heating or hot water [although not at the same time]. In this situation tenants would be asked to switch off hot water and use their boost on their individual immersion heaters for periods of ¼, ½, 1 or 2 hours. This was done to ensure that the local immersion heaters would automatically switch off after a set period irrespective of tenant intervention.

The project aimed to reduce the amount of water used by the residents as far as possible with a target 80 litres/person/day [in line with the requirements of the highest levels of the CfSH and well below the existing requirements of Building Regulation of 125 litres/person/day]. This was achieved partly through the specification of "low-flow" taps and showers and supply of A–rated washing machines and dishwashers. Emphasis was also placed on reducing water use throughout the construction period of the properties, and water use was monitored through the Contractor's Site Waste Management Plans. The development includes a rainwater harvesting system to provide water for the toilets, washing machines and gardening for all properties. Houses and apartments are supplied with water for toilet flushing by a rainwater harvesting system [i.e. these being individual systems for the 9 houses and one communal system for the 12 apartments]. The development design originally looked at using rainwater for washing machines but this was abandoned following initial trials due to discoloration in the water from the roof shingles.

All dwellings had water butts for use in gardening, and the rainwater harvesting system on apartments also fed an external ground water supply [for use by outside taps].

All dwellings were supplied with a 'Current Cost' energy meters and ten separate appliance adapters; with which individual appliances could be plugged in [i.e. for tenants to find out how much they are spending on each]. Additionally a manual/guide book for this was supplied as part of the initial tenant Handover Pack.

The houses and apartments were fitted with a Mechanical Ventilation Heat Recovery (MVHR) unit, which was designed to operate 24/7 with a separate boost linked to the light switch in the bathroom and an additional boost switch located in the kitchen. The bathrooms in houses are internal with no windows so the MVHR boost always turned on whenever the bathroom was in use. The kitchen also featured a separate extract fan over the cooker. In the apartments, the MVHR units were located in the storage cupboard. In the houses, the MVHR units were located in the loft space. There is a loft hatch and walk way for servicing and access for replacement of filters. The tenants of these properties were not expected to replace the filters and this is the housing association's role as part of a biannual maintenance plan.

The MVHR installation uses flexi ducts pipework. When the build took place the first 3 houses were built the joists were misaligned and so the flexi duct for MVHR had to wind around them. However this was spotted early in the construction process and as a consequence joists in subsequent properties were installed in such a manner as to enable straight runs (see also Figure 51 – Dwelling A: MVHR Unit in Loft, page 72 and Figure 52 – Dwelling A: Flexible Duct, page 72). A challenge the design team raised about the MVHR systems was to get tenants to push the boost button and not just open the window [for example when they burn toast].

The solar PV systems have individual smart meters and are installed on the mains (landlord's network). Each house has a solar PV array fitted to the roof, although tenants don't directly benefit from the Feed-in-Tariff (FiT). Although the tenants were initially encouraged to operate and use appliances during the day, at the mid project review in October 2013, Three Rivers Housing Association confirmed that it was unable to set tenants up on a multiple tariff scheme to allow them to get free electricity during the day. To reflect this Three Rivers Housing Association had reduced the overall energy cost [p/kWh] to the tenants.

The biomass-fuelled district heating system included a 24 kW immersion heater in case of boiler failure. In the original design, additional buffer storage was also considered but it was not deemed possible to physically fit this into the boiler plant room. Since the development was built, an additional explosion proof panel was added to the biomass material storage area for additional safety. In the apartment blocks, there are hallways and stairwells linking the external door to the front doors of these flats. These spaces are heated using electric heaters.

A control/meter box provided billing information for the properties which included electricity use, heating and hot water, solar PV generated electricity output and both cold water and grey water usage. At the time of the design team walkthrough the plan was for there to be a computer located in the boiler room which would have ESCo monitoring software installed to enable the team to interrogate the utility data. This was however changed and the computer was not installed: However all meters at site can be read remotely via an internet portal.

2.3 SAP calculation review

The houses on the development were built in accordance with the requirements of Part L1a 2006. All SAP calculations provided had therefore been carried out with SAP 2005, with the SAP assessor using National Home Energy Rating (NHER) Plan Assessor version 4.5.21. CfSH assessments were completed using the NHER software version of the Code compatible with SAP 2005. A review of the SAP assessments was carried out using data from the as-built SAP worksheets for one of the apartments (ground floor apartment, dwelling B) and one of the houses (end terrace, dwelling A). These assessments were all dated for the 9th August 2012.

2.3.1 SAP Energy and Carbon Performance Data

The SAP outputs for useful energy requirement for space heating and DHW are given in Table 22. It can be seen that the annual requirement for delivered heat energy for both dwelling types is dominated by that for domestic hot water, which accounts for around 80 per cent of the heat requirement. In both cases, the space heating requirement is less than 1000 kWh. This very low space heating requirement is mainly a result of the very low designed heat loss from the building fabric.

Table 22 – SAP Annual Useful Energy Requirement for Heat

Heat Energy	Dwelling A	Dwelling B
Heat for DHW (kWh)	3312.9	2696.6
Heat for Space Heating (kWh)	894.5	428.5
All Heat (kWh)	**4207.4**	**3125.1**

The SAP outputs for annual energy consumption and energy production are given in Table 23. These values take into account the assumptions for boiler efficiency [given as 92.1 per cent in the SAP worksheet] and distribution losses from the district heating system [distribution loss factor given as 1.05 in the SAP worksheet].

Table 23 – SAP Annual Energy Consumption and Energy Production

Energy Type	Dwelling A	Dwelling B
All Heat (kWh)	4796.7	3562.8
Lighting (kWh)	481.0	306.6
Pumps & Fans (kWh)	194.1	115.9
Solar PV Produced (kWh)	4158.8	2581.7

The SAP outputs for carbon emissions are given in Table 24. The designed emissions due to energy consumption for the dwelling are very low due to the low carbon intensity of biomass-fuel heat [0.025 $kgCO_2/kWh$ in SAP2005]. The overall emissions are dominated by the effect of the carbon offset from the solar PV generation which result in negative overall emissions. This is part of the design strategy for a CfSH6 dwelling to offset the nominal electricity use for appliances and cooking in the dwellings.

Table 24 – SAP Annual Carbon Emissions

Energy Type	Dwelling A	Dwelling B
All Heat ($kgCO_2/a$)	119.9	89.1
Lighting ($kgCO_2/a$)	203.0	129.4
Pumps & Fans ($kgCO_2/a$)	81.9	48.9
Solar PV Electricity Exported	-2362.2	-1466.4
Total Emissions ($kgCO_2/a$)	**-1957.4**	**-1199.0**

The calculated Dwelling Emission Rate (DER) is of the order -18 $kgCO_2/m^2.a$ for both dwelling types (Table 25) and easily exceeds the target emissions rate of around 23 $kgCO_2/m^2.a$; as would be expected for CfSH6 compliant dwellings.

Table 25 – Target Emission Rate and Dwelling Emission Rate from SAP Assessment and Part L Checklist

	Dwelling A	Dwelling B
Target Emission Rate ($kgCO_2/m^2.a$)	23.31	23.97
Dwelling Emission Rate ($kgCO_2/m^2.a$)	-18.27	-18.03

The total predicted carbon emissions from the CfSH assessments are given in Table 26. The overall predicted net carbon emissions are -2.85 $kgCO_2/m^2.a$ for the apartment and -6.26 $kgCO_2/m^2.a$ for the house. The dwellings as designed therefore exceed the requirements of a zero carbon home.

It can be seen that there is a mismatch of around 1.3 $kgCO_2/m^2$.a between the DERs obtained from the as-built SAP worksheets [-18.03 $kgCO_2/m^2$.a and -18.27 $kgCO_2/m^2$.a respectively] and those given in the CfSH assessments [-16.67 $kgCO_2/m^2$.a and -16.91 $kgCO_2/m^2$.a respectively]. Analysis of the data indicates that this discrepancy will be due to the use of 100 per cent low energy lighting in the as-built SAP calculations. This should have been limited to 30 per cent for compliance calculations [even where the installed low energy lighting exceeds this limit].

The correct DERs are those as given in the CfSH assessment. The correct annual lighting energy for compliance purposes as calculated using Appendix L of SAP 2005 at 30 per cent low energy lighting would be 521 kWh.a for the apartment and 827 kWh.a for the house. The difference between these lighting values and those given in Table 23 is consistent with the adjustment for low energy lighting of 1.36 $kgCO_2/m^2$.a [as given in the CfSH worksheet].

Table 26 – Dwelling Emission Rate from Code for Sustainable Homes Assessment

	Dwelling A	Dwelling B
Dwelling Emission Rate ($kgCO_2/m^2$.a)	-16.91	-16.67
Appliances and Cooking ($kgCO_2/m^2$.a)	12.01	15.18
Adjustment for Low Energy Lighting and Secondary Heat ($kgCO_2/m^2$.a)	-1.36	-1.36
Net CO_2 Emissions ($kgCO_2/m^2$.a)	-6.26	-2.85

2.3.2 Dwelling Dimensions

The dwelling dimensions given in the SAP worksheets were cross checked against those calculated directly from the supplied drawings. The comparison of gross floor area showed that the SAP values and calculated values were consistent for both the apartment and house (Table 27). Calculated values for room height were also consistent with those in the SAP worksheets (Table 28).

Table 27 – Comparison of Gross Floor Area from SAP Worksheet with Values Calculated from Drawings

	Dwelling A	Dwelling B
Gross Floor Area (m^2) from SAP Worksheet	107.12	66.51
Gross Floor Area (m^2) Calculated from Drawings	107.26	66.45

Table 28 – Dimensions of Monitored Dwellings

Dwelling Code	Floor Area (m^2)	Internal Volume (m^3)	Room Height (m)	Envelope Area (m^2)	Glazed Area (m^2)	External Wall Area (m^2)	Total Exposed Area (m^2)
Dwelling A	107.1	279	2.5	350	22.2	115.3	243.9
Dwelling B	66.5	166	2.5	220	12.8	66.5	129.7

The fabric, ventilation and total heat loss coefficients for the two monitored dwellings are given in Table 29. The heat loss parameters for the house and flat are very low at 0.59 W/m^2K and 0.51 W/m^2K respectively.

Table 29 – Predicted SAP 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)	Heat Loss Parameter (W/m^2K)
Dwelling A	47.6	15.2	62.8	0.59
Dwelling B	25.0	9.0	34.0	0.51

2.3.3 Sun-Space

The houses on the development were designed with a sun-space on the ground and first floors. Examination of the drawings showed that this feature is not a sun-space in the traditional sense as it is contained within the heated envelope of the dwellings. There are glazed partitions and glazed doors separating the sun-space from the rest of the building, but in terms of the SAP calculation it is treated the same as any other conditioned space. The SAP calculation assigns no energy benefit to the presence of the sun-space.

2.3.4 SAP U-value Inputs

The nominal wall U-value given in the SAP worksheets is 0.14 W/m^{2}K. This is slightly better than the U-value of 0.15 W/m^{2}K given in the manufacturer's datasheet for the wall system as used on the development. The wall value calculated according to the combined method using the manufacturer's data for thermal conductivity of the insulation and standard timber fraction of 15 per cent also gives a wall of 0.15 W/m^{2}K.

The effect of the difference in wall U-value is small; and would result in an increase in the fabric heat loss of around 2 per cent for both the house and apartment.

The nominal value given for the cold roof in the house SAP worksheet is 0.09 W/m^{2}K. This compares to a value of 0.08 W/m^{2}K calculated using the combined method. The effect of the difference in roof U-value is small, and would result in a decrease in the fabric heat loss of around 1 per cent for the house; thus offsetting to some degree the difference in wall U-value.

The fabric heat loss calculations in the SAP worksheets for the apartments do not include the walls between the apartments/flats and stairwells/commons spaces as heat loss elements. In SAP 2005 this is a valid assumption as long as the common spaces are heated. The supplied drawings do show that electrical panel heaters will be installed on the ground floor of the stairwells in the apartment block. The common areas are treated as a non-domestic building for the purposes of building regulations and their energy performance would require to be assessed under Part L2a using Simplified Building Energy Model (SBEM); although the Building Regulation UK part L (BRUKL) output for this assessment was not available for analysis.

2.3.5 Thermal Bridging

The SAP calculations for the development use a y-value of 0.02 W/m^{2}K for the thermal bridging component of heat loss. This represents a significant reduction in heat loss compared to that assumed for designs that use the default y-value of 0.08 W/m^{2}K allowable in SAP2005 [when designing with standard accredited construction details]. It is understood that a full set of thermal bridging calculations have been carried out by the developer using numerical thermal modelling in order to assign a y-value of 0.02 to the house designs on the development; but it has not been possible to verify these calculations. An alternative method of compliance would have been to provide modelled psi-value for each junction type and to calculate the thermal bridging for each dwelling design according to the overall length of each junction type. This method is slightly more time consuming than the y-value approach, but would result in a more accurate determination of thermal bridging heat loss. This is because applying a standardised y-value across all dwelling types can result in an underestimate of thermal bridging for some dwelling types, especially apartments and bungalows.

2.3.6 Air Permeability

The design air permeability for the development was 2.5 m^3/h.m^2. The measured values of air permeability given in the Part L1a checklists were given as 1.62 m^3/h.m^2 for the apartment and 1.64 m^3/h.m^2 for the house (Table 30), showing both compliance with the design target and being significantly better than the Part L1a 2006 default limit of 10 $m^3/h.m^2$.

The values of air permeability used for the air infiltration calculation in the SAP worksheet are consistent with the measured values (infiltration = air permeability/20); demonstrating that the actual pressure test data have been used in the as-built SAP calculation.

Table 30 – Design and Measured Air Permeability and SAP Infiltration Rate

	Dwelling A	Dwelling B
Design Air Permeability ($m^3/h.m^2$)	2.50	2.50
Measured Air Permeability in L1a Checklist ($m^3/h.m^2$)	1.64	1.62
Infiltration Rate in SAP Worksheet (h^{-1})	0.08	0.08

A check of the data given on the pressure test certificates shows a small discrepancy in the calculated ground floor areas compared to those given in the SAP worksheet; possibly because the building data were taken from the actual building rather than the drawings (Table 31). This would also result in a small difference in the calculated envelope area and hence the measured air permeability value. However the impact of these differences would not be significant in terms of the final SAP calculation and is within the scale of expected errors in dimensional calculations.

Table 31 – Comparison of Floor Area Values in SAP worksheet and Air permeability Certificate

	Dwelling A	Dwelling B
Ground Floor Area (m^2) from SAP Worksheet	53.56	66.51
Ground Floor Area (m^2) from Air Permeability Certificate	58.1	68.1

2.3.7 Hot Water Cylinder

The Part L1a checklist requires the assessor to confirm that any hot water cylinder meets the requirements Domestic Heating Compliance Guide in terms of the insulation. The response given in the Part L checklists for the apartment and house both state that the dwellings have no hot water cylinders. However, all the dwellings on the development do in fact have a 120 litres hot water cylinder which is linked to the heat interface unit (HIU). The cylinder used [Range Tribune HE] does meet the requirements in the Heating Compliance Guide. It was also noted that the SAP worksheets also failed to record the fact that dwellings had a hot water cylinder; which is possibly linked to software inputs in the Part L checklist or SAP worksheet.

The way SAP 2005 accounts for hot water storage losses in the case where water is provided instantaneously via a HIU is to assume a nominal cylinder volume of 110 litres with 50 mm factory applied insulation [where this is to account for losses for the HIU heat exchanger itself]. Using these data, the water storage loss is calculated as 377 kWh.a; which is consistent with the value used in the SAP worksheet. However, using the actual cylinder size of 120 litres with the manufacturers declared heat loss factor of 1.05 kWh/day, would give a lower water storage loss of 230 kWh.a. As a consequence this means that the as-built SAP assessments have over-estimated hot water storage losses by around 50 per cent.

2.3.8 Mean Monthly Temperature

The trend in mean monthly temperature was similar for both dwellings, with the main difference being slightly higher temperatures in dwelling B during winter (around 21 to 22°C) compared to dwelling A (around 20 to 21°C). Mean temperatures in the summer were of the order 24 to 25°C in both dwellings (see Section 7.2 - Internal Temperature, page 87 for additional information). The winter temperatures were higher than that assumed by the two-zone model in the SAP calculations [i.e. SAP mean temperatures were 19.3°C for the house and 19.3°C for the apartment.] The SAP model will therefore underestimate the actual heating load.

The conclusion is that the Sinclair Meadows residents are living at higher internal temperatures in winter than is typical for the UK.

2.3.9 Summertime Overheating Risk Assessment

The Part L1 checklists for the apartment and house both state that there is no significant overheating risk in the summer. The parameters given for these assessments are summarised in Table 32. The TMP's used in the assessment are consistent with the low thermal mass of the timber frame construction on the development. The assessments both assume the SAP default shading factors for dark curtains.

Table 32 – Assumptions used in SAP Overheating Risk Assessment

	Region	Thermal Mass Parameter (W/m^{2}K)	Hot Weather Ventilation Rate (h^{-1})	Blinds/Curtains
Dwelling A	Borders	5.30	4.00	Dark Curtain or Roller Blind
Dwelling B	Borders	4.53	6.00	Dark Curtain or Roller Blind

The hot weather ventilation rate for the dwelling A is given as 4.0 h$^{-1;}$ which is consistent with that given in SAP 2005 appendix P for a two storey dwelling with windows open half the time and with cross ventilation. The ventilation rate for ground floor apartment, dwelling B is given as 6.0 h^{-1}. However this value is only applicable for ground floor apartments where there is secure night time purge ventilation provided to at least two sides of the dwelling.

The drawings and specifications indicated that no additional provision for secure purge ventilation [in addition to the windows] has been made to the ground floor apartments; and this was confirmed by a site visit (see Section 12.2 - Site Monitoring Observations, page 138). SAP 2005 states that windows in ground floor flats cannot be left open all night due to security issues and it should be assumed that windows are only left slightly open using security latches to around 50 mm. As a consequence Appendix P of SAP2005 gives the effective air change rate for such slightly open windows in apartments with cross ventilation as 0.8 h^{-1}. Replacing the ventilation rate value of 6.0 h^{-1} with 0.8 h^{-1} in the overheating assessment for the apartment, results in a calculated high risk of excessive internal temperatures in the summer. This assessment includes an allowance for the shading effect of the balcony on the south facade.

2.3.10 Boiler Efficiency

The efficiency of the Hargassner communal biomass boiler is given as 92.1 per cent in the SAP 2005 assessments. This is consistent with the manufacturers quoted net efficiency value for a Hargassner WTH HSV 70 wood pellet boiler. However, information provided by the housing association and in the M&E specification indicated that the boiler may actually be a Hargassner WTH HSV 110 model [which has higher manufacturers quoted net efficiency of 93.6 per cent]. There was therefore some confusion as to the exact model of district heating boiler installed. The commissioning certificate provided for the biomass system does not state the model number for the boiler. The installers commissioning checklist also does not state the model number, but does state that the boiler rating is 70 kW. A site visit to the plant room carried out on the 13th May 2014 showed that the boiler was designated as a Hargassner WTH 110 HSV 100S with heat output of 116.5 kW for pellets (Figure 17). The manufacturer's datasheet gives the efficiency of a HSV100S boiler as 93.3 per cent.

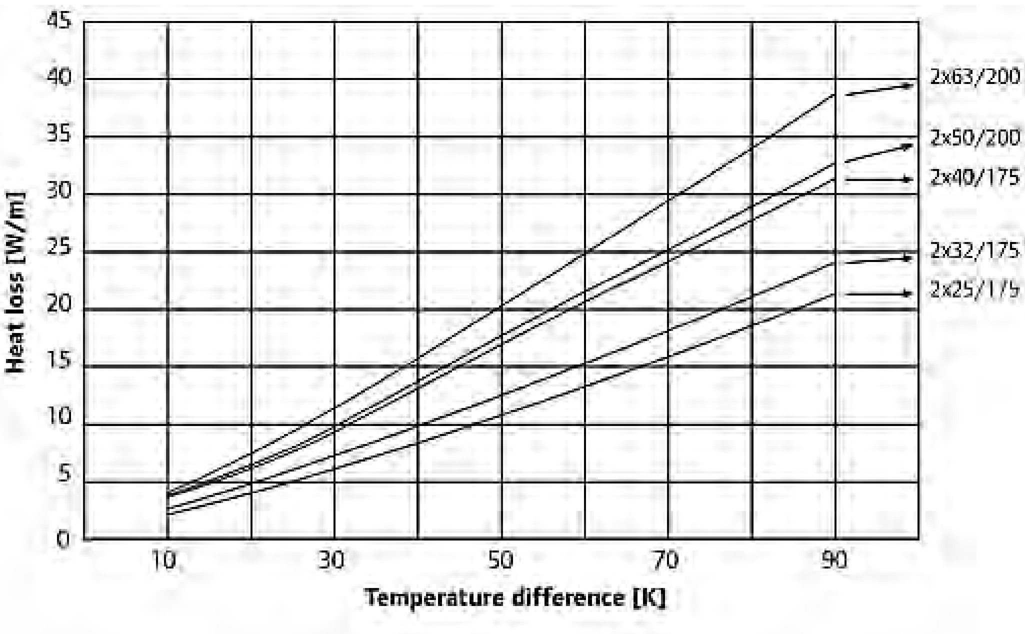
Figure 17 – Photograph of Boiler Plate Showing Model Information

2.3.11 Community Heating

The main inputs for the district heating system in SAP 2005 are the boiler efficiency and the distribution loss factor. The distribution loss factor used in the SAP 2005 worksheets for the development is 1.05, which is equivalent to a distribution loss of 4.76 per cent. This factor is consistent with the nominal value for modern pre-insulated district heating pipework operating below 100°C as given in Table 12c of SAP 2005.

The M&E specification for the development gives the installed district heating pipework as 63 mm Uponor Thermo Twin. The manufacturer's heat loss curves for this pipe are shown in Figure 18.

Figure 18 – Pipe Heat Loss Factor for Uponor Thermo Twin District Heating Pipe



Assuming a flow temperature of 80°C and return temperature of 50°C, this would give an average pipe temperature of 65°C. Assuming a ground temperature of 10°C gives a delta-T of 55°C. Interpolating this temperature difference on the heat loss curve in Figure 18 equates to a pipe heat loss factor of about 22.5 W/m.

The total length of external district heating pipework from the energy centre to the houses and apartment block is around 180 m [length scaled from site M&E drawing]. This therefore gives the heat loss from the pipework as 4050 W: The system runs continuously, so the predicted annual energy loss from the external pipework is 35478 kWh.a.

The total predicted annual delivered heat energy requirement for all 21 dwellings on the development is 75426 kWh.a [data taken from SAP worksheets]. The total heat energy output from the energy centre including expected distribution losses is therefore 110,904 kWh.a. On this basis the expected distribution loss due to the external pipework is about 32 per cent and the distribution loss factor would be 1.47. This is considerably higher than the distribution loss factor of 1.05 assumed in SAP 2005.

Note: These calculations do not include any system losses, storage losses from the energy centre thermal store or losses from district pipework running inside the common areas of the apartment block.

The effect of a higher distribution loss factor on the overall carbon emissions from the dwellings is small, as the carbon intensity of biomass heat is relatively low: However, it will increase the unit cost of delivering heat.

It is also interesting to note that SAP 2005 calculation does not include inputs for the parasitic electricity use of the pumps and controls for the district heating system. The energy use of these pumping systems can be significant in small district heating systems, but the workings of SAP 2005 mean that this energy does not need to be taken into account in the assessments for this development. The actual distribution pumps used on the development typically use 20 kWh/day.

2.3.12 MVHR Performance Parameters

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).

Analysis of the inputs for MVHR performance in the SAP worksheets showed that they were based on SAP Appendix Q data for the specified MVHR unit [Greenwood Fusion HRV2]. The Appendix Q data for this unit give a specific fan power of 0.48 W/l/s for 1 wet room and 0.47 W/l/s for 2 wet rooms and a heat exchange efficiency of 93 per cent. The analysis also showed that the worksheet input for the MVHR in-use factors was for systems using insulated, rigid ductwork [In-use factors are 1.4 for specific fan power and 0.85 for exchange efficiency].

It is a requirement of SAP 2005 that where manufacturers Appendix Q performance data are used then the installers must complete the appropriate Appendix Q checklist. There are clear incentives to use the Appendix Q process in preference to the SAP default data which are very conservative. For example, the default SAP data for MVHR efficiency is 66 per cent with an in-use factor of 0.7. However it has not been possible to verify this from the commissioning data as the Appendix Q checklists have not been provided.

2.3.13 Heating Circulation Pump

The HIUs installed on the development provide hydraulic separation between the district heating network and the space heating and hot water systems in the dwellings. This means that the HIU includes a circulation pump to pump hot water to the cylinder and around the radiators. However, the SAP assessments for the apartment and house do not include the energy use of this pump.

The tables in SAP 2005 give a standardised value of 130 kWh.a for electricity to run central heating pumps. The community heating worksheets in SAP 2005 do include an input for circulation pump and fan energy, but the wording in the worksheet is somewhat ambiguous and indicates that only energy for fans need be included.

2.3.14 Solar PV Energy

The SAP assessments for the development include contributions for generation of electricity by the solar PV panels located on the roofs of the houses and apartment block. The amount of solar PV energy assigned to each SAP assessment is equivalent to 38.82 kWh per m^2 of floor area for each dwelling type. The total solar PV energy from the SAP assessments for all 21 dwellings is therefore 70845 kWh.a.

The designed total output of the overall solar PV array is 85 kWpeak, with an area of approx. 700 m^2. Using the solar PV algorithm in SAP 2005, this would give a predicted output of approx. 70856 kWh.a for a nominally south facing array at a pitch of 30° and with no over-shading.

This is consistent with the values used in the SAP worksheet. However the actual pitch of the array on the development is unclear as, although the pitch of the roof is shown as 40° on the drawings, there is a suggestion that this may have been changed to 35° during construction.

It should be pointed out that the solar PV energy algorithm in SAP 2005 is relatively crude, and takes no account of location in the UK. The algorithm also includes a very conservative efficiency factor of 0.8 to account for inverter losses and other balance of system effects, and as such is likely to underestimate energy production, especially during the early years of the installation.

2.3.15 Heating Controls

The houses on the development have heating controls with full time and temperature control to 2 zones. The zone separation is between the upstairs and downstairs and the radiators are all fitted with Thermostatic Radiator Valves (TRVs). Two-zone controls of this nature have significant advantages over a single zone system and this is reflected in a higher temperature difference between zones in the algorithms in SAP 2005 for houses with individual heating systems. However, in the case of community heating systems (i.e. where heat is charged according to use), SAP 2005 makes no distinction between single and multi-zone controls.

2.4 Design and Construction Rationale & Process

2.4.1 Decision making

Three Rivers Housing Association appointed a clerk of works onto the design team for the last 6 months of the design process and through to completion. The role of the clerk of works was to provide knowledge of the standards and requirements for funding, as well as to ensure that the project was being delivered to the client requirements. Additionally during the actual construction the clerk of works was present on the site to inspect the installation; and by way of example, on the first install the manufacturer of the Sega tape, the clerk of works checked both the quality of the install of the timber frame and insulation before and after the covering plasterboard was installed.

It was reported that the combination of the clerk of works and CfSH code assessor together with the project design and delivery team played a significant contribution to the overall success of the project.

2.4.1.1 Design team meetings

The design team had weekly technical meetings on site; to smooth any issues out and to make decisions. The team meetings included M&E consultants, the architects, the M&E installers and construction contractors. When issues were raised at these meetings, the architect and/or contractor could go away to undertake further detailed investigations and then at the next meeting the issue would be discussed with the other members of the core team to decide a way forward together.

These team meetings took place in the lead up to the build phase and throughout the construction of the site, the core team were present along with any specialists as and when required; for example, the biomass-fuelled boiler manufacturer or the wall construction element manufacturer contacted to explain how to tape the products together. This was seen by the clerk of works to be the best thing about the project as the meetings covered aspects of the design and construction methodology and achieving CfSH6 and the use of advanced technologies. The CfSH code assessor also attended the meetings at least once a month to provide additional support and to review any changes proposed and ultimately to ensure that the CfSH6 would be achieved.

2.4.1.2 Construction process

Achieving the required level of air tightness was a major focus for the team during the construction process. During construction, the installation was checked by the clerk of works together with the relevant specialist contractor who visited the site to check the installation of the insulation. This was particularly noticeable when there were “pre start” meetings and training on the correct application of Sega tape to the installation boards with the clerk of works and the relevant team members involved in the particular installation.

At the time of the actual construction there were further demonstrations on site to ensure that everyone was up to speed with the specific installation method. Additionally there were ‘tool box’ talks taking place on a daily basis, together with instruction on how to install correctly and construct to ensure all personnel on site had a good understanding of why, how and what was required.

During construction there were specialists who were brought in to explain the methodology for correct construction and installation of products and technologies used. For example, the concrete floor which was used in the apartments to achieve the required sound density. Additionally during bad weather, the construction team used vacuum cleaners to drain the floor out to make sure there was no standing water when the floor cassettes were put in.

2.4.1.3 Post construction project review

There was a post construction project review meeting on 12th May 2014. Present were representatives from Three Rivers Housing Association (lead), the main contractor, the mechanical and electrical (M&E) contractor, community engagement specialists, consultant engineers and consultant construction specialists, the surveyor and material suppliers to the project (see Section 8.1 - Post construction project review, page 112 for additional information).

The objective of the post construction project review meeting was to constructively reflect on the Sinclair Meadows development and to identify, agree and discuss the main learning points that could be taken away from the project. Specific areas discussed were to remind the team of the original brief for the project which centred on client/developer/contractor partnership (Figure 19).

In summary it was agreed that the project had been successful in a number of significant areas, most notably in the ultimate delivery of the development. It was agreed that there had been minimal building defects since handover, but that there were a number of ongoing M&E defects including issues associated with the operation of the MVHR units, the biomass-fuelled boiler and the rainwater harvesting system (specifically the system used on the apartments).

Figure 19 – The partnering Cycle [Three Rivers Housing Association Partnering Workshop 1st December 2011]

2.5 Conclusions and key findings for this section

From the start of the project, the emphasis was placed on the quality of the building fabric, especially on air tightness and heat loss. The principal adopted was that by starting with a *high quality* building fabric would mean less energy required to heat/cool the buildings during occupancy. This approach was reflected in the stretching design targets for thermal performance and air permeability of the dwellings.

The houses on the development were built in accordance with the requirements of Part L1a 2006. All SAP calculations provided had therefore been carried out with SAP 2005. CfSH assessments were completed using the NHER software version of the Code compatible with SAP 2005.

The fabric heat loss calculations in the SAP worksheets for the apartments do not include the walls between the apartments/flats and stairwells/commons spaces as heat loss elements. In SAP 2005 this is a valid assumption as long as the common spaces are heated.

The supplied drawings do show that electrical panel heaters will be installed on the ground floor of the stairwells in the apartment block. The common areas are treated as a non-domestic building for the purposes of building regulations and their energy performance would require to be assessed under Part L2a using Simplified Building Energy Model (SBEM).

The design air permeability for the development was 2.5 $m^3/h.m^2$. The measured values of air permeability given in the Part L1a checklists were given as 1.62 $m^3/h.m^2$ for the monitored apartment and 1.64 $m^3/h.m^2$ for the monitored house; showing both compliance with the design target and being significantly better than the Part L1a 2006 default limit of 10 $m^3/h.m^2$. The values of air permeability used for the air infiltration calculation in the SAP worksheet are consistent with the measured values (infiltration = air permeability/20); demonstrating that the actual pressure test data have been used in the as-built SAP calculation.

A check of the data given on the pressure test certificates showed a small discrepancy in the calculated ground floor areas compared to those given in the SAP worksheet; possibly because the building data were taken from the actual building rather than the drawings; however the impact of these differences would not be significant in terms of the final SAP calculation and is within the scale of expected errors in dimensional calculations.

The Part L1a checklist required the assessor to confirm that any hot water cylinder meets the requirements Domestic Heating Compliance Guide in terms of the insulation. The response given in the Part L checklists for the apartment and house both stated that the dwellings had no hot water cylinders. However, all the dwellings on the development did in fact have a 120 litres hot water cylinder; which is linked to the heat interface unit (HIU). The cylinder used [Range Tribune HE] does meet the requirements in the Heating Compliance Guide. It was also noted that the SAP worksheets also failed to record the fact that dwellings had a hot water cylinder; which is possibly linked to software inputs in the Part L checklist or SAP worksheet.

3 Key findings from the design and delivery team walk through

3.1 Overview

During the initial design team walkthrough in September 2012, the overall building features were outlined by the architect and the system features and aspects relating to monitoring of the properties were led by the M&E consultant. The key findings are outlined below. Additionally key members of the design and delivery team were independently interviewed by telephone during January and February 2013 (see Section 3.3 - Design team interviews, page 34 for additional information).

3.2 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.

From the outset of the project it was stated that the over-arching aim of the scheme was to develop a 'carbon negative housing' development rather than to achieve the CfSH6. The design objective was therefore to ensure that the design element fabric U-values of the building were as low as possible and to supplement the remaining heating requirements with renewable energy sources wherever possible (Table 33).

Table 33 - Summary designed building fabric U-values

Design Element	Design U-value
Walls	0.14 W/m^{2}K
Floor	0.1 W/m^{2}K
Windows	0.7 W/m^{2}K
Roof	0.09 W/m^{2}K

The design process followed in order of priority:

1) **Site position and design;**
2) **Building fabric; and**
3) **Renewable energy**.

It was stated that the development of the Sinclair Meadows project involved a massive learning curve for all involved. The architect in particular noted that although they had designed timber framed properties before everything else had to be considered; and the design process was described as being:

'…a journey… '

3.2.1 Sinclair Meadows design concept overview

As outlined previously the design of Sinclair Meadows development was such that all roofs were facing in a southerly direction with all homes having East, South and West aspects. The biomass-fuelled plant room was on the north of the terrace row of houses so that all dwellings avoided having northern elevations. The apartments were designed so that the main living spaces were on the south side of the plots with kitchens and bathrooms facing north and west. As well as maximising solar gain, this layout also provided additional natural surveillance.

The walls are constructed from 220 mm timber stud filled with wood fibre insulation. The architect had originally considered using hemp insulation, but the intended supplier had stopped using this material prior to commencement of the build and so it was decided to use a wood fibre option instead.

The design uses carbon negative and natural materials as much as possible. The building contractor for the development undertook a Post Construction Carbon Review in August 2012; for which the outcome was summarised as:

> ***'…each Sinclair Meadows… …house exceeds the 2013 Zero Carbon definition by 10.66 Kg/CO_2/m^2 per year, or 16.96 tonnes of CO_2 will be offset by all the dwellings per year. In 2.8 years, the Sinclair Meadows… …homes will have offset 39.6 tonnes from the sites total construction CO_2…' [Consensus of Design Team View]***

3.3 Design team interviews

During the months of January and February 2013, key members of the team involved in the design and construction of the Sinclair Meadows scheme were independently interviewed by the project co-ordinator, with each telephone interview lasting between 20 and 40 minutes. The aim of the design team interviews was to gather views and insights from the design and delivery team on the best and worst aspects of the project: both process and product, and the things that worked well and things that didn't; to help avoid making the same mistakes in the future. The telephone interviews were semi-structured, with some key planned questions asked, but allowing for open discussion about various issues, challenges and learning in the following areas:

- Original Design and Design Intent vs Reality
- The Design-Build Process
- Post-Construction
- Handover, Aftercare & Maintenance Processes
- Other Insights on the Completed Site (Post Construction and Early Occupancy)

The questions included/covered:

- Involvement/role in the project
- Background to the scheme, original design aims etc.
- Impact of CfSH6 and other requirements/restrictions
- Any changes to the original design, compared to what has now been delivered?
- The design/build process and delivery timescale
- Main challenges/issues with design/build process
- Design and construction responsibilities
- Level of checking/supervision of standards on site
- Training requirements and/or involvement/requirement for any specialists or sub-contractors
- Issues/challenges with initial operation
- Key learning during construction
- Maintenance and reporting of issues
- Best aspects of the design and construction
- Any recommended changes to design and/or process if started over again (in hindsight)
- Tenant engagement process

3.3.1 Data Analysis Method

The interview data were rearranged to fit within the five categories which were used to structure the interview questions:

- Original Design and Design Intent versus Reality
- The Design-Build Process
- Post-Construction
- Handover, Aftercare & Maintenance Processes
- Other Insights on the Completed Site (Post Construction and Early Occupancy)

The data within these categories were then coded for underlying shared themes between interviewees. This was then written up with reference to key quotes, used to illustrate, reinforce and expand on the observations which were made (see Section 12.3, Key Findings from the Design and Delivery Team Walk Through, page 149 for additional information).

3.3.2 Original Design and Design Intent vs. Reality

3.3.2.1 Concept stage

On-site renewables

Some early design ideas considered the use of solar thermal and offsite wind turbines; the final scheme uses a combination of PV, a biomass boiler and heat recovery ventilation.

Procurement and tenure

From the outset of the project the design aspiration was to create a ‘carbon negative’ development; however, there was some discussion over what this really meant and how such performance could be proven. The design team considered Passivhaus certification as a possible strategy but in the end decide to use SAP; as it was a well understood methodology in the UK.

Initial bid for the project was developed with a different organisation however when the RSL came on board the proposed tenure changed to social housing only.

Another requirement of Homes and Communities Agency (HCA) funding was that the scheme complied with CfSH Level 6 (CfSH 6). The design team only found out about this requirement after the planning stage.

As a result of being part a CfSH 6 project, the design had to be amended to include some features that were not specifically related to energy consumption. These included the size of the washing line, the provision of two cycle spaces per dwelling as well as an external storage box.

Housing Quality Indicators

Some of the original design ideas were lost due to the prescriptive nature of Housing Quality Indicators (HQIs). These included the green roofs and circular form of the originally three storey homes. However, due to the innovative nature of the design [which relied on natural ventilation and getting light right through the home] they were able to push through the open plan living spaces which were, in this case, deemed to be an integral element of the design.

Design research

The architects dedicated a lot of time to researching design ideas and construction projects, probably because this was the first carbon negative scheme they were involved in and the first time they had worked to the CfSH.

The initial design proposed the use of a lightweight steel frame and polystyrene insulation. However, during design research the team considered various 'natural materials' as alternatives (such as hempcrete), and finally selected the Pavatex-NBT Timber Frame Pavaclad System.

3.3.2.2 Value engineering

A number of adjustments were made to the scheme as part of the value engineering process. The changes were significant enough to require a second planning application to be made two years after the original planning was granted.

Contaminated land

The original design proposed 3 storey houses across the whole site. It was then discovered that ground conditions at the site were very poor, making it prohibitively expensive to excavate it all. The site layout and design of the dwellings was amended to comprise a mix of 2 storey houses and a 3 storey apartment block. Overall the number of units was reduced from 27 to 21.

Monitoring and feedback to residents

Value engineering process also meant that the scope of the monitoring and feedback was not as broad as some members of the design team would have liked.

Value engineering activities with possible energy repercussions

It is possible that some of changes made as a result of value engineering have had an effect on the final energy consumption of the as built schemes. In some instances this effect may have been negligible or hard to quantify, such as in the case of the size of the homes. However, the reduction in the amount of insulation and the reduction in size of the balconies [so that the overhang no longer prevented high summer sun from entering the floors beneath], were very likely to have had a noticeable impact on energy use and building performance in terms of comfort.

3.3.2.3 Deviations from design intent during construction

In general, once construction began the design was more or less fixed because of the planning constraints and rigidity of CfSH compliance. However, there were a few instances where elements of the building differed from the design.

Rainwater harvesting

The original design called for rainwater to be used for the washing machines as well as toilet flushing; however, it was subsequently found that the timber roof shingles were staining the water so this was not possible. Also, initially a small rainwater harvesting system was planned for each house and apartment. In the end it was not practical to install a separate system for each apartment so a 'group scheme' was used instead on the apartment block.

Biomass-fuel boiler fuel storage

The biomass-fuel store was designed in such a way that it is too small to fit a full lorry load of fuel, despite there being adequate room on the site for a bigger store.

3.3.3 The Design-Build Process

3.3.3.1 Challenges

The interviews identified a number of challenges that the team had to deal with during the design and construction process. These challenges could broadly be grouped into:

- technical challenges;
- practical challenges;
- project management challenges; and
- personal challenges.

Technical challenges

Examples of technical challenges included ensuring a sufficiently high air tightness was achieved, finding out that the timber roof shingles ***'…didn't work with the lead struts for flashing the PV system…'*** and fitting the MVHR flexi-ductwork around the roof joists.

Practical challenges

Practical challenges insured keeping the construction site dry during inclement weather

Project management challenges

Project management challenges were centred on the issue of the protracted length of the project; as well as some of the rigorous procedures required as part of CfSH compliance.

Personal challenges

Personal differences between members of the design team also proved a challenge on a complicated project where teamwork was essential.

3.3.3.2 Weekly site meetings

One of the tools that the design team employed to overcome some of these challenges was holding weekly site meetings to discuss and ultimately resolve any issues. Overall this seems to have been viewed as a positive feature of the project which led to the resolution of several problems which arose from the complex and innovative nature of the project and the level of detailing required. However this was likely to have been quite time consuming.

3.3.3.3 Compliance and certification

As mentioned previously, compliance with the CfSH required a very rigorous process of certification. This resulted in it being necessary to check any deviations from the original design with the Code Assessor to make sure the project was still on track to meet the requirements of CfSH6. This led to some frustration within the design team and may have contributed to the lengthy duration of the construction period as well as possibly adding to costs in securing bespoke ratings for certain atypical construction elements.

3.3.3.4 Skills and training

Training

Onsite training took place throughout the construction phase, largely organised by the RSL.

Quality control

The training was linked to the quality assurance procedures which involved carrying out airtightness testing during construction, clear communication to all team members about the importance of taping and other best practice building techniques and regular inspections by the RSL. The design team also requested that the manufacturers of the MVHR and rainwater harvesting systems train their installers. However, despite this and the rigorous system of training and inspecting, there were some issues with the installation of these building services. Ultimately it appears that regular onsite checks were the most successful form of quality control and resulted in the delivery of a sufficiently airtight building envelope.

In some cases it was hard to find tradesmen with the required skills within the construction budget.

Professional skills

As well as training up the labour force to have the required construction skills, the design team also had a lot to learn over the course of the project. Since being involved in the project the contractor have now established a local sustainability team and taken part in various training activities. This could be seen as a very positive outcome of the project.

3.3.3.5 Successful outcome

Despite the numerous challenges and steep learning curve, the design-build process seems to be a successful one with all interviewed team members expressing some satisfaction with the project.

3.3.4 Post-Construction (Snagging and Commissioning)

There were some initial teething problems with many of the mechanical systems, including the biomass boiler, the rainwater harvesting system, and the commissioning of the MVHR. The contractor was unsatisfied with the quality of the insulation which was also highlighted during snagging. However, the general feeling seems to be that issues were resolved quickly and effectively and that things are now [at the time of the interviews] working well.

3.3.5 Handover, Aftercare & Maintenance Processes

3.3.5.1 Resident training during and post-handover

The RSL seems to have been quite heavily involved in the handover of the houses to the residents; whereas the architect and M&E contractor had become much less hands-on by this point.

Note: The architect mentioned that the RSL have teamed up with another HA, who had experience of writing user manuals. However, the RSL did not mention this so it is hard to ascertain whether this took place or how successful it was.

The RSL were able to train the residents how to use the heating as effectively as possible so that they were comfortable without wasting energy. There has also been some training about how to get the most out of the solar PV system. Several of the respondents to the BUS questionnaire mentioned that they had changed their clothes washing practices to make best use of free energy which suggests that the training had been quite effective. It's good to see that the RSL are continuing the training and aftercare beyond the immediate handover stage and have acknowledged that living at the scheme involves a whole lifestyle change, something which they are hoping their tenants will engage with and participate in.

3.3.5.2 Maintenance of mechanical systems and day-to-day repairs

A number of maintenance and reporting regimes appear to be in place so that hopefully the properties will be well looked after and any problems resolved in good time. The communal boiler has an automatic immersion heater as backup and a warning light in case of boiler failure. Furthermore, each dwelling has an individual hot water tank with one hour immersion heater back up.

Initial reports suggest that residents are taking care of "their" properties.

3.3.5.3 Handover – delays, boiler malfunction and keeping the residents happy

The construction phase of the project took longer than expected, resulting in delays in commissioning and handover. Consequently there was not time to 'stress test' the mechanical systems before residents moved in. To compensate for the inconvenience cause by the initial 'teething problems' with the boiler, the RSL paid the residents' first energy bill.

3.3.6 Other Insights on the Completed Site (Post Construction and Early Occupancy)

3.3.6.1 Comments on the final product

The interviewed members of the design team seem to be relatively satisfied with the end result which is a very positive outcome. One issue that was raised by the RSL was the 'no parking' rule; which the residents are struggling with. This issue is exacerbated by the fact that the site in a rundown area and there are some security concerns with leaving cars at a distance from the homes.

3.3.6.2 Building performance

The contractor was particularly interested in the environmental impact of the construction materials. This was referred to by him frequently during the interview, and he appears proud of his efforts in this area. He was also engaged with the simulation of building performance and a keen exponent of in depth in use monitoring. This was something which he would have liked to see more of, mentioning rainwater collection per house and internal humidity as variables that should be monitored.

3.3.6.3 Occupant behaviour

Preliminary evidence suggests that there is a wide variety in end use energy consumption across the site, and that this may be caused by differences in occupant behaviour. The contractor draws on previous experiences to argue that it is important to monitor a wider range of variables to really understand what is going on in a dwelling.

Behaviour change or passive design?

The design intent in terms of the building services was to design a home that would be carbon negative without the occupants having to make any conscious changes to their routines. On the other hand, some of the more general design features, such as using the provided compost bins, do require a more active engagement on the part of the occupants. The interview data suggest that there is still some way to go in terms of the adoption of new sustainable behaviours by all the residents at the site.

3.4 Conclusions and key findings for this section

Sinclair Meadows was felt by the design and delivery team to have been a success and the team were proud to be part of it. It was agreed by all participants that there had been reasonable to good co-operation during the project that had been enhanced through the use of weekly on-site meetings. The participants enjoyed the design and delivery feedback process which they perceived as having been useful and productive. There was a general consensus that all would be interested in taking part in similar processes in the future. Achieving CfSH6 and being carbon negative was seen as challenging as CfSH included features that were not specifically related to energy consumption; although it was widely acknowledged by the team that the support provided by the Code Assessor was extremely useful.

There are a number of areas where design team members have learnt from their experience on the project and would, given the choice, do things differently in the future. These are discussed below.

- The design and build contract that the scheme was procured under was not deemed to have been appropriate as it was felt that quality may have been compromised at the expense of an emphasis on cutting costs.
- An issue shared by both the architect and the contractor was the prescriptive nature of the CfSH. It was felt that CfSH mandated a number of relatively minor features such as the length of the washing line and the size of the bike store and that those took emphasis away from the more important fabric and thermal considerations.
- There was also a sense that CfSH compliance was more of a box-ticking exercise that could be manipulated to award more points, than a template for improving design quality.
- There appears to have been a missed opportunity in terms of promoting the project to the public and to a wider audience. There does not seem to have been as much press coverage as for other exemplar schemes such as Bed Zed in London for example.
- The contractor outlined a number of aspects of the construction that could be improved. These included more insulation, something which was not possible because they were tied into using a proprietary wall system with their funding; taking advantage of the energy storage capabilities of district heating and changing some of internal and external finishes.
- There was also some learning in terms of the specification and configuration of the building services which could be improved in future projects.

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 design of CfSH timber framed buildings.

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 Sinclair Meadows presented numerous problems. For example locations of the unit within the dwellings have given rise to installation and access issues together with difficulties with both maintenance and operation.

4 Fabric testing (methodology approach)

The fabric testing of the two monitored properties comprised:

- Thermal Transmittance (U-value) in-situ test
- Infra-red Thermal Imaging Survey
- Airtightness and Air Permeability Measurement

4.1 Thermal Transmittance (U-value) In-situ Measurement Interpretation

A Thermal Transmittance (U-value) in-situ measurement of an external wall of dwelling A and dwelling B was carried out by a specialist thermal transmittance subcontractor between 26th February and 12th March 2013. Tests were undertaken to establish the "as built" U-value of the walls as detailed below compared to the design U-value (Table 34).

Table 34 – Thermal Transmittance (U-value) - As Designed v's As Built

Wall detail	Design U-Value W/(m^{2}K)	Final averaged U-Value W/(m^{2}K)
Dwelling A, Sinclair Meadows – South Facing External Wall	0.14	0.10
Dwelling B, Sinclair Meadows – North West Facing External Wall	0.14	0.09

4.1.1 Test Method

The U-values were determined by placement of Hukseflux HFP01 sensors on walls using the "Average method" detailed in ISO 9869:1994, Thermal insulation – Building elements – In-situ measurement of thermal resistance and thermal transmittance. For calculation purposes internal/external air temperatures were recorded within the dwelling adjacent to the sensors and outside adjacent to the corresponding wall space. Measurements were recorded over a two week period whilst the properties were occupied. The data reported is the final seven days of measurement, with the first seven days data excluded to allow for stabilisation of the instrumentation.

The equipment used to test the u-values in these two properties is detailed in Table 35.

Table 35 – Thermal Transmittance (U-value) in-situ Test Equipment

Measurement	Device	Manufacturer	Model	Equipment identifier
Dwelling A	Heat Flux Sensor 1	Hukseflux	HFP01	1417
	Heat Flux Sensor 2	Hukseflux	HFP01	1416
	Data Logger	Eltek	451L	451L-8073
Dwelling B	Heat Flux Sensor 1	Hukseflux	HFP01	4744
	Heat Flux Sensor 2	Hukseflux	HFP01	4745
	Data Logger	Eltek	451L	451L-9993

In the apartment, dwelling B, the heat flux sensors were located on the North West facing wall in the main living area. Due to the layout of the house, dwelling A, having no north facing external wall, and the kitchen being located on the west facing wall, the heat flux sensors were installed on the south facing wall in the main living area. This was next to a radiator, which was isolated during the testing period (Figure 21). It is not known who approved this change to the approved test method as defined in ISO 9869. In addition to the results obtained by the sub-contractor a separate analysis was completed (see Section 4.1.3 - General Comments, page 43).

Figure 20 – Equipment Placement, Dwelling B, Living Room

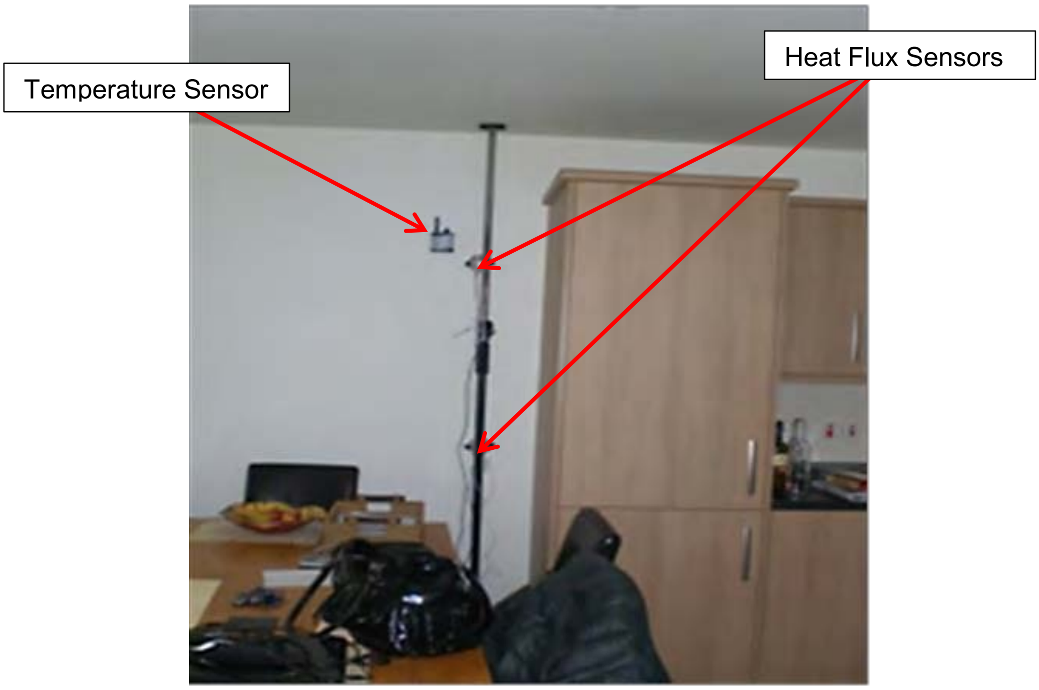


Figure 21 – Equipment Placement, Dwelling A, Living Room

4.1.2 Graphical Data

The test results are shown in Figure 22 and Figure 23.

Figure 22 – Thermal Transmittance, Dwelling B, 1 Week (1/3/13-8/3/13), Final Value = 0.09 W/m²K

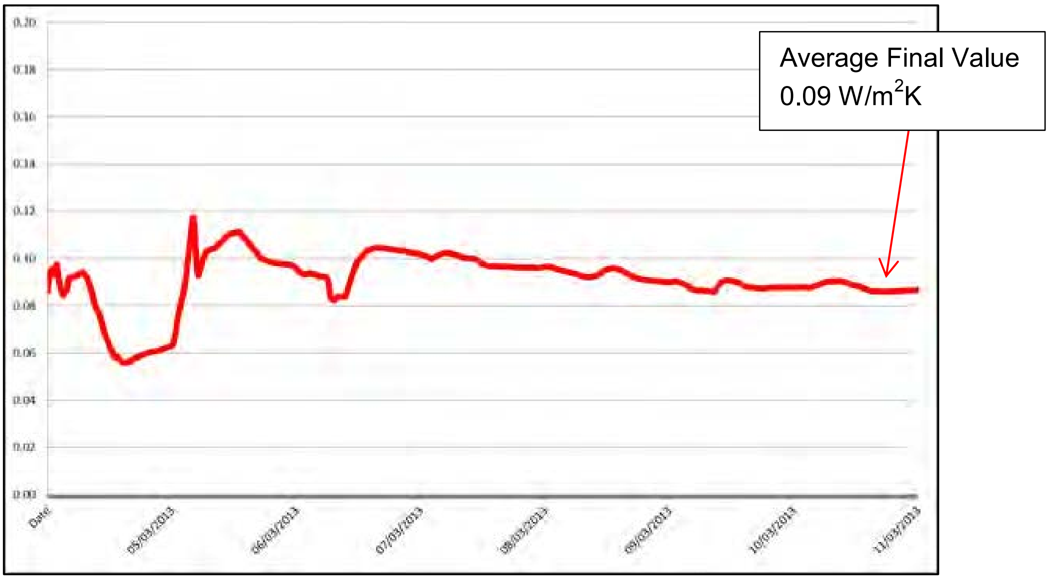
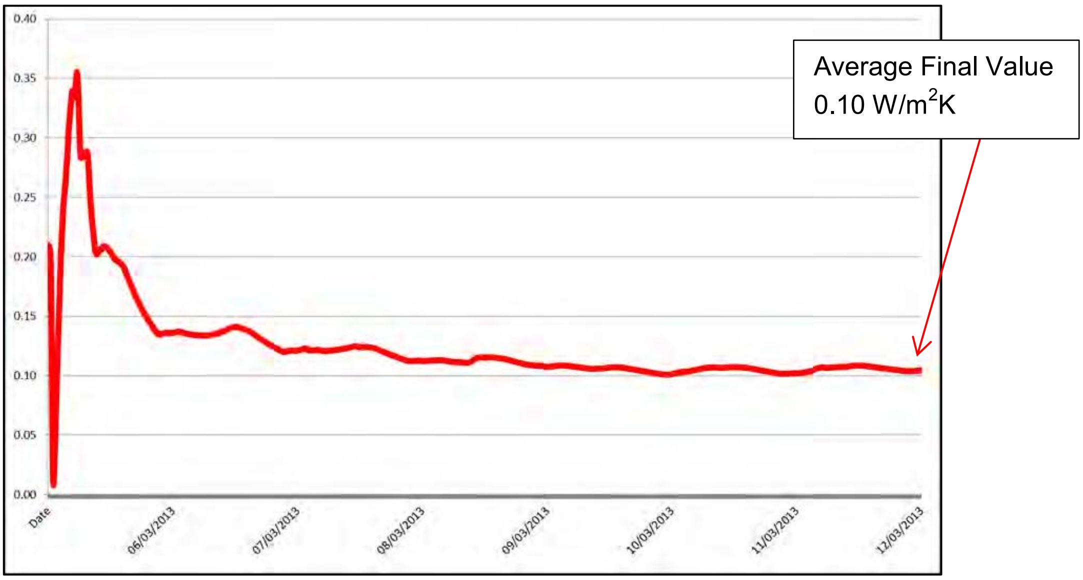


Figure 23 – Thermal Transmittance, Dwelling A, 1 Week (2/3/13-9/3/13), Final Value = 0.10 W/m²K



4.1.3 Data Analysis

As the thermal transmittance in situ U-value test for Dwelling A was realised using a south facing wall, an additional analysis was completed that used the sub-contractors 1 minute data for both heat flux sensors and internal temperatures sensors, together with the 5 minute external temperature from an external weather monitoring station (see Section 7.1.1 - Data Integrity, page 81 and Figure 61 – Comparison of External Temperature Data with Met Office Data for Newcastle Airport (10/3/14), page 84 for additional detail).

For the test period 27/2/13 to 10/3/13 the results were as follows (Table 36):

Table 36 – Thermal Transmittance (U-value) in-situ Additional Comparison

Dwelling	Heat Flux 1 [W/m2K]	Heat Flux 2 [W/m²K]	Average [W/m²K]
Dwelling A	0.101 +/- 0.006	0.089 +/- 0.005	0.09
Dwelling B	0.086 +/- 0.007	0.091 +/- 0.007	0.09

4.2 Infra-red Thermal Imaging Survey

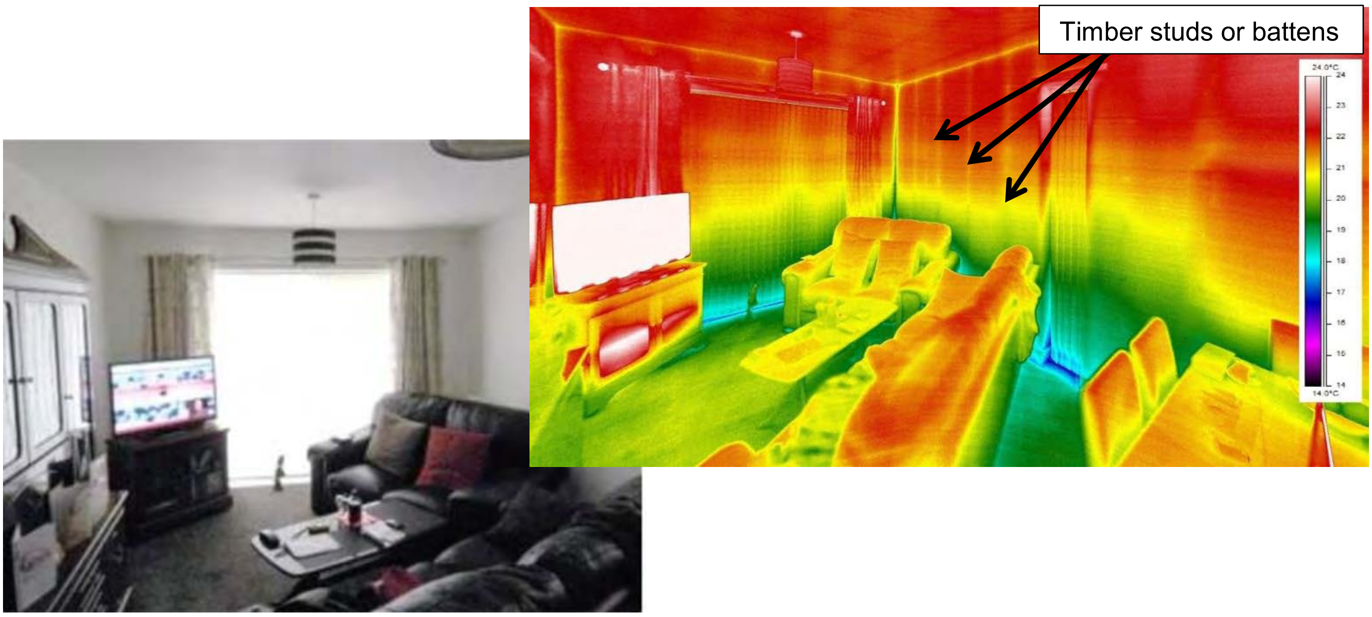
4.2.1 Infra-red Thermal Imaging Interpretation

An infra-red thermal imaging survey of the inside and outside of dwelling A and dwelling B was carried out by a specialist thermal imaging subcontractor on the 2nd April 2014. Due to limitations regarding access to the dwellings, the survey was conducted during the day between 5:00pm and 7:00pm. The sky was overcast during the test period, with external temperatures of around 6°C and no precipitation. The internal temperatures were around 21°C, giving an inside-outside temperature difference (ΔT) of around 15°C. The thermal camera used was a FLIR SC640 with a 23° lens. The resolution of the thermal imaging array on the camera was 640x480 pixels with a thermal sensitivity of 60 mK. All internal images are scaled 14°C to 24°C and external images scaled 1°C to 12°C. Photographs to accompany the thermal images are only available for dwelling B due to a specific request from the occupants of dwelling A.

4.2.2 Dwelling B

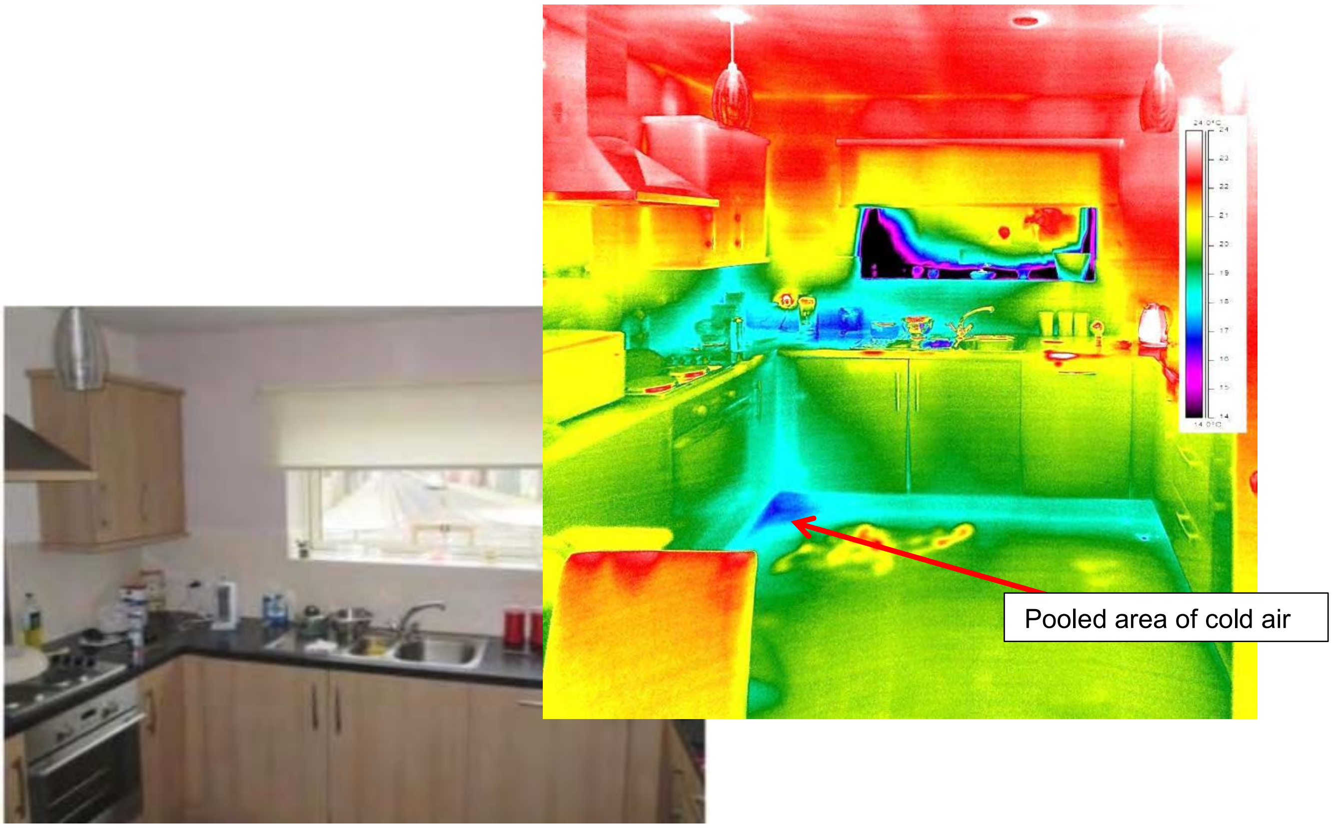
The living room of dwelling B is shown in the thermal image in Figure 24. The image shows the inside face of the external walls to the south and west. It can be seen that the surface temperatures on the walls range from around 18°C at the floor-wall junction to around 22°C at the wall-ceiling junction. This variation is indicative of typical temperature stratification of a heated room. The walls also show slightly colder vertical lines which will correspond to the location of timber battens for the service void or the timber studs in the timber frame. There are no indications of any significant thermal anomalies in the external walls or ground floor.

Figure 24 – Thermal Image of Dwelling B, Living Room



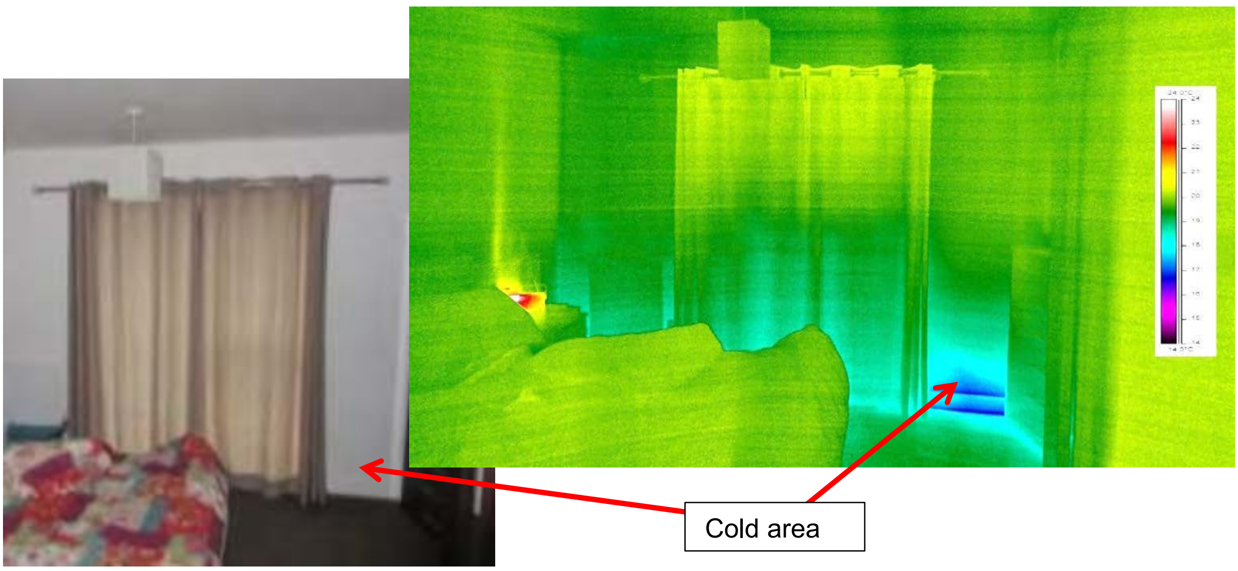
The kitchen of dwelling B is illustrated in the thermal image in Figure 25. The image shows similar temperature stratification as observed in the living room. The kitchen window had been left open by the residents and the image shows cold air infiltrating through the windows and pooling on the work surface and down to the floor.

Figure 25 – Thermal Image of Dwelling B, Living Room



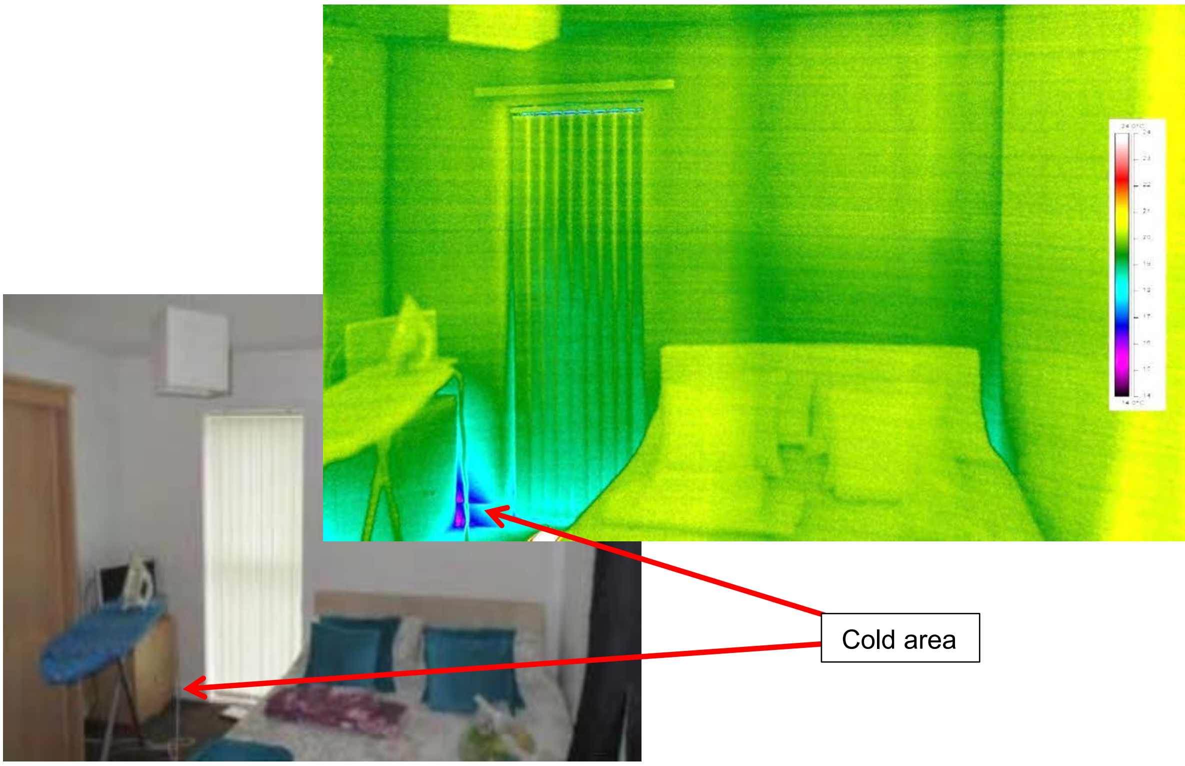
Bedroom one of dwelling B is illustrated in the thermal image in Figure 26. The image indicates there is much less temperature stratification than seen in the living room and kitchen, suggesting that the room was not being actively heated at the time. A cold area by the skirting board at the right of the curtain could be related to an air infiltration path or may be caused by movement of cold air from behind the curtain.

Figure 26 – Thermal Image of dwelling B, Bedroom 1



Bedroom two of dwelling B is illustrated in the thermal image in Figure 27. The image indicates there is less temperature stratification than seen in the living room and kitchen, suggesting that the room was not being actively heated at the time. A cold zone can be seen in corner of the room the bottom right of the image. This could just be an effect due to cold static air behind the furniture: Alternatively there could be an area of air infiltration at the floor wall junction.

Figure 27 – Thermal Image of Dwelling B, Bedroom 1

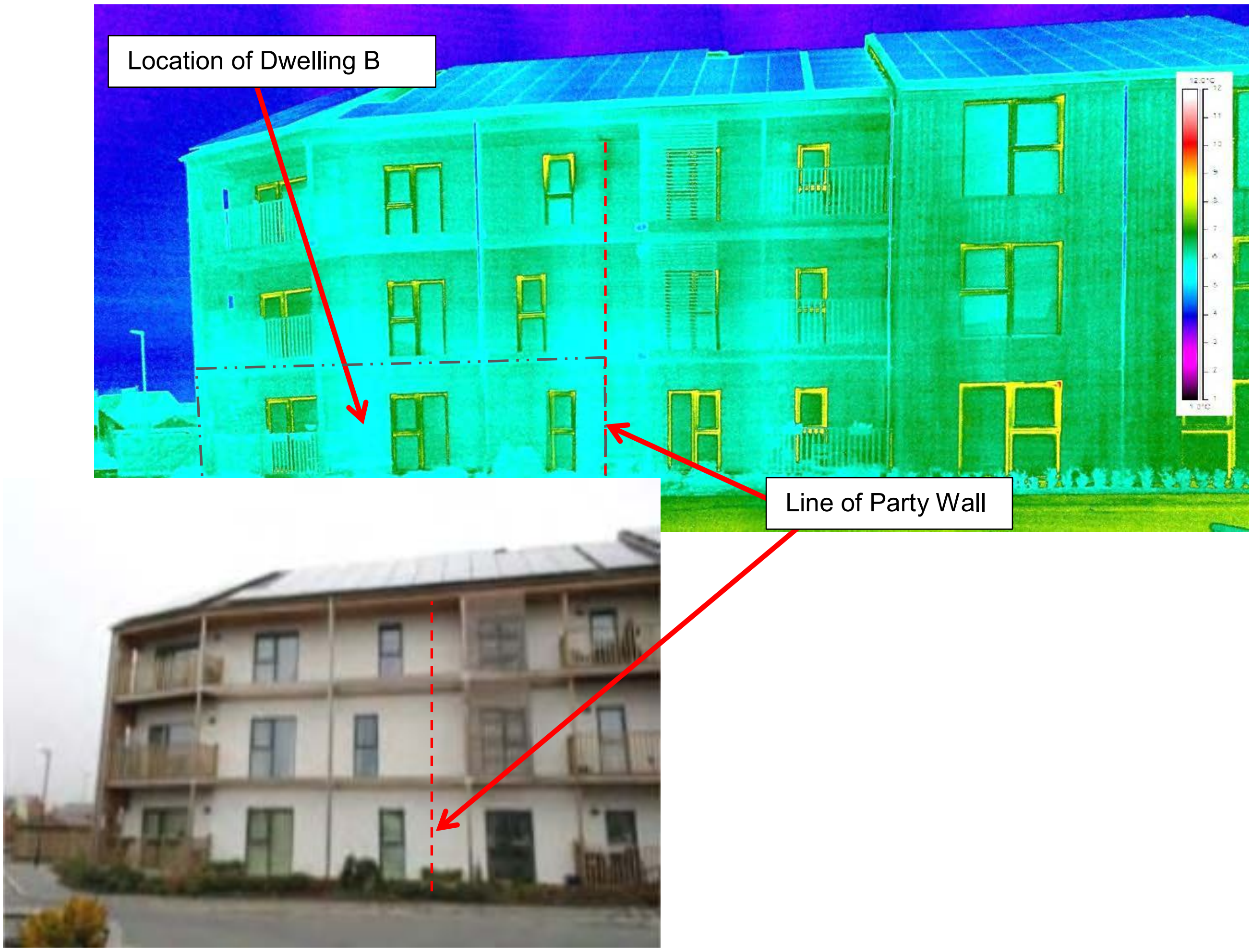


The South facade of the apartment block is shown in the thermal image in Figure 28. Dwelling B is at the bottom left of the block. In general, there are no significant thermal anomalies visible in the image. The wall on this facade has rendered external insulation with no external cavity to mask any heat flow.

The lack of anomalies would therefore suggest that the wall has been well constructed with no major gaps in the insulation layer.

The line of the party wall junction (dotted red line) can be seen in the image as a slightly warmer area as shown by the red arrow, although the temperature difference ΔT is relatively small. Given the layer of continuous external insulation across the party wall junction, this is a surprising finding and may indicate the presence of a bypass in the party wall cavity or other thermal defect.

Figure 28 – Thermal Image Apartment Block, South Facade



The south facade of the apartment block is shown in the thermal image in Figure 28. Dwelling B is at the on the ground floor of the block. No thermal anomalies can be seen in this thermal image: However the presence of the timber cladding on this facade of the block would in any case tend to mask any thermal defects.

Figure 29 – Thermal Image Apartment Block, West Facade

The corner of the north and west facades of dwelling B is shown by the thermal image in Figure 30.

No thermal defects are apparent in the rendered wall; although heat can be seen coming from the exhaust terminal vent for the MVHR. As expected, no heat is evident from the MVHR inlet vent. The apparent temperature of the extract air is >12°C, which is higher than expected. It is unusual to have the inlet located above the exhaust, although this is the same for all apartments (Figure 31).

Figure 30 – Thermal Image Dwelling B, North-West Corner

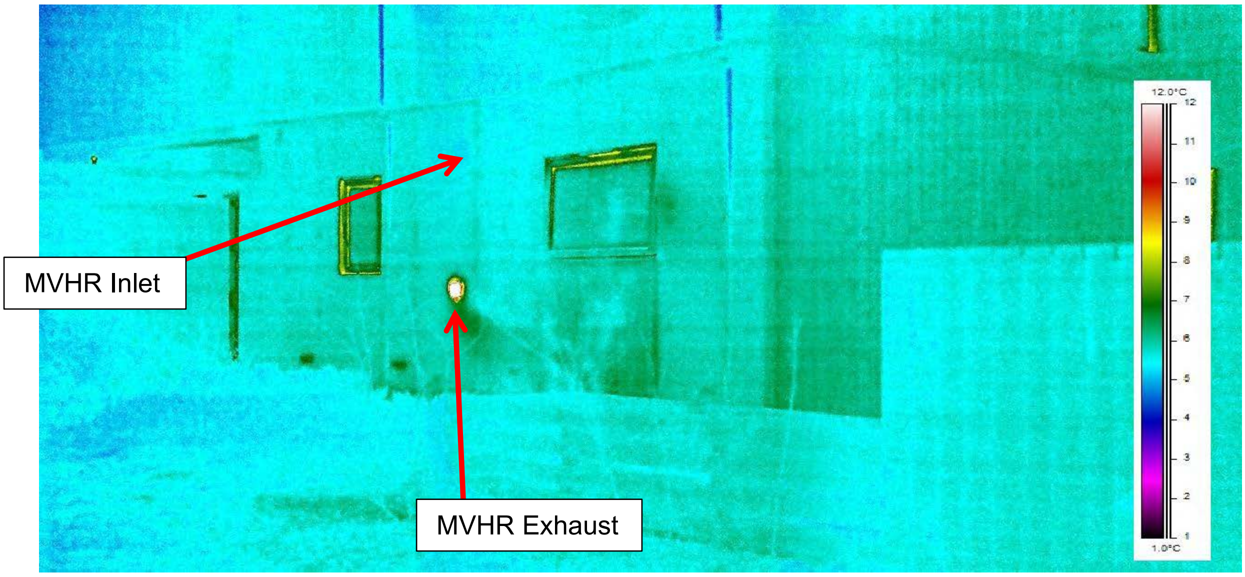
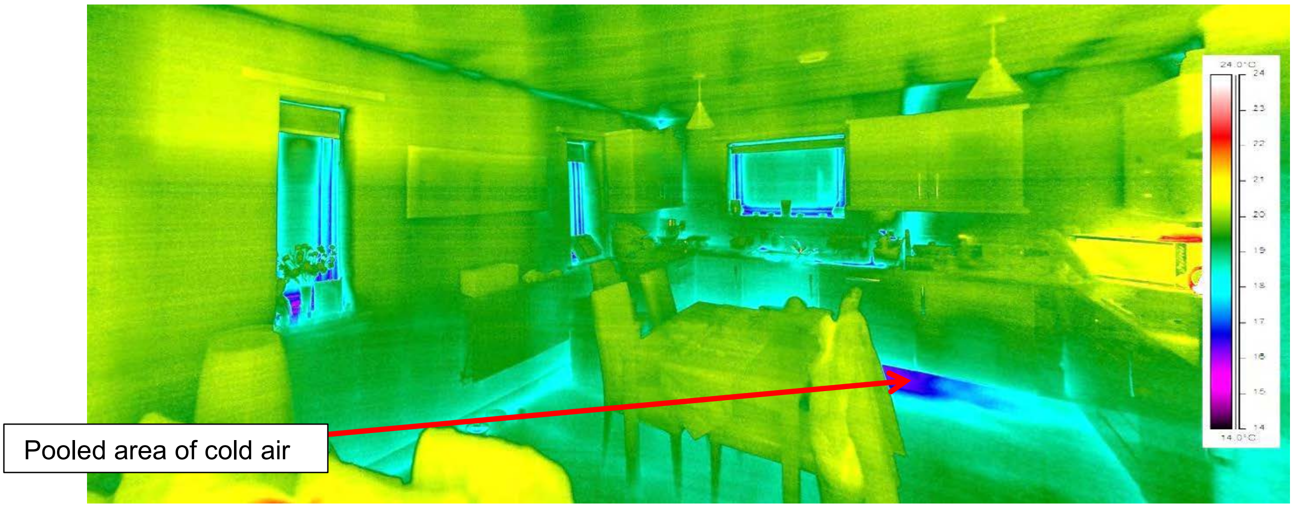


Figure 31 – Photograph of Apartment Block North and West Facades

4.2.3 Dwelling A

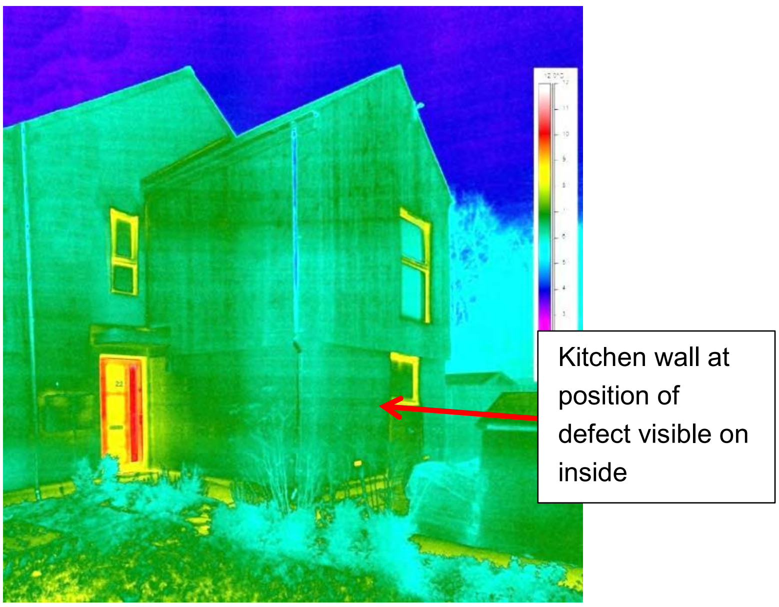
The thermal image in Figure 32 shows the kitchen in dwelling A. It can be seen that there is much less temperature stratification than in the apartment; indicating that the house is not being heated to the same degree as the apartment. There is a cool zone in blue/purple on the floor just below the sink. It is possible that this is due to air infiltration at a service penetration hidden behind the cupboard. There is also a colder blue vertical line which runs behind a cupboard just above the location of the blue/purple spot on the floor. These two thermal defects are likely to be associated with each other.

Figure 32 – Thermal Image Dwelling A, Kitchen



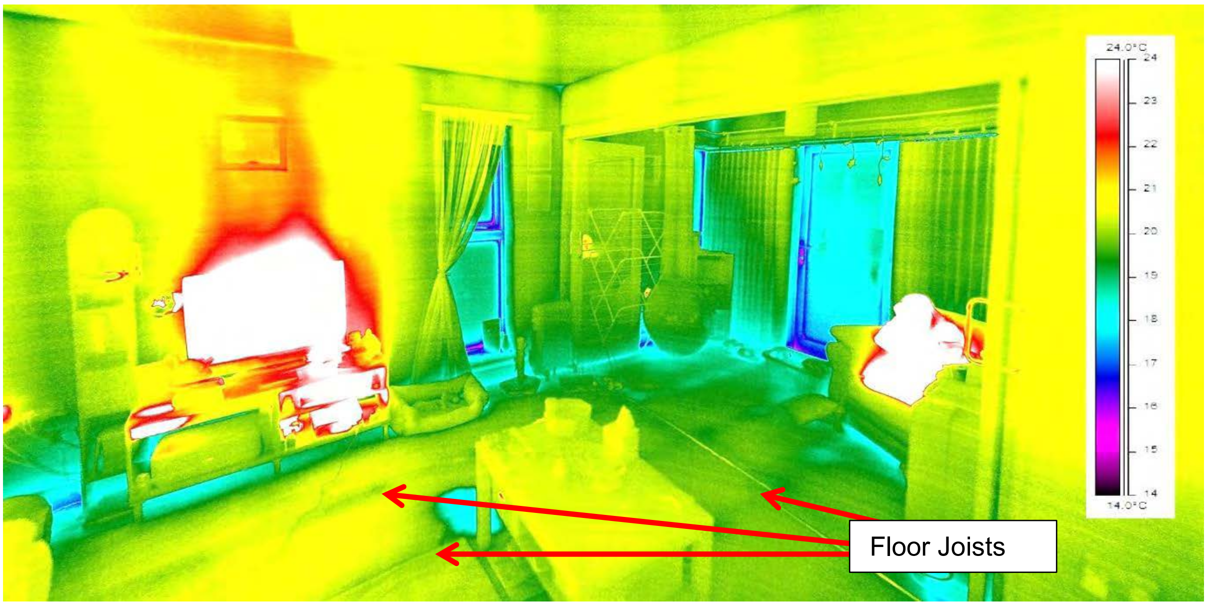
The thermal image of the west external facade of dwelling A does not show any corresponding thermal defect by the kitchen window, and there are no external features such as lights or penetrations in this area (Figure 33). Heat loss from the door is higher than that from the walls or other openings. This would be expected as the door specification gives a relatively high nominal U-value (1.1 W/m^{2}K) and the door glazing is only double glazed. In addition, there would be expected to be thermal bridging due to the solid timber at the door jambs [the detail drawings do not show any reveal insulation to reduce thermal bridging at jambs].

Figure 33 – Thermal Image Dwelling A, West Facade



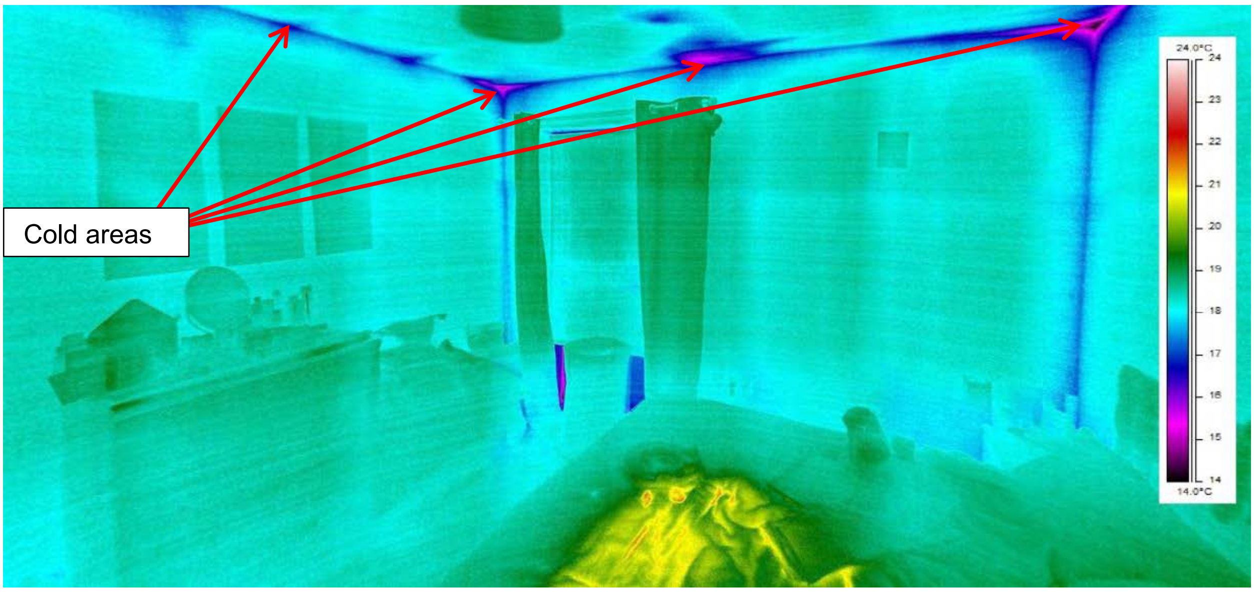
A thermal image of the living room of dwelling A is shown in Figure 34. There is little temperature stratification in this room other than that cause by the heat emitted by the flat screen television of the left hand side of the picture. Colder areas underneath/behind furniture and towards the bottom of the window reveals will be a result of still air. The window reveals indicate potential thermal bridging as a result of uninsulated framing timber in the wall panels. Warmer lines on the floor in the thermal image are consistent with the location of the joists in the insulated floor cassette.

Figure 34 – Thermal Image Dwelling A, Living Room



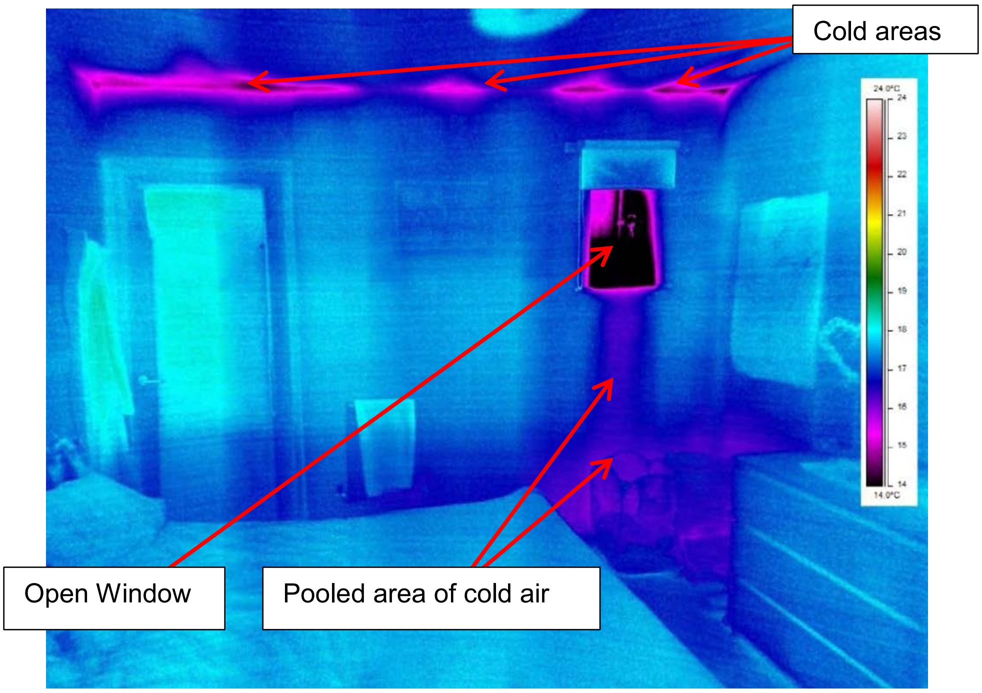
The thermal image in Figure 35 shows the master bedroom in dwelling A. Surface temperatures of the walls are even and are around 2°C colder than the temperatures observed downstairs. Colder patches on the ceiling (blue-purple) are likely to be caused by either missing insulation in the loft or insulation quilt that is not laid so that it is in contact with the ceiling plasterboard; thus allowing air movement between insulation and plasterboard.

Figure 35 – Thermal Image Dwelling A, Master Bedroom



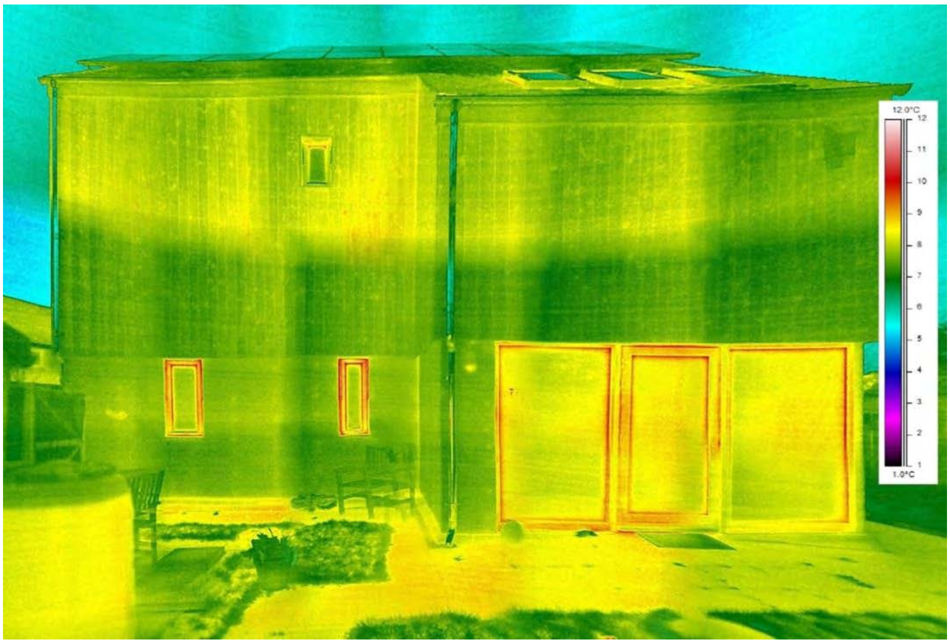
The thermal image in Figure 36 shows bedroom 2 in dwelling A. The window is open and cold air external air can be seen to be infiltrating and pooling in the corner of the room. There are significant thermal defects along the wall-ceiling junction which are indicative of poor placement of loft insulation at the eave.

Figure 36 – Thermal Image Dwelling A, Bedroom 2



The thermal image in Figure 37 shows the south facade of dwelling A. This image has artefacts and distortions caused by image manipulation and post processing: It is therefore not possible to draw any conclusions with regard to thermal performance of the structure.

Figure 37 – Thermal Image Dwelling A, South Facade



4.2.4 General Comments

The evidence from the thermal imaging surveys indicates that the residents of both apartment and house are opening the windows even when the external temperatures are cold. This will be contrary to the advice given to the residents to close windows during the heating season to maintain effective operation of the MVHR system. It is possible that the residents are opening windows to provide fresh air due to poor internal air quality. It is known that there were problems with the MVHR system in dwelling A at the time of the visit and that there were signs of damp/mould growth in the bathroom (Figure 38). These are further indicators (see Figure 71 – Monthly Mean CO2 Concentration for Dwelling A (House) and B (Flat), page 91 for additional information) that there are underlying issues with adequate ventilation to the dwellings which will need to be investigated further.

Figure 38 – Evidence of Damp/Mould Growth, Dwelling A, Bathroom Ceiling

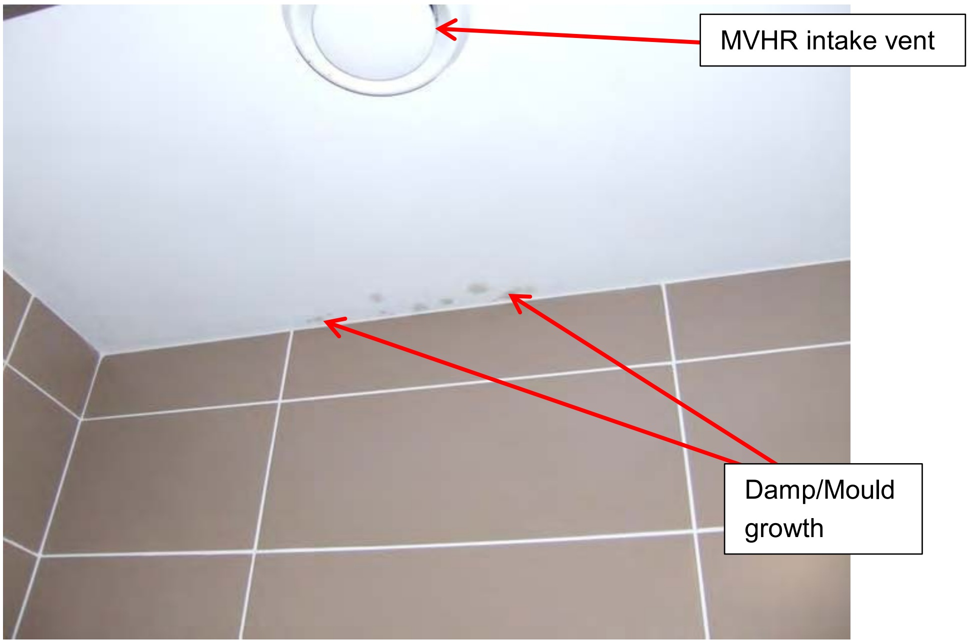
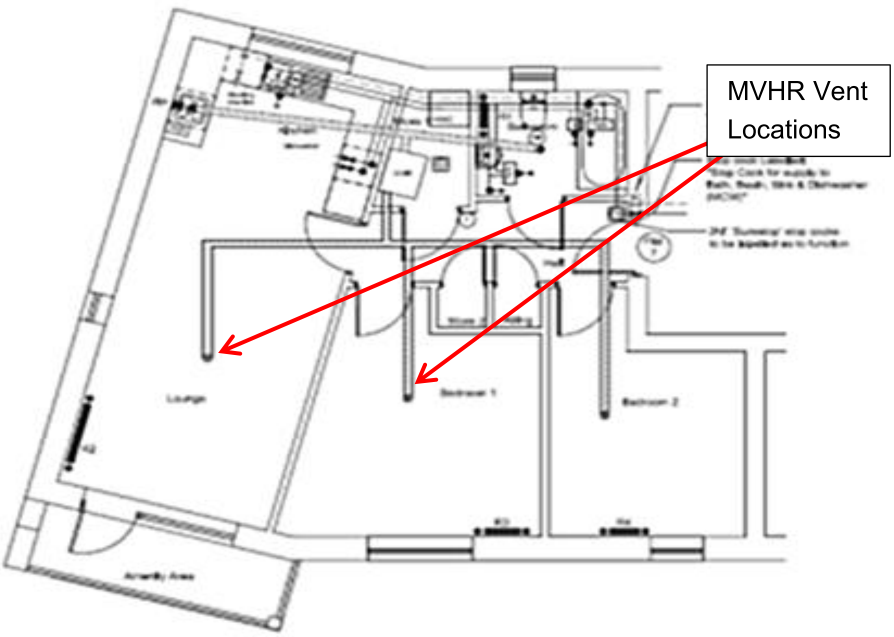


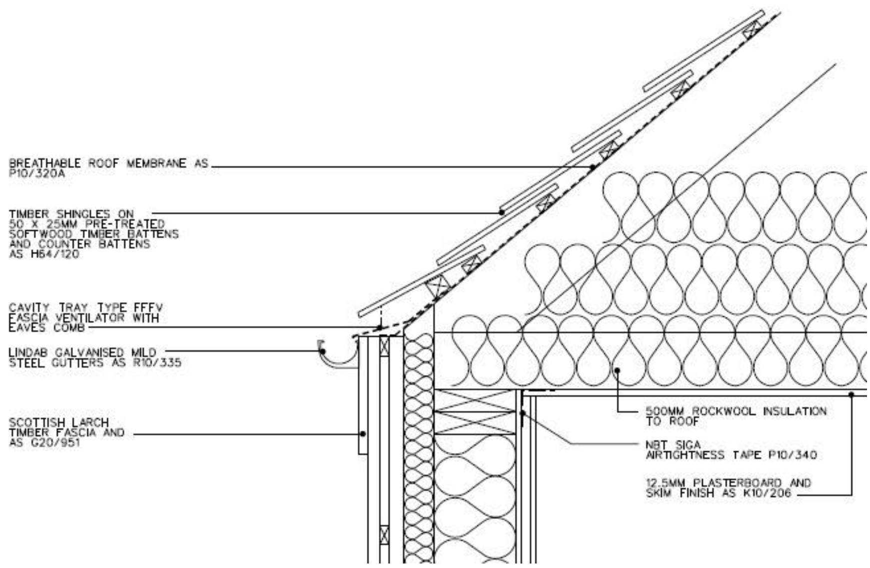
Figure 39 – Apartment: M&E Design Drawing: MVHR Vent Locations



The M&E specification for the development as provided to the research team does not provide any information with regard to the location of the exhaust and intake vents for houses, other than to refer to the apartment drawings and to stipulate that they should be a minimum of 1000 mm apart (this distance is in line with the manufacturers recommendations) (see Figure 31 – Photograph of Apartment Block North and West Facades, page 48, and Figure 39).

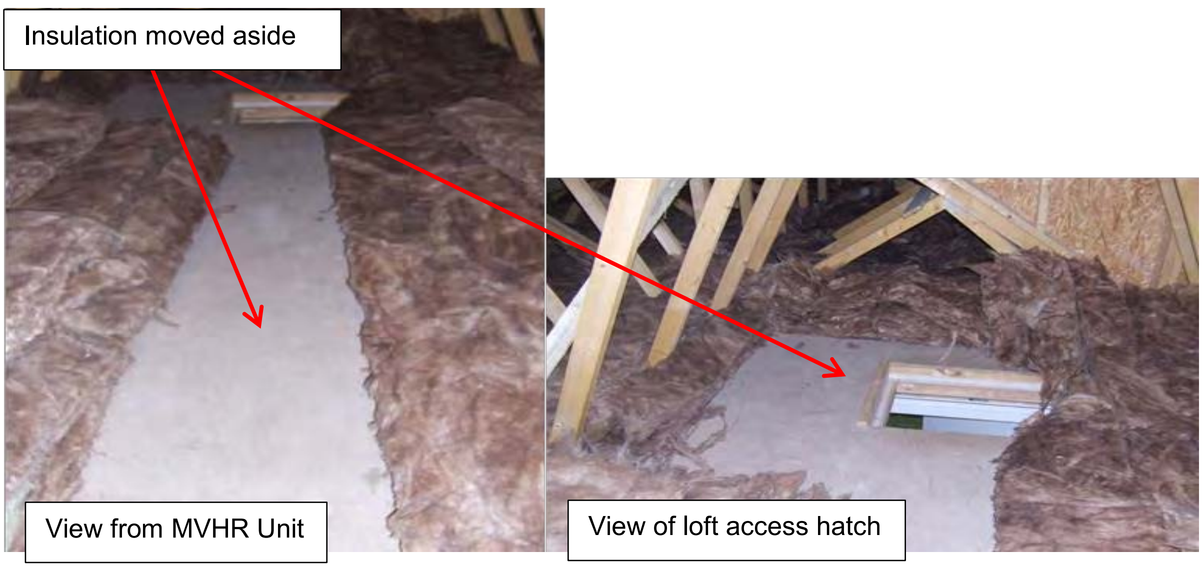
The problem observed with the fitting of mineral wool insulation at the eaves in cold roof construction is common across the industry. This issue is related to the buildability and effectiveness of this detail relative to the perfect fit of insulation in the detail as drawn (Figure 40). The design of this sort of ventilated eave means that cold external air is allowed to flow into the loft via the eaves ventilator. This cold air can then flow through, around and underneath the insulation quilt at the eave and degrade its thermal performance (see Section 11.2 - Construction Drawings, page 124 for additional information).

Figure 40 – Detail Drawing of Eaves



Additionally it was observed that mineral wool insulation had been moved in dwelling A [presumably during a previous attempt to gain access to the MVHR unit (Figure 41)].

Figure 41 – Dwelling A: Loft Mineral Wool Insulation Material



4.3 Airtightness Measurement Survey

4.3.1 Airtightness Measurement Interpretation

A sample of dwellings on the development was pressure tested for regulatory purposes by the developer's sub-contract tester. These tests were carried out at building completion in June 2012. Additional pressure tests were carried out on the two dwellings being monitored as part of the BPE project. Two sets of tests were carried out towards the start and end of the monitoring (as per Table 39).

The applicable building regulation standards for airtightness of the dwellings are given in Part L1a 2006. The regulatory maximum air permeability in Part L 2006 is 10 $m^3/h.m^2$ @50Pa: However, the design of the development called for much better airtightness than the regulations, and the design target air permeability given in the specification and the design stage SAP2005 assessment was a maximum of 2.5 $m^3/h.m^2$ @50Pa (Table 38).

4.3.1 Regulatory Pressure Testing Sampling Regime

The sampling regime for pressure testing given in Part L1a 2006 is based on the number of instances of each dwelling type and whether the dwelling designs have adopted approved construction details. For the purposes of the regulations, each block of flats are treated as a separate development.

The data given in Table 37 gives the number of each dwelling type, the number of regulatory pressure tests required for each type under Part L 2006 and the number of compliance tests actually carried at completion. It can be seen that the number of tests carried out meets the required sampling regime for the development, with a total of 7 tests being conducted; representing a third of the total number of dwellings constructed.

The results are summarised in Table 38.

Table 37 – Regulatory Pressure Testing Sampling Numbers

Dwelling Type	No. of Dwelling Type on Development	Required Pressure Tests under L1a 2006	Number of Compliance Tests Conducted
Semi-detached or End-terrace	1	1	1
Mid-terrace	8	2	2
Ground Floor Flat	4	1	1
Mid Floor Flat	4	1	2
Top Floor Flat	4	1	1
Total	**21**	**6**	**7**

4.3.2 Regulatory Pressure Test Results

The regulatory pressure tests were carried out by a commercial tester in depressurisation mode only and in accordance with the requirements of ATTMA TS1.

The test results are summarised in Table 38. The results from 7 test dwellings [four apartments identified as *apartment a, b, c* & *d* and three houses, identified as house *a, b* & *c*] were below the maximum design target of 2.5 $m^3/h.m^2$ with a mean of 1.6 $m^3/h.m^2$.

Table 38 – Regulatory Pressure Test Results

Dwelling	Test Date	Envelope Area (m^2)	Air Permeability ($m^3/h.m^2$ @50Pa)
Apartment *a*	14/6/2012	220.8	1.62
Apartment *b*	14/6/2012	220.8	1.49
Apartment *c*	14/6/2012	259.8	1.25
Apartment *d*	14/6/2012	231	1.53
House *a*	15/6/2012	350.2	1.62
House *b*	15/6/2012	350.2	1.84
House *c*	15/6/2012	350.2	1.64
		Mean & SD	**1.57 +/- 0.18**

These results demonstrate good attention to airtightness detailing and construction practice on a repeatable basis. At these low levels of air permeability, the supply of fresh air to the dwellings will be highly dependent upon the operation of the MVHR systems (Table 38).

Figure 42 – Dwelling A: Installing Airtightness Measurement Equipment

The *as-built* Part L1a checklists were checked to see whether the actual test data had been used in the final as-built SAP calculations for those dwellings which had been tested. In 5 out of the 7 tested dwellings, the correct test value had been used in the SAP assessment. In one case [house *a*], the design value of 2.5 $m^3/h.m^2$ had been used rather than the test value of 1.62 $m^3/h.m^2$. In the remaining case [apartment *c*], a value of 1.49 $m^3/h.m^2$ had been used rather than the test value of 1.25 $m^3/h.m^2$; however in both examples, the discrepancy would have little impact on the calculated DER.

In the case of the houses and apartment that had not been tested, these correctly used the design value of 2.5 $m^3/h.m^2$.

4.3.3 BPE Pressure Test Results

Additional pressure tests were undertaken on dwelling A and B as part of the BPE project. These were carried out by the same commercial tester that carried out the regulatory tests for the main contractor. The tests were conducted in accordance with the requirements of ATTMA TS1 and were carried out in both depressurisation and pressurisation modes. The tests were carried out in both dwellings at the start of the monitoring programme in January 2013, and again towards the end of the monitoring programme in April 2014. The results are shown in Table 39.

Table 39 – BPE Pressure Test Results

Dwelling	Test Date	Envelope Area (m^2)	Air Permeability ($m^3/h.m^2$ @50Pa)		
			Depressurisation	Pressurisation	Mean
Dwelling A	7/1/2013	350.2	1.32	1.95	1.64
Dwelling A	2/4/2014	350.2	1.67	1.76	1.72
Dwelling B	7/1/2013	225.51	1.91	2.49	2.20
Dwelling B	7/5/2014	225.51	1.81	1.91	1.86

It was noted that the calculated envelope area used for the apartment in the BPE test result calculations was slightly higher at 225.5 m^2 than the value used by the same tester for the regulatory test (220.8 m^2). Small discrepancies in calculated areas between testers should be expected, but it is unusual to see a different value used by the same test engineer.

The effect of the difference on the calculated air permeability is small. For example, if the value of 220.8 m^2 is used for the envelope area in the BPE test calculation, the depressurisation air permeability in January would have been increased from 1.91 to 1.95 $m^3/h.m^2$.

The depressurisation test result for the apartment had increased slightly from 1.62 $m^3/h.m^2$ at the time of the regulatory test to 1.91 $m^3/h.m^2$ seven months later for the first BPE test and slightly lower at 1.81 $m^3/h.m^2$ for the second BPE test in May 2014. This difference is within the expected variation that can be caused by both by settlement of the building and by thermal expansion-contraction effects due to seasonal changes at the time of testing. It is also within the magnitude of experimental variation expected for pressure testing.

The pressurisation test result for the apartment was around 25 per cent higher than the depressurisation results. This scale of difference can sometimes be observed in dwellings; and is generally considered to be caused by the effect of pressure exerted on the seals of outward opening windows and doors.

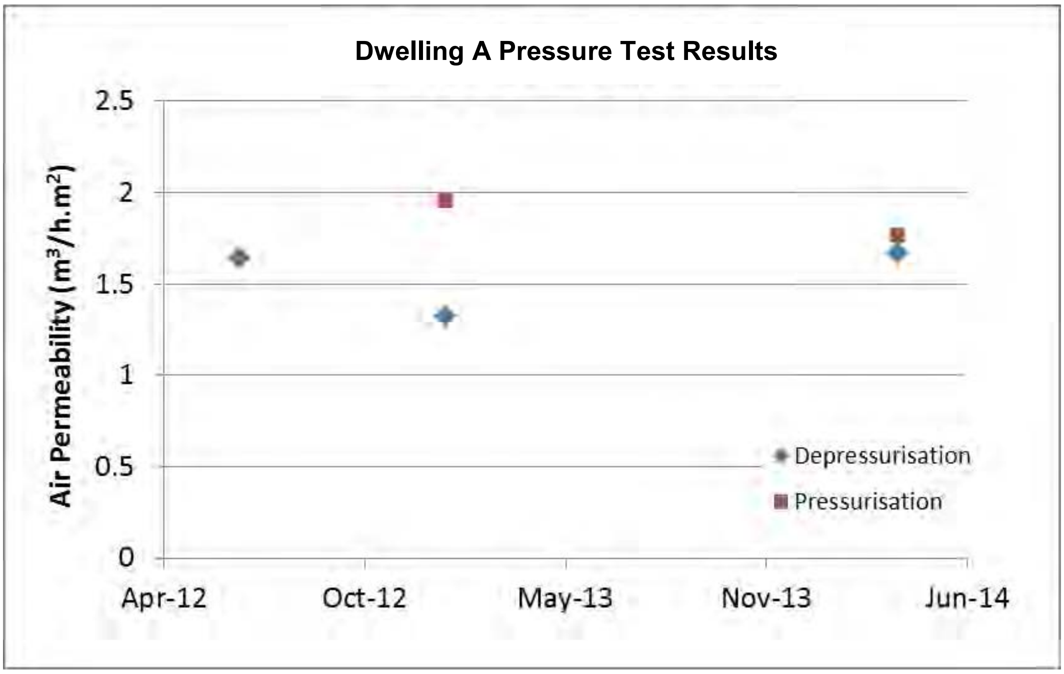
The graph in Figure 43 shows the timeline for the pressure test results for dwelling A (both regulatory and BPE tests). It can be seen that whilst the depressurisation test results in June 2012 and April 2014 and very consistent at around 1.65 $m^3/h.m^2$, the result for January 2013 is much lower at around 1.3 $m^3/h.m^2$. It can also be seen that the difference between depressurisation and pressurisation tests is much larger in January 2013 than that in April 2014.

This does raise some doubt as to the validity of the test in January. However, the mean of the depressurisation and pressurisation tests are consistent at 1.6 to 1.7 $m^3/h.m^2$ and the absolute differences in test results are small and not of any significant concern. The difference is similar to that seen for the dwelling B for the first BPE test; which indicates that this is a real effect caused by the conditions at the time of testing.

4.3.4 Leakage Detection

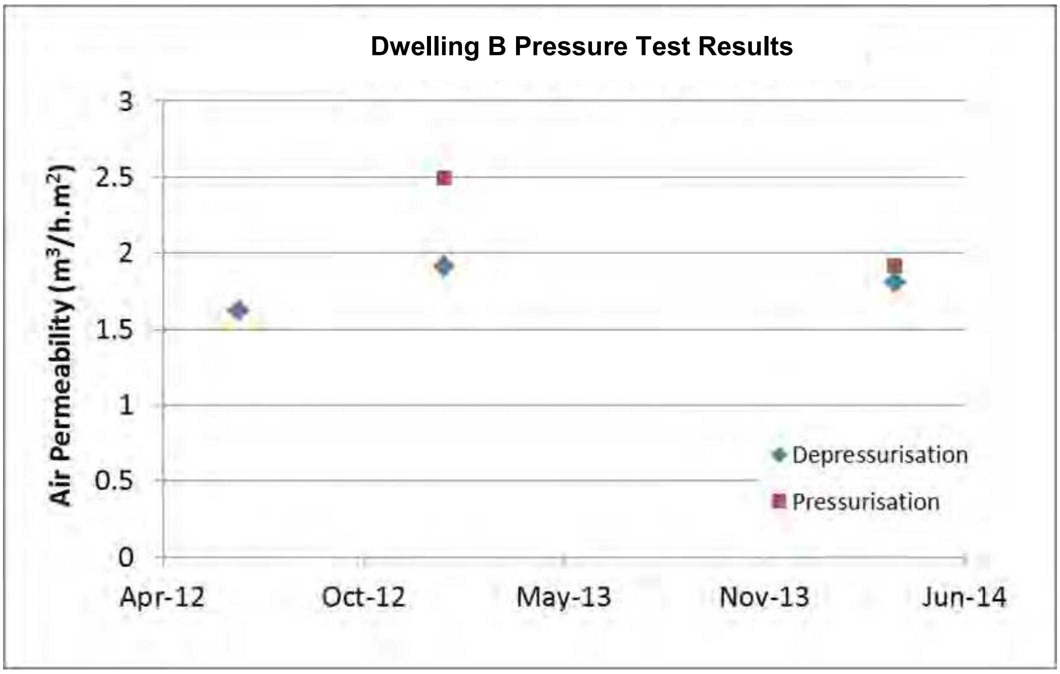
No leakage detection studies were undertaken during the pressure tests. As the dwellings as tested have been found to be very airtight, there would not be expected to be any significant leakage paths.

Figure 43 – Dwelling A, Pressure Test Result Timeline



The graph in Figure 44 shows the timeline for the pressure test results for dwelling B (both regulatory and BPE tests).

Figure 44 – Dwelling B, Pressure Test Result Timeline



4.4 Conclusions and key findings for this section

In-situ transmittance (U-value): In-situ thermal transmittance (U-value) heat flux data showed that the thermal performance of the external walls exceeded the design U-values, although the measurement was carried out in two locations only [and the test carried out in the house was incorrectly completed on a south facing wall for the reasons identified earlier]. This demonstrates the need to carry out tighter and auditable control using the correct and appropriate test methodology.

Thermographic Imaging: Infra-red thermal imaging surveys of both the inside and outside of the dwellings were carried out by a specialist thermal imaging subcontractor on the 2nd April 2014. Due to limitations regarding access to the dwellings, the surveys were conducted during the day between 5:00pm and 7:00pm. The sky was overcast during the test period, with external temperatures of around 6°C and no precipitation. The internal temperatures were around 21°C, giving an inside-outside temperature difference (ΔT) of around 15°C.

Photographs to accompany the thermal images were only available for the apartment due to a request from the house occupants.

The evidence from the thermal imaging surveys indicated that the residents of both the apartment and the house were opening windows even when the external temperatures were cold. This will be contrary to the advice given to the residents to close windows during the heating season in order to maintain the effective operation of the MVHR system. It was possible that the residents were opening windows to provide fresh air due to poor internal air quality (see Section 7.4 - Carbon Dioxide Concentration, page 91). It is known that there were problems with the MVHR system in dwelling A at the time of the site visit and that there were signs of damp/mould growth in the bathroom. This will need to be investigated further.

The problem observed with the fitting of mineral wool insulation at the eaves in cold roof construction is common across the industry. This issue is related to the buildability and effectiveness of this detail relative to the perfect fit of insulation in the detail as drawn. The design of this sort of ventilated eave means that cold external air is allowed to flow into the loft via the eaves ventilator. This cold air can then flow through, around and underneath the insulation quilt at the eave and degrade its thermal performance.

Apartment: The line of the party wall junction could be seen in the image as a slightly warmer, although the temperature difference ΔT is relatively small. Given the layer of continuous external insulation across the party wall junction, this is a surprising finding and may indicate the presence of a bypass in the party wall cavity or other thermal defect. Additionally the placement and co-location of MVHR exhaust and inlet terminal vents is non-typical and may give rise to future issues.

Image manipulation and post processing has given rise to artefacts and distortions and therefore on occasion it is therefore not possible to draw any conclusions with regard to thermal performance of the structure. This may have wider implication for specialist contractors carrying out Thermographic imaging surveys.

Airtightness test: The measured air permeability values of the Sinclair Meadows dwellings were all less than the design target of 2.5 $m^3/h.m^2$ @50Pa with a mean of 1.6 $m^3/h.m^2$ @50Pa and significantly better than the regulatory maximum air permeability in Part L 2006 is 10 $m^3/h.m^2$ @50PaA.

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

5.1 Tenant selection and behaviour

From the outset tenants of the properties were required to be sympathetic to the aims and ethos of the Sinclair Meadows development scheme as well as being in housing need. It was important that these buildings were used in the way that they were designed to be; and in partnership with the local council, Three Rivers Housing Association marketed the properties in an attempt to get prospective tenants in to skills and knowledge training to understand the concept and design of their home. This resulted in prospective tenants being interviewed to determine attitudes towards factors including sustainable living, energy appreciation and natural environment. Subsequently successful applicants were supported by way of an additional 12 month Community Development Programme.

During the first 12 months of occupancy, Three Rivers Housing Association partnered and worked with a non-profit organisation to develop and deliver a community development programme that included the provision of Home User Guides.

One of the key aims of the development was to create a cohesive zero carbon community at Sinclair Meadows. With this in mind, Three Rivers Housing Association engaged a specialist consultant to carry out community development training and activities during the first year (September 2012-September 2013). The consultant provided collective activities such as workshops – held at the nearby 1 Trinity Green – along with additional 1-2-1 appointments for tenants on request.

As well as providing targeted information and advice to help the tenants get the best out of their homes and save energy and money, the consultant also started to work on helping the residents to set up a Tenants Association (and a Garden Group). At a meeting at the end of January 2013, eight residents showed initial interest in being part of the Association, five of whom were from the flats and three from the houses. Residents were asked to contribute to a Resident Charter, which includes specification for residents and their behaviour, as shown below.

Resident Charter:

- The resident actively wants to start a new way of living
- The resident is openly engaged in the environmental sustainability agenda
- The resident is fully committed to community engagement.
- The resident demonstrates willingness to learn about new technologies for the home
- The resident agrees to, and is aware of, the constraints posed by living in a home at Sinclair Meadows
- The residents agrees to act as a champion for the low carbon lifestyle required by living at Sinclair Meadows

Resident Specification:

- General Requirements:
- Excellent customer status – or equivalent
- No history of tenant dispute
- No history of anti-social behaviour
- Matches all elements of the Resident Charter
- Transport:
- It is desired that the Resident does not own a vehicle
- It is desired that the Resident prefers to use public transport
- If the Resident does own a car they must agree not to park it within the Sinclair Meadows development.

5.1.1 Building Use Studies (BUS) survey and Behaviour Change Research Introduction

Building Use Studies (BUS) survey

See also Section 12.4 - Building Use Studies (BUS) Survey, page 168, for additional detail and supplementary information for both the BUS survey and Behaviour Change Research. Both the BUS survey and Behaviour Change Research studies were complimentary and have been included within the appendices in order to maintain the anonymity of the residents.

The BUS survey was conducted at Sinclair Meadows in 2013.

A copy of the questionnaire was posted to each of the 21 households in July/August 2013. 17 completed questionnaires were returned during August/September 2013, representing a response rate of 81 per cent. 82 per cent of the respondents were female and 88 per cent had lived at the site for less than one year. Sections 12.5.1 and 12.5.2 (page 192) details the findings of two reports commissioned by Three Rivers Housing Association to study in depth the expectations, experiences, attitudes, knowledge and behaviours of residents of Sinclair Meadows over two years, between September 2012 and October 2014, exploring the range of impacts that living in the development has on tenants, and highlighting interactions between the built environment, the community, and individual residents.

Behaviour Change Research Programme

Section 12.5 - Behaviour Change Research, page 178 through to 204 details the findings of a Behaviour Change Research Programme – Phase 1 and 2 – conducted at Sinclair Meadows in 2013/2014.

The Behaviour Change Research programme is set to run in five phases, with in-depth interviews with tenants taking place pre-occupation (phase 1), at the one year stage (phase 3) and at the two year stage (phase 5). Various group activities will take place at the six-month and 18-month stages (phases 2 and 4). Technical and energy performance monitoring data being collected will also be analysed for comparison and verify self-report and value judgements.

The completed homes all have energy monitoring equipment installed, both for the purposes of monitoring and evaluating the performance of the tenants and for collecting data for billing of tenants. The properties also have electricity monitors installed to allow the occupiers to see the energy they are using at any one time, and make informed decisions about reducing their energy use and saving money. All tenants at Sinclair Meadows have been provided with a Current Cost EnviR home energy monitor (Figure 45), which allows users to monitor their electricity use, and individual appliance monitors to measure the consumption of up to eight appliances in the home.

The EnviR system provides users with information on:

- Total instantaneous electricity energy consumption (Watts)
- Cost of electricity consumption per day and per month (based on input tariff cost)
- Cost saving when turning off an appliance or expenditure when turned on and equivalent decrease or increase in energy usage.
- Graph showing how much energy has been used between 7am and 3pm during the previous day, 3pm to 11pm the previous evening and 11pm to 7am the previous night.
- Accumulative energy in kWh for last day, last seven days and last 30 days.
- Time and temperature.

Figure 45 - Current Cost EnviR Home Energy Monitor system with 8 Individual Appliance Monitor (IAM) Plugs

5.2 Conclusions and key findings for this section

5.2.1 Building Use Studies (BUS) survey - Conclusion

To summarise, overall satisfaction at the site appears to be quite high, with residents reporting many positive experiences of their new homes and scores comparing well with benchmark datasets. Satisfaction with the dwellings appears to be high, with overall comfort, perceived health and needs all scoring in the 99th percentile. All residents feel that their needs are being met, and the majority are comfortable in their new home.

In terms of thermal comfort the flats are performing much better in winter than during the summer. While in the winter the residents seem to appreciate the ability of the flats to retain heat, during warmer periods there appears to be some significant overheating problems with 80 per cent of residents answering that it is too hot in the summer. High levels of natural light combined with limited control over cooling may be causing the flats to overheat. The lack of control over cooling is probably the greatest concern at Sinclair Meadows, with over a third of residents stating that they are unable to control cooling. It is also surprising that the dwellings are reported as too hot during the winter as residents believe that they have full control over heating and therefore would be expected to be able to maintain a comfortable temperature. Another issue may be the limited amount of shading [a design strategy which can be effective in reducing solar gain during summer]. This is something which needs to be investigated further as without remedial action the residents may resort to using electric fans to cool the spaces; which will increase electricity consumption at the site.

It is evident that 85 per cent of respondents do believe that living in the new development has changed their lifestyle; with a large number of comments relating to the ways in which residents have changed their lifestyle, in terms of diet, leisure, travel and work.

Owing to the small size of the sample, it is hard to identify recurring patterns or themes in the data. In particular, most of the issues raised in the comments were only mentioned once or at most twice. Consequently, it is hard to determine whether these are outlying values or ‘one-offs’ or whether they are truly representative of wider concerns at the site. Furthermore, care should be taken when comparing average scores calculated from such a small dataset as it is possible for one outlying value to skew the results quite considerably.

Figure 46: Comparison of key Comfort and Satisfaction variables between flats and houses

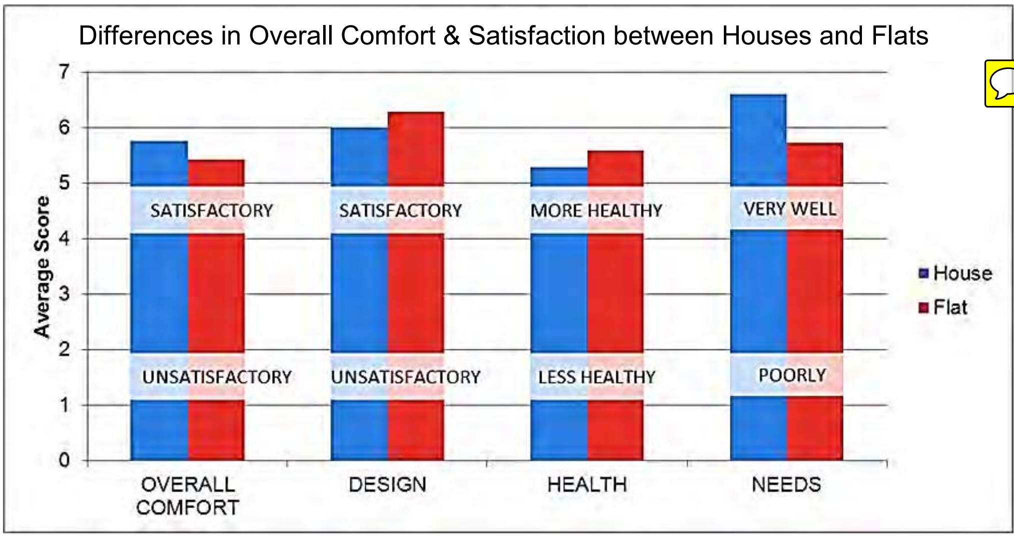


Figure 47: Comparison of Perceived Control variables between flats and houses

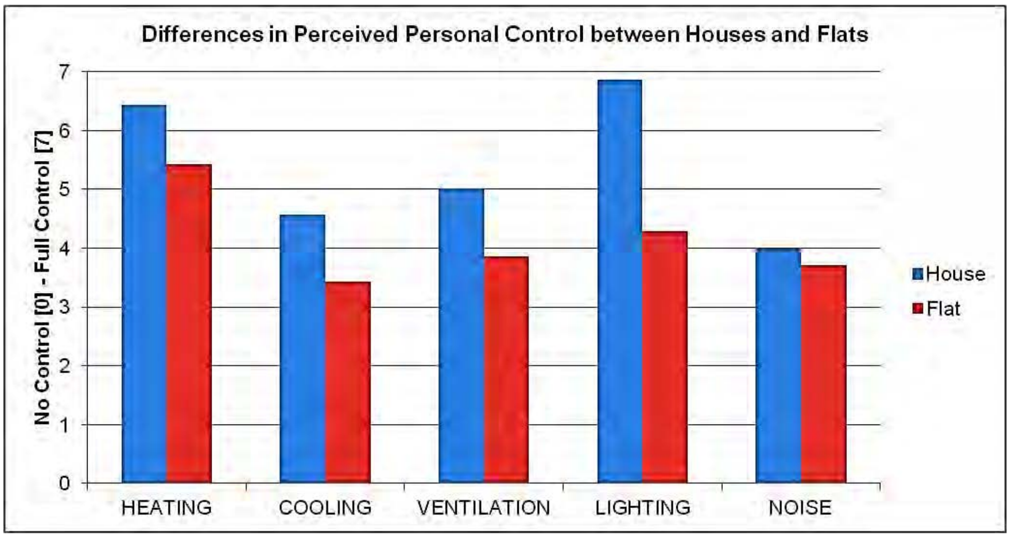
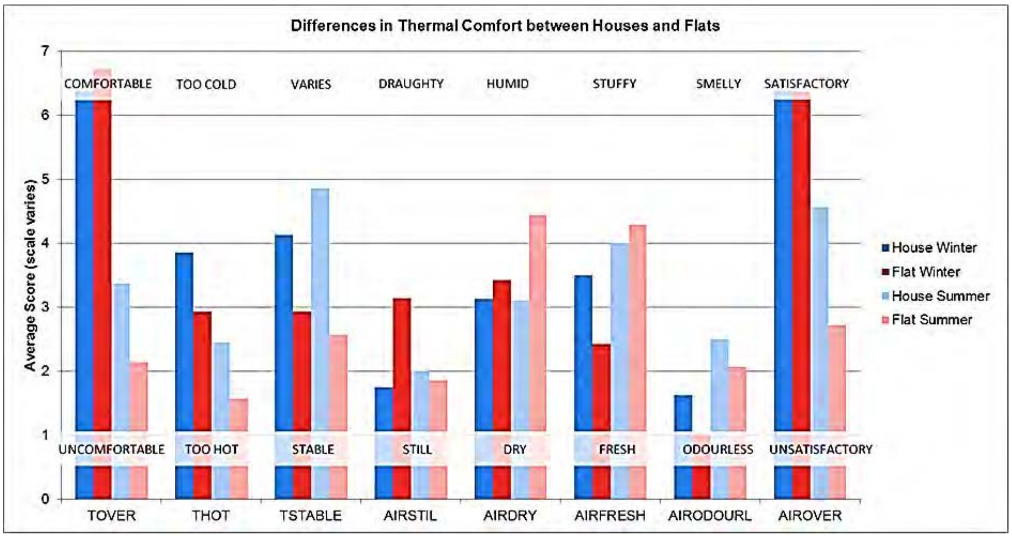


Figure 48: Comparison of Thermal Comfort variables between flats and houses



Finally, it is important to remember that the benchmark data has been collated based on only 9 completed surveys and therefore is unlikely to be representative of the UK housing stock, new-build or otherwise, and so care should be taken when interpreting these results based on a comparison with benchmarks.

5.2.2 Behaviour Change Research - Conclusion

5.2.2.1 Phase 1

The results from Phase 1 of the behaviour change research suggested that the new tenants of Sinclair Meadows were largely willing to engage with carbon-negative lifestyles and become part of new type of community. Despite some initial teething problems, most residents were very pleased with their new homes (in the words of one person, *'I feel like I've won the lottery!'*), and appeared to be willing to enter into the ethos of the development.

While most tenants already displayed at least some pro-environmental attitudes and beliefs, there were areas for potential improvement in their habits and everyday behaviours, e.g. reducing the amount of time spent in the shower, reducing packaging waste, and re-using items. Possible next steps included boosting awareness of the environmental impacts of all types of purchases, and educating people about checking labels on products, 'green' products and the importance of buying local to reduce transportation.

Tenants identified a number of areas in which they would have liked more information and support, with the most common ones being advice about how the heating system and boiler works, composting, bin use and recycling on site, problems with toilets, and information about how IAMs and monitors work. Ensuring that people get the information and support they require, and managing potential problem issues such as onsite car parking, was identified as being a potential challenge in the coming months and years.

5.2.2.2 Phase 2

The results from Phase 2 of the behaviour change research were published after approx. six months of residency. It was found that the residents were settling in to their new lives. They were largely happy with their new homes and the wider development. Their energy bills were lower than average, although there was a wide variation between households, which will be explored further in the next phases of the behaviour change research. Although tenants appeared to have different perceptions regarding heating needs, the homes were on the whole very warm even in a fairly chilly April, and most tenants were keeping windows open, often for long periods, to keep their homes cool.

The primary problem so far has been car parking, which has been a cause of division, rows and ill-feeling involving a number of tenants. In two cases where tenants left the development after less than six months, their desire to leave arose from disagreements around parking. There was also uncertainty around the future availability of off-site parking due to adjacent land being developed. The parking issue is a threat to the success of Sinclair Meadows in terms of providing a pleasant living environment for its tenants, and in particular to the aim of building a cohesive community. Action needs to be taken to resolve matters and rebuild goodwill between tenants, which has in some cases been lost.

A community development training programme developed and provided by external consultants, as well as efforts by Three Rivers Housing Association staff to address tenants' concerns and needs, has had a vital role in ensuring that the new community settled in and problems were dealt with. As well as car parking, these issues have included 'teething problems' such as how to use the heating and other technologies, and what to do when things do not work. A great deal of time had been dedicated to ensuring that tenants were supported in the early months in their new homes. However, there is still more to be done, with several tenants reporting that their heating was still not working properly in April.

In terms of tenants' daily energy use, there is evidence that resident diarists were being thoughtful about their energy use, and 'working with their homes' by ensuring that electrical appliances were mainly used during the daytime when solar PV energy was believed to be available to run them. The main exception to this is leisure activities such as watching TV and using the computer, which tend to be evening activities. This is likely to be linked to working patterns for most people, and therefore may not be easily changed. Tenants also seem to be considering their food purchasing behaviour carefully, which was an area that was flagged up for further attention in phase 1.

At the time of the research, little progress in gardening had yet been made, although a number of tenants had expressed an interest and were hoping to start soon. Help and support is being provided, and this may prove crucial with regard to managing expectations as well as passing on skills and advice. Some tenants were getting involved in other grounds maintenance activities, such as sweeping paths. This is preferable to paying maintenance charges because it encourages tenants' sense of responsibility for the site's upkeep, as well as saving them money.

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

6.1 Introduction

The properties on the development were all provided with a whole house balanced continuous mechanical ventilation system with heat recovery. The applicable building regulation standards for ventilation performance of the MVHR system for the dwellings on the development are given in approved document Part F 2006. To assess compliance with the Part F 2006 a series of measurements were carried to check the flow rates from the air valves in two of the dwellings (dwelling codes A and B). The measured data are compared with the design data.

The flow rates of the Mechanical Ventilation and Heat Recovery (MVHR) systems at all settings were measured in two monitored dwellings by a specialist Airtightness Test subcontractor on 7th January 2013 and again on 2nd April 2014 [dwelling A] and 7th May 2014 [dwelling B]. The comparison of Gross Floor Area (m^2) from SAP Worksheet with Values calculated from drawings is given in Table 40 (see also Table 4, page 10 for additional information). By comparison the Gross Internal Floor Area (m^2) used by the specialist contractor is also given in Table 40.

Table 40 – Comparison of Gross Floor Area from SAP Worksheet with Values Calculated from Drawings and Values as Used by Specialist Air Test Sub Contractor

	Dwelling A	Dwelling B
Gross Floor Area (m^2) from SAP Worksheet	107.12	66.51
Gross Floor Area (m^2) Calculated from Drawings	107.26	66.45
Gross Floor Area (m^2) Used by Specialist Air Test Sub Contractor	**116**	**68**

6.1.1 Regulatory Targets

The regulatory ventilation performance targets in Part F 2006 for dwellings with MVHR system are summarised in Table 41. The approved document requires that the MVHR system can supply a minimum level of fresh air at the fan unit trickle setting with an overall flow rate set according to either the number of bedrooms or on the dwelling gross internal floor area [flow rate = floor area x 0.3]. The design trickle flow rate is then adjusted downwards to take account of a nominal factor for air infiltration depending upon the number of storeys in the dwelling.

The minimum extract rate for the fan unit at boost rate is determined according to minimum flow rates set for each type of wet room; with the total whole building extract rate being the sum of the individual room rates. The minimum total boost rate must be at least the same at the whole building ventilation rate in trickle mode.

Part F 2006 also requires that all habitable rooms are provided with provision for purge ventilation at a rate of 4 air changes per hour [ach] directly to outside. Design provision for purge ventilation is normally done with open able windows where security issues are not a concern. There is no requirement in Part F 2006 to provide a commissioning sheet for mechanical ventilation systems in dwellings.

The calculations for the minimum regulatory ventilation flow rates for the house dwelling A and apartment dwelling B, according to Part F 2006 are given in Table 42 and Table 43 respectively. For dwelling B, the minimum trickle supply rate is 10 l/s and the minimum total boost rate is 21 l/s. For dwelling A, the minimum trickle supply rate is 21 l/s and the minimum total boost rate is 29 l/s.

Table 41 – Ventilation Requirements for MVHR in Dwellings in Part F 2006

Minimum Supply Rate in Trickle Mode		Minimum Extract Rate in Boost Mode	
Number of Bedrooms	**Flow Rate (l/s)**	**Wet Room Type**	**Flow Rate (l/s)**
1	13	Kitchen	13
2	17	Utility Room	8
3	21	Bathroom	8
4	25	W/C	6
Whole Building Ventilation Rate (l/s)	Greater of bedroom rate or (0.3 x Floor Area)	**Whole Building Extract Rate (l/s)**	Sum of individual wet room rates
Infiltration adjustment for single-storey dwellings	Minus (0.06 x Volume)		
Infiltration adjustment for multi-storey dwellings	Minus (0.04 x Volume)		

Table 42 – Dwelling A: Part F 2006 Targets

Minimum Supply Rate in Trickle Mode		Minimum Extract Rate in Boost Mode		
No. of Bedrooms	3	**Room Type**	**No. of Rooms**	**Total Flow Rate (l/s)**
Bedroom Total Flow Rate (l/s)	21	Kitchen	1	13
Floor Area (m^2)	107.1	Utility Room	1	8
Floor Area Total Flow Rate (l/s)	32.1	Bathroom	1	8
Volume (m^3)	279.1	W/C	0	0
Infiltration Adjustment (l/s)	11.1	**Whole Building Extract Rate (l/s)**		**29**
Whole Building Ventilation Rate (l/s)	**21.0**			

Table 43 – Dwelling B: Part F 2006 Targets

Minimum Supply Rate in Trickle Mode		Minimum Extract Rate in Boost Mode		
No. of Bedrooms	2	**Room Type**	**No. of Rooms**	**Total Flow Rate (l/s)**
Bedroom Total Flow Rate (l/s)	17	Kitchen	1	13
Floor Area (m^2)	66.5	Utility Room	0	0
Floor Area Total Flow Rate (l/s)	20.0	Bathroom	1	8
Volume (m^3)	166.3	W/C	0	0
Infiltration Adjustment (l/s)	10.0	**Whole Building Extract Rate (l/s)**		**21**
Whole Building Ventilation Rate (l/s)	**10.0**			

6.1.2 Design Targets

The drawings and M&E specification do not give any detail on the design flow rates for the MVHR system other than to state that they must be complaint with building regulations. The commissioning sheets for the MVHR installation provide data for minimum flow requirement for individual air valves in both trickle and boost mode. These are assumed to have been calculated by the designer/supplier of the ventilation system. The commissioning design data are shown in Table 44 [dwelling A] and Table 45 [dwelling B] respectively.

Table 44 – Dwelling A: Design MVHR Flow Rates from Commissioning Sheet

	Trickle Flow Rate (l/s)	Boost Flow Rate (l/s)
Kitchen	10	13
Bathroom	6	8
Utility Room	6	8
Total Extract	**22**	**29**
Living Room	9	12
Bedroom 1	5	7
Bedroom 2	5	7
Bedroom 3	5	7
Total Supply	**24**	**33**

Table 45 – Dwelling B: Design MVHR Flow Rates from Commissioning Sheet

	Trickle Flow Rate (l/s)	Boost Flow Rate (l/s)
Kitchen	10	13
Bathroom	6	8
Total Extract	**16**	**21**
Living Room	8	11
Bedroom 1	5	7
Bedroom 2	5	7
Total Supply	**18**	**25**

The design data for boost extract rates given in the commissioning sheets are compliant with the Part F 2006 minimum rates for both individual wet rooms and the total boost rate. However, the design data for total trickle supply rates (18 l/s for dwelling B and 24 l/s for dwelling A) are higher than the Part F 2006 minimum (10 l/s for dwelling B and 21 l/s for dwelling A).

The M&E specification does not provide any data on expected commissioning flow rates other than to state that the MVHR system should be installed and commissioned in accordance with the manufacturer's recommendations. This is normal practice and the clause is likely to be a standard specification clause. However, it is more usual for the design flow rates to be included on the M&E mechanical drawings that show the location of the MVHR ductwork; but this was not found to be the case for this development. It should also be noted that the design rates for supply and extract were not balanced resulting possibly from the residents adjusting the air vent(s).

When the total design requirement for supply or extract rates differ, it is normal practice to adjust the flow rates for the lower total so that it matches the higher. This is to maximise the efficiency of the heat exchanger and so that pressure differences between supply and extract zones do not create unnecessary infiltration and exfiltration through the building fabric.

6.1.3 Commissioning Data

The MVHR flow results given in the installers commissioning sheets are shown in Table 46 for dwelling B and in Table 47 for dwelling A. The measured flow rates exceed the quoted minimum design requirements and are significantly higher than the minimum requirements in Part F 2006. These data indicate that the system was commissioned in line with the design data. However, the total flow rates were not balanced between supply and extract, although this imbalance is similar to that for the target flow rates given on the commissioning sheets.

Table 46 – Dwelling B: Commissioning Results (Tested 20/6/2012)

	Trickle Flow Rate (l/s)	Boost Flow Rate (l/s)
Kitchen	11	13
Bathroom	7	9
Total Extract	**18**	**22**
Living Room	8	12
Bedroom 1	6	7
Bedroom 2	6	8
Total Supply	**20**	**27**

Table 47 – Dwelling A: Commissioning Results (Tested 19/6/2012)

	Trickle Flow Rate (l/s)	Boost Flow Rate (l/s)
Kitchen	11	15
Bathroom	7	8
Utility Room	7	9
Total Extract	**25**	**32**
Living Room	9	13
Bedroom 1	6	8
Bedroom 2	6	8
Bedroom 3	6	8
Total Supply	**27**	**37**

6.1.4 Initial BPE Test Results

Initial MVHR flow tests for the BPE project were carried out in dwelling A and B during January 2013. The tests were carried out by a commercial testing organisation using a calibrated Testo 417 vane anemometer and flow hood. The results are shown in Table 48 for dwelling A and Table 49 for dwelling B. There is a significant discrepancy between the values measured for the BPE project and those given in the original commissioning sheets and imbalances between supply and extract rates for both dwellings in both trickle and boost modes. These results indicate that the systems were either not commissioned correctly or that changes have been made to fan speed settings or air valve positions post commissioning. Given that the measured boost flow rates are relatively high, the potential influence of blocked filters on performance is thought unlikely but cannot be discounted.

Table 48 – Dwelling A: Initial MVHR Flow Measurements for BPE (7/1/2013)

	Trickle Flow Rate (l/s)	Boost Flow Rate (l/s)
Kitchen	4.54	6.98
Bathroom	4.38	5.30
Utility Room	6.88	9.12
Total Extract	**15.80**	**21.40**
Living Room	1.06	8.12
Bedroom 1	2.94	10.06
Bedroom 2	2.86	7.24
Bedroom 3	2.86	5.86
Total Supply	**9.72**	**31.28**

Table 49 – Dwelling B: Initial MVHR Flow Measurements for BPE (Test Date 7/1/2013)

	Trickle Flow Rate (l/s)	Boost Flow Rate (l/s)
Kitchen	6.22	7.14
Bathroom	8.82	10.2
Total Extract	**15.04**	**17.34**
Living Room	1.90	16.32
Bedroom 1	2.06	10.00
Bedroom 2	1.66	14.20
Total Supply	**5.62**	**40.52**

The data given in Table 50 summarise and compare the total supply and extract rates as given in Part F 2006 and the measured values obtained both during the commissioning tests and as part of the initial BPE testing. It is recognised that at the time of construction, Building Regulations was achieved, however it can be seen that in the case of the trickle supply rate, the measured data from the initial BPE tests means that the system would fail to meet the minimum air flow requirements of Part F 2006 by a factor of around 50 per cent for both the House and Apartment. The measured boost extract rate from the BPE tests would also fail the requirements of Part F 2006, but by a smaller margin (~30 per cent).

Table 50 – MVHR Total Flow Rates: Part F 2006 Targets, Commissioning and Initial BPE Test Results

		Dwelling A	Dwelling B
Trickle Supply Total (l/s)	Part F 2006	21.0	10.0
	Commissioning	27.0	20.0
	BPE Test	9.7	5.6
Boost Extract Total (l/s)	Part F 2006	29.0	21.0
	Commissioning	32.0	22.0
	BPE Test	21.4	17.3
Trickle Extract Total (l/s)	Commissioning	25.0	18.0
	BPE Test	15.8	15.0
Boost Supply Total (l/s)	Commissioning	37.0	27.0
	BPE Test	31.3	40.5

6.1.5 Final BPE Test Results

Final BPE MVHR flow tests for the BPE project were carried out in dwelling A in April 2014 and in dwelling B in May 2014. The understanding is that the M&E subcontractor visited site between the initial and final BPE tests in order to carry out checks and repairs on the MVHR systems on the development. It was therefore expected that the measurements would have changed since the initial tests. The final flow tests were carried out by the same commercial tester that conducted the initial BPE tests and using the same equipment. The measured flow rates from the final BPE test are given in Table 51 for dwelling A and Table 52 for dwelling B.

Table 51 – Dwelling A: Final MVHR Flow Measurements for BPE (2/4/2014)

	Trickle Flow Rate (l/s)	Boost Flow Rate (l/s)
Kitchen	0.0	5.3
Bathroom	0.1	7.7
Utility Room	0.2	1.5
Total Extract	**0.3**	**14.5**
Living Room	0.0	15.1
Bedroom 1	0.1	9.0
Bedroom 2	0.0	8.2
Bedroom 3	0.1	6.0
Total Supply	**0.2**	**38.3**

Table 52 – Dwelling B: Final MVHR Flow Measurements for BPE (7/5/2014)

	Trickle Flow Rate (l/s)	Boost Flow Rate (l/s)
Kitchen	5.2	9.7
Bathroom	5.7	7.3
Total Extract	**10.9**	**17.0**
Living Room	0.2	1.8
Bedroom 1	0.8	3.3
Bedroom 2	0.9	2.5
Total Supply	**1.9**	**7.6**

It can be seen that, rather than an improvement in MVHR performance since the contractor has revisited the dwellings, there has been a significant deterioration in measured flow rates by the time of the final BPE tests. In particular, the measured supply rates in trickle mode are negligible and fail to meet the Part F targets. A measured value of less than 0.5 l/s will likely be due to background pressure effects.

- The total flow rates in boost mode were severely imbalanced, with 14.5 l/s in extract and 38.3 l/s in supply for the house.
- The boost extract rates do not meet the Part F 2006 requirement.
- All measured values for supply and extract were found to have changed since the initial tests.

The graphs in Figure 49 and Figure 50 and show the timeline of total trickle supply flow measurements for dwelling A and dwelling B respectively. These are compared to the minimum flow requirements in both Part F 2006 and Part F 2010. It can be seen that there is a significant reduction in measured values over time.

It is not known whether this is a real effect showing a gradual decline in performance or if this due to other factors such as differences in measurement protocols (commissioning vs BPE), component failure or interventions by the householders.

Figure 49 – Dwelling A: MVHR: Timeline of Total Trickle Supply Measurements

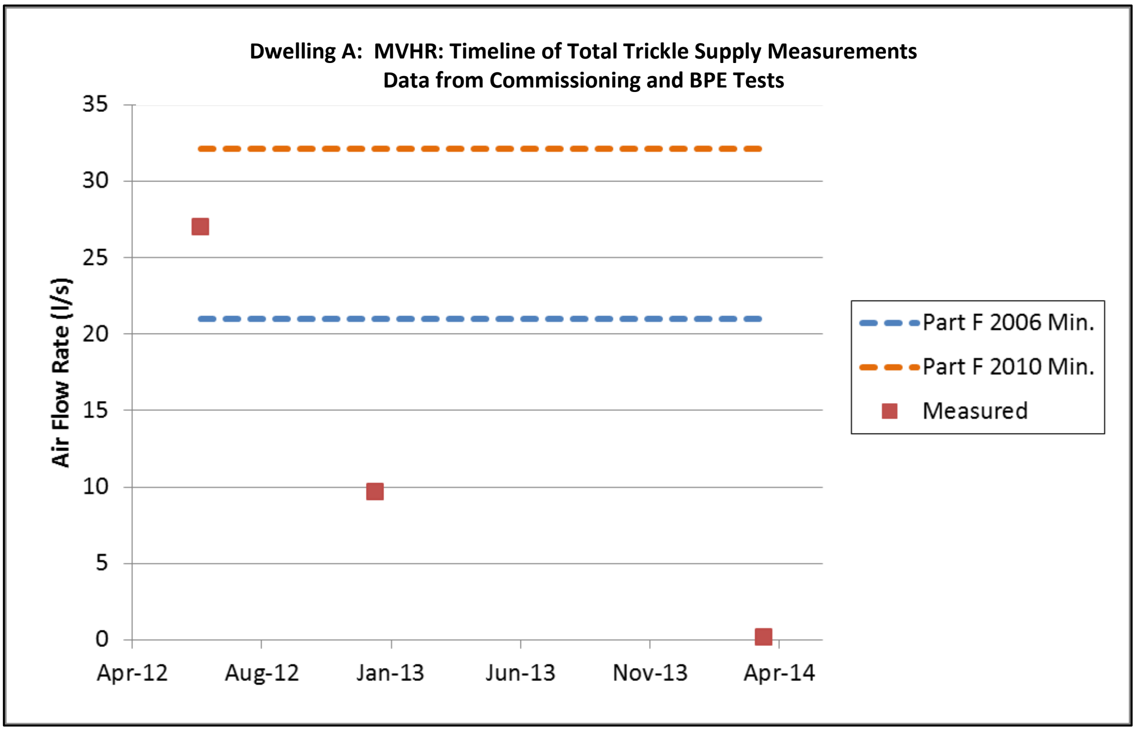
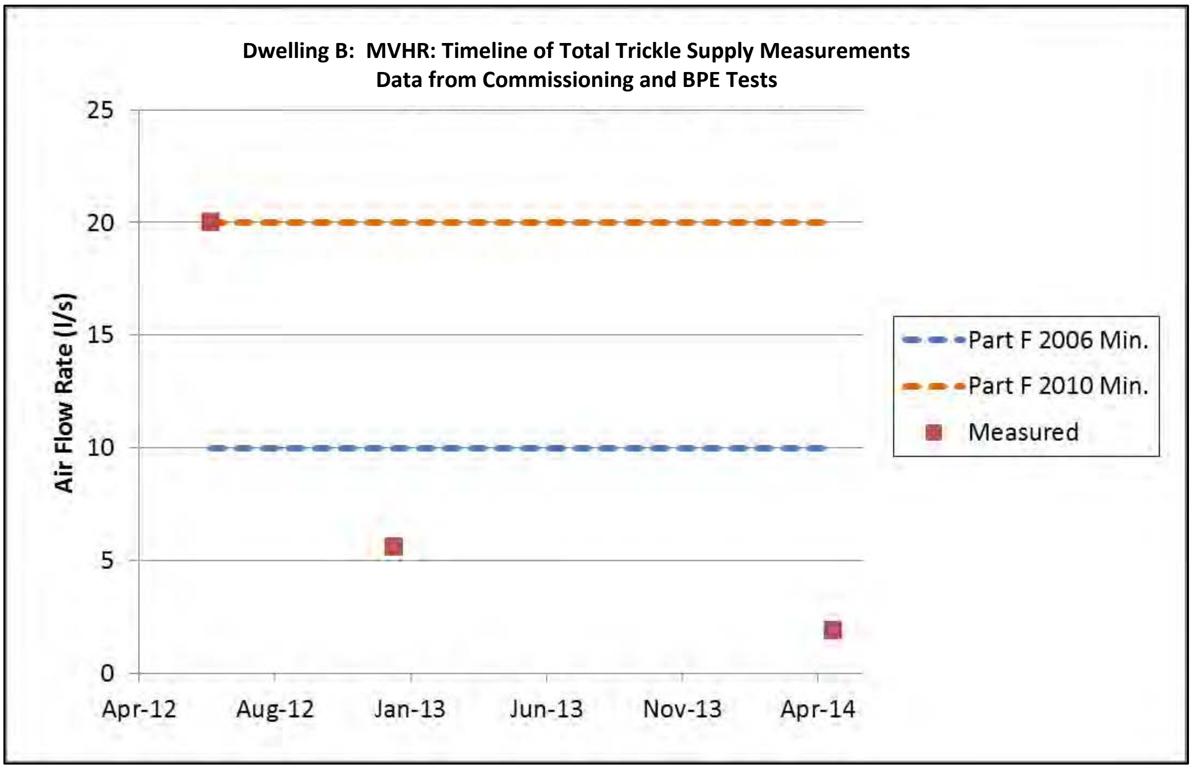


Figure 50 – Dwelling B: MVHR: Timeline of Total Trickle Supply Measurements



6.1.6 Site Observations

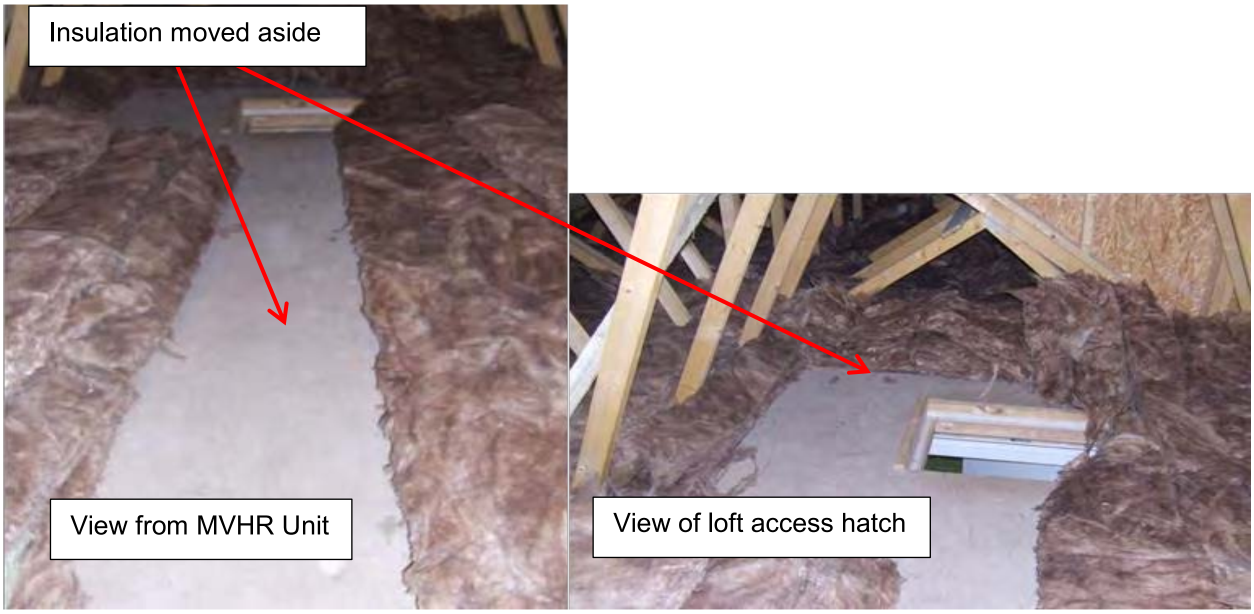
The photograph in Figure 51 shows the MVHR unit in the loft of dwelling A. The installation demonstrates the correct use of insulated duct in the cold space and provision of a walkway for access to the unit and the filters. However, the length of flexible duct used is excessive and the ductwork is not properly supported to prevent collapse of the duct or damage to duct connections (Figure 52).

Figure 51 – Dwelling A: MVHR Unit in Loft

Figure 52 – Dwelling A: Flexible Duct Across Purlin

It was also observed that the effectiveness of the loft insulation under the walkway had been compromised (Figure 53).

Figure 53 – Dwelling A: Loft Mineral Wool Insulation Material



One of the connections between the ductwork and MVHR units was found to have worked loose, with the inside of the duct being visible from the outside (Figure 54). This was at the connection between the extract from the dwelling wet rooms to the unit. The effect of this fault would have been to cause significant duct leakage and increase the amount of power needed to run the fans. The other potential problem would be condensation on cold surfaces in the loft due to the flow of moisture laden air from the faulty connection. In the long term this could give rise to mould/or and rot on the loft timbers.

Figure 54 – Dwelling A: Poorly Sealed Duct Connection at MVHR (Room Extract Duct)

The photograph in Figure 55 shows the MVHR unit in the cylinder cupboard of dwelling B. In common with the house, there is excessive use of flexible ducting which is not properly supported. It was also found that the intake and exhaust ducts leading between the MVHR unit and outside were not insulated. This could give rise to condensation on the outside of the ducting.

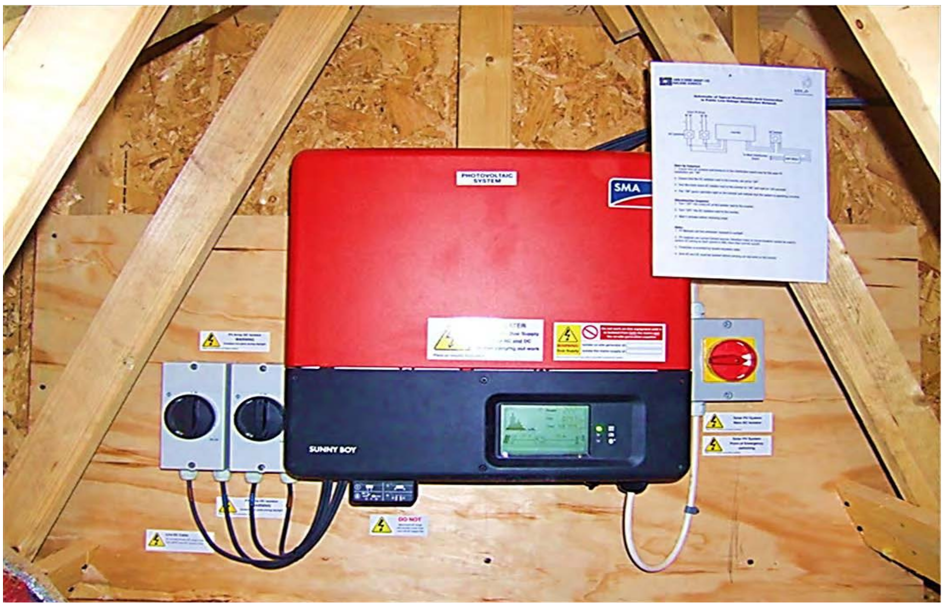
Figure 55 – Dwelling B: MVHR unit in Cylinder Cupboard

6.2 Renewable energy systems

6.2.1 Performance of Solar Photovoltaic (PV) Array

Figure 56 shows the solar PV inverter in dwelling A. The annual output from the solar PV arrays of the houses and flats on the Sinclair Meadows development was obtained from the ESCo data. The annual total electricity output from the arrays ranged from a high of 87,594 kWh.a (Feb-13 to Jan-13) to a low of 72,964 kWh.a (Mar-13 to Feb-14) (see Table 53). The variation in output was mainly due to a technical issue of the array on one of the houses rather than differences in annual solar radiation. The latest ESCo data indicate that these technical issues have now been resolved and it would be expected that the annual output from the solar PV arrays will increase in future years; as long as there are no further problems with the operation of the system.

Figure 56 – Dwelling A: Solar PV Inverter in Loft



The total predicted annual output for the overall 85 kWpeak array based on the inputs to the SAP2005 assessments for the dwellings was 70,845 kWh.a. The measured output from the array is therefore higher than the predication. It should be noted however that SAP is relatively conservative in its calculation of solar PV performance, and the SAP algorithm applies a factor of 80 per cent to account for the system efficiency whereas the measured data from Sinclair Meadows indicate that system efficiency factor is of the order 90 per cent or better.

Table 53 - Total Annual Output from Solar PV Arrays

Period	Total PV Output Use (kWh.a)	Total PV Output from Apartment Array (kWh.a)	Total PV Output from House Arrays (kWh.a)
1/12/12 to 30/11/13	86059	40299	45760
1/1/13 to 31/12/14	86731	40429	46302
1/2/13 to 31/1/14	87594	40702	46892
1/3/13 to 28/2/14	72964	40914	32050
1/4/13 to 31/3/14	75062	41709	33353
1/5/13 to 30/4/14	74153	40881	33272
1/6/13 to 31/5/14	74597	40652	33945

6.2.2 Performance of District Heating System

The overall performance of the district heating system was assessed using ESCo data and biomass-fuel delivery data for the period 25th March 2013 to the 24th March 2014. This period was chosen to match with biomass-fuel deliveries that took place on both these dates and therefore minimises any potential variability caused by the periodic nature of the deliveries. The performance data for this period used to calculate the efficiency of the district heating system are given in Table 54.

Table 54 - District Heating System Performance Data for Period 25/3/13 to 24/3/14

Energy from Biomass Deliveries (kWh.a) (Based on net calorific value)	254976
Heat Energy Output from Biomass Boiler (kWh.a)	209618
Total Heat Delivered to Dwellings (kWh.a)	55016
Total Parasitic Electric Use DH Pumps, Controls & Buffer Immersion (kWh.a)*	15466
Total Immersion Heat to Buffer Tank (kWh.a)	5504

*Corrected for missing data due to logger faults

The calculated efficiencies for the district heating system are given in Table 55. The overall system efficiency for delivery of heat to the dwellings was 20.3 per cent. This is perhaps an indication that the use of district heating for small scale low energy developments such as Sinclair Meadows may be inappropriate due to the lack of a sufficiently large heat demand to offset the system inefficiencies and distribution losses. Recent research carried out by the National Energy Foundation on a number of district heating schemes in London found similarly poor system efficiencies. This is an area that requires further industry research.

The net efficiency of the biomass boiler was 82.2 per cent. This is based on the net calorific value for biomass-fuel wood pellets of 4,800 kWh/tonne [as specified by the biomass supplier (Verdo 2014)]. This compares to the manufacturers' quoted boiler efficiency of 93.6 per cent. The reason for the under-performance of the boiler is unknown.

The parasitic electricity used to run the communal system (pumps, boiler controls, buffer tank immersion) was very high at 28.1 per cent as a function of delivered heat. This factor increases to as high as 40 per cent later in the monitoring period; where the use of immersion heat is higher due to the failure of the biomass-fuelled boiler in April 2014.

Table 55 - District Heating System Calculated Efficiencies for Period 25/3/13 to 24/3/14

Efficiency of Biomass Boiler (%) (Based on net calorific value)	82.2
District Heating System Distribution Efficiency Biomass Heat Only (%)	26.2
District Heating System Distribution Efficiency All Heat (including buffer immersion heat) (%)	25.6
Parasitic Electricity as Function of Delivered Heat (%)	28.1
District Heating System Overall System Efficiency (%)	**20.3**

The distribution efficiency of the heat via the district heating system was only 26 per cent. This compares to the assumption used in the SAP calculation of 95 per cent [although it should be noted that the SAP 2005 protocol is based on a nominal figure for distribution efficiency and does not require detailed calculation of pipe losses]. It is generally recognised that this SAP figure is unrealistic and requires revision.

6.3 Conclusions and key findings for this section

Mechanical Ventilation with Heat Recovery (MVHR):

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).

It is recognised that at the time of construction, Building Regulations compliance was achieved. Flow measurements of the MVHR systems in two occupied dwellings on the development have shown that the systems do not meet the ventilation requirements of Part F 2006. Due to the length of time elapsed between initial commissioning and the BPE performance tests, it is unknown whether this is an issue related to the commissioning process, problems with reliability of the MVHR system, a gradual deterioration in performance, as a result of occupant behaviour or some combination of factors.

The design and installation of the MVHR systems at Sinclair Meadows presented numerous problems. It should be noted that many of these problems have also emerged at other BPE projects, which have investigated MVHR systems. One of the consequences of this has been that the Technology Strategy Board has commissioned a separate Meta-study into MVHR. Issues found at Sinclair Meadows included locations of the unit within the dwellings giving rise to installation and access issues together with difficulties with both maintenance and operation.

The consequence of the very low measured trickle supply flow rates in the two test dwellings is that they will likely be under-ventilated unless the residents take action to increase air flow by opening windows. The knock on effects of under-ventilation will be poor internal air quality and an increased risk of condensation and mould growth. Physical evidence of mould growth has already been observed in the bathroom of dwelling A (see Figure 38, page 52).

The commissioning and BPE data also show that the total flow and extract rates were not balanced, which would affect the heat exchange efficiency.

It is recommended that the MVHR systems in dwelling B and dwelling A are checked and re-commissioned. It is suggested that the housing association consider using updated targets for this in line with the advice given in Part F 2010. It is also recommended that the housing association conduct further flow measurements and checks on the MVHR systems in the other 19 dwellings on the Sinclair Meadows development to determine if the problems observed in the two test dwellings are more widespread.

7 Monitoring methods and findings

The in-use monitoring programme at Sinclair Meadows investigated the performance of two occupied dwellings, dwelling A (three bedroom two story end-terrace house) and dwelling B (two-bedroom ground floor apartment). Monitoring of the households commenced on the 7th March 2013, and this report includes an analysis of data up to the end of May 2014, giving a total of 14 months' worth of data. The analysis therefore includes one full heating season and one full summer season. Both monitored households remained in the monitoring programme for the duration of the project.

See Section 10.1.1, Building Performance Evaluation Methodology, page 117, and Section 12.1, Monitoring and Metering, page 129 for additional information. The data collected by the monitoring programme was obtained from three different sources.

Information on internal conditions, disaggregated energy consumption and external weather for the two test houses, was collected by an Eltek wireless monitoring system installed by the main contractor on behalf of the housing association. This data was logged at 5 minute intervals by a data logger located in the biomass boiler plant room. The data was manually downloaded by the M&E contractor on a regular basis and sent to the research team at the National Energy Foundation for analysis.

The second set of energy data were the meter readings for heat and electricity for all 21 dwellings on the development. These were provided by the housing association for the period August 2012 to May 2014 from the ESCo billing data.

The final set of data were the weights of biomass-fuel and dates of deliveries to the district heating plant room, details of which were provided by the housing association from their financial records.

The monitored characteristics of the two test dwellings, ESCo metering and weather station are detailed by the set-up given in Table 56. Some monitoring of the performance communal heating system was provided by heat meters and electricity meters located in the plant room on the development. This was limited to the heat output from the communal biomass boiler and electrical sub-meters on the biomass-fuel boiler circuit and the circulation pump/buffer tank immersion heater circuit. This biomass boiler heat data was collected by the ESCo and was provided as daily meter readings for the period August 2012 to May 2014; with a resolution of 1kWh. The boiler and circulation pump sub-meter data were collected by the Eltek wireless monitoring system at 5 minute intervals with a resolution of 1 kWh.

Table 56 – Dwelling Monitoring Set-up

Dwelling Characteristic	Type of Sensor	Resolution	Number and Location of Sensors
Total communal heat input to dwelling	Heat meter	1 kWh	1 ESCo heat meter fitted to communal heat main input to Heat Interface Unit (HIU) in all 21 dwellings.
DHW heat input to dwelling	Heat Meter	1 kWh 1 Wh	1 ESCo heat meter fitted to DHW circuit in all 21 dwellings. In addition, a second heat meter fitted to DHW circuit in 2 test dwellings.
Space heating output from HIU to dwelling	Heat meter	1 Wh	1 heat meter fitted to heating circuit in 2 test dwellings only.
Total electricity input to dwelling	kWh meter	1 kWh	1 ESCo kWh meter fitted to main electrical board in all 21 dwellings.
Disaggregated electricity use	kWh meter	0.5 Wh	8 sub-meters fitted to 8 of the electrical circuits in house A (upstairs lighting, downstairs lighting, MVHR, cooker, sockets, kitchen sockets, heating controls, immersion

		0.5 Wh	heater). 7 sub-meters fitted to 7 of the electrical circuits in apartment B (lighting, MVHR, cooker, sockets, kitchen sockets, heating controls, immersion heater).
Output from solar PV arrays	kWh meter	0.625 Wh 1kWh	1 sub-meter fitted to output from array on House A. ESCo kWh meters also fitted to PV arrays of all 9 houses and the array on the apartment block.
Internal temperature °C and relative humidity RH%	Temperature and RH sensor		5 temperature/RH sensors in each of the 2 test dwellings. Sensors were located in living room, kitchen, master bedroom, hallway and bathroom.
Internal air quality	CO_2 sensor		1 infra-red CO_2 sensor in both test dwellings. Sensors were located in the living room. Measurement range of CO_2 sensor from 0 to 5000 ppm.
External weather	Weather station		Eltek external temperature/relative humidity weather stations fitted to both house A and apartment B. In addition, a south facing pyranometer in horizontal plane was fitted to house A.

7.1 Description of monitored dwellings and households

Dwelling A is a 2 storey end-terrace dwelling with 3 bedrooms and is located at the south end of a terrace of 9 houses. Dwelling B is a single-storey dwelling on the ground floor of a 3-storey block of 12 apartments. The apartment is accessed via a common stairwell. The floor plans of the house and apartment are shown in Figure 57, Figure 58 and Figure 59 respectively [Note: Drawing of house is for a mid-terrace, so it is shown with party wall construction on the south wall where Dwelling A would have external wall. It can be seen that the built form of both dwellings is relatively complex].

Figure 57 – Ground Floor Plan Drawing of Representative House (Dwelling A)

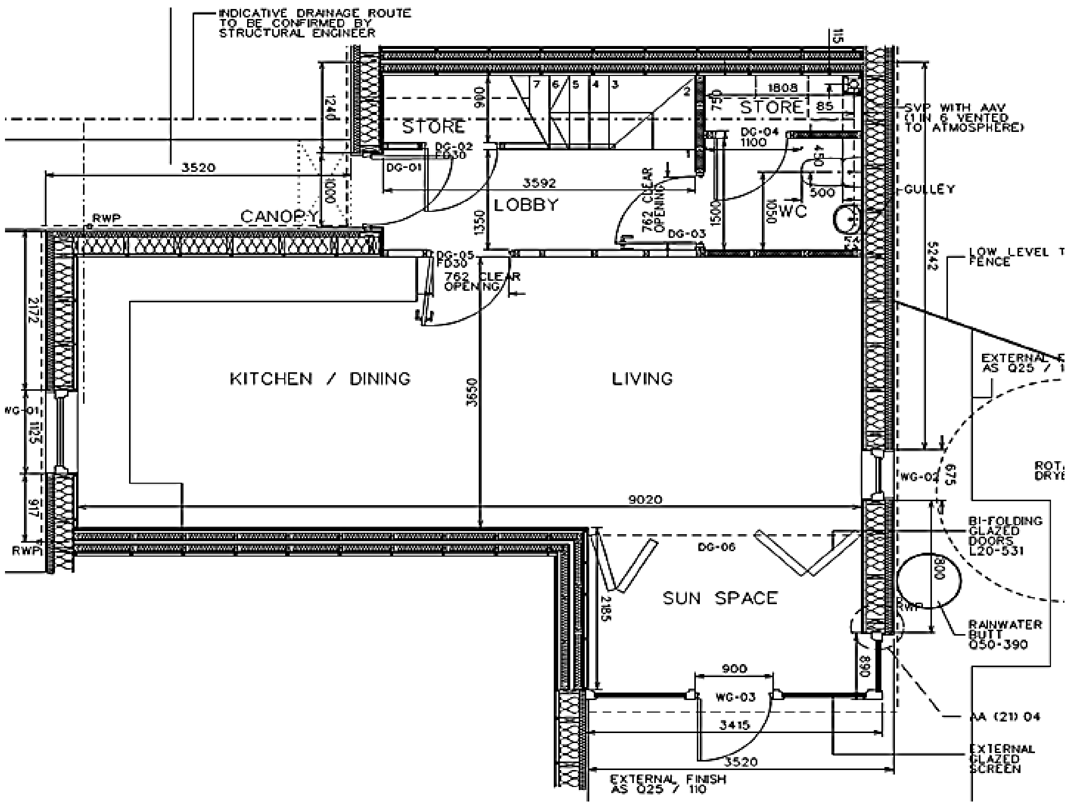


Figure 58 – First Floor Plan Drawing of Representative House (Dwelling A)

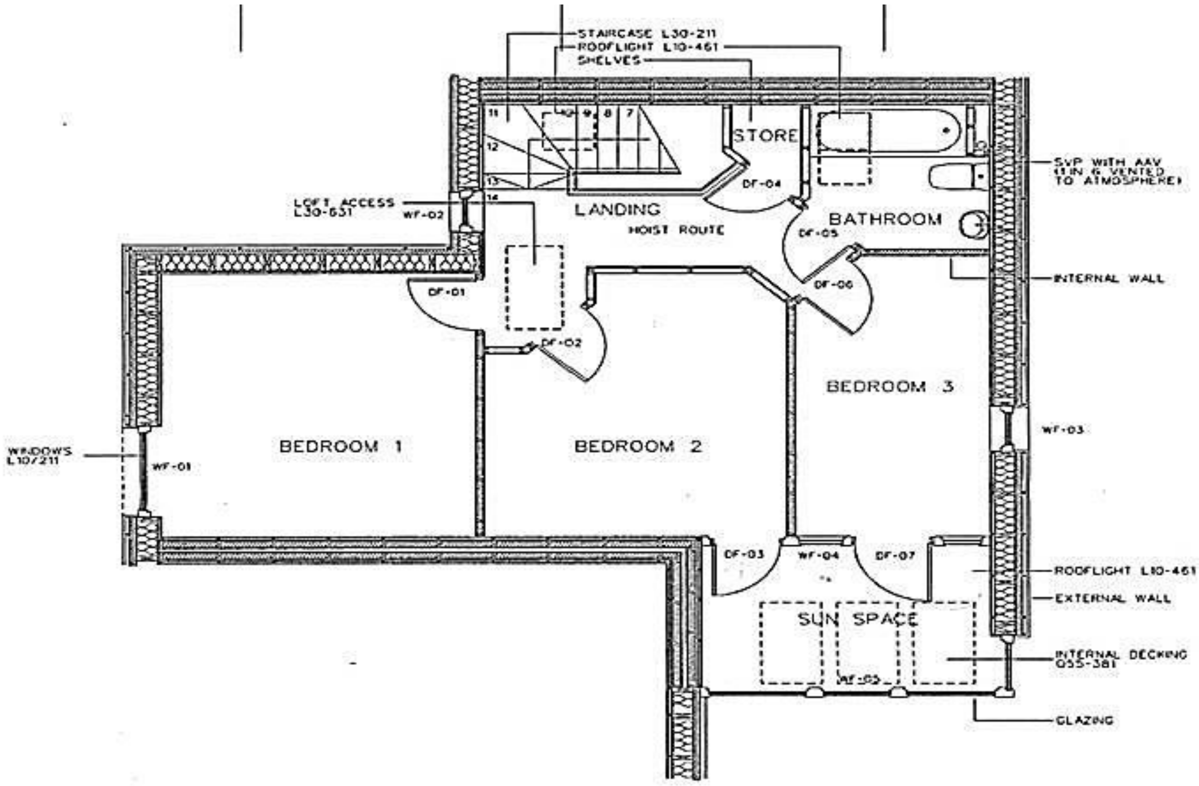
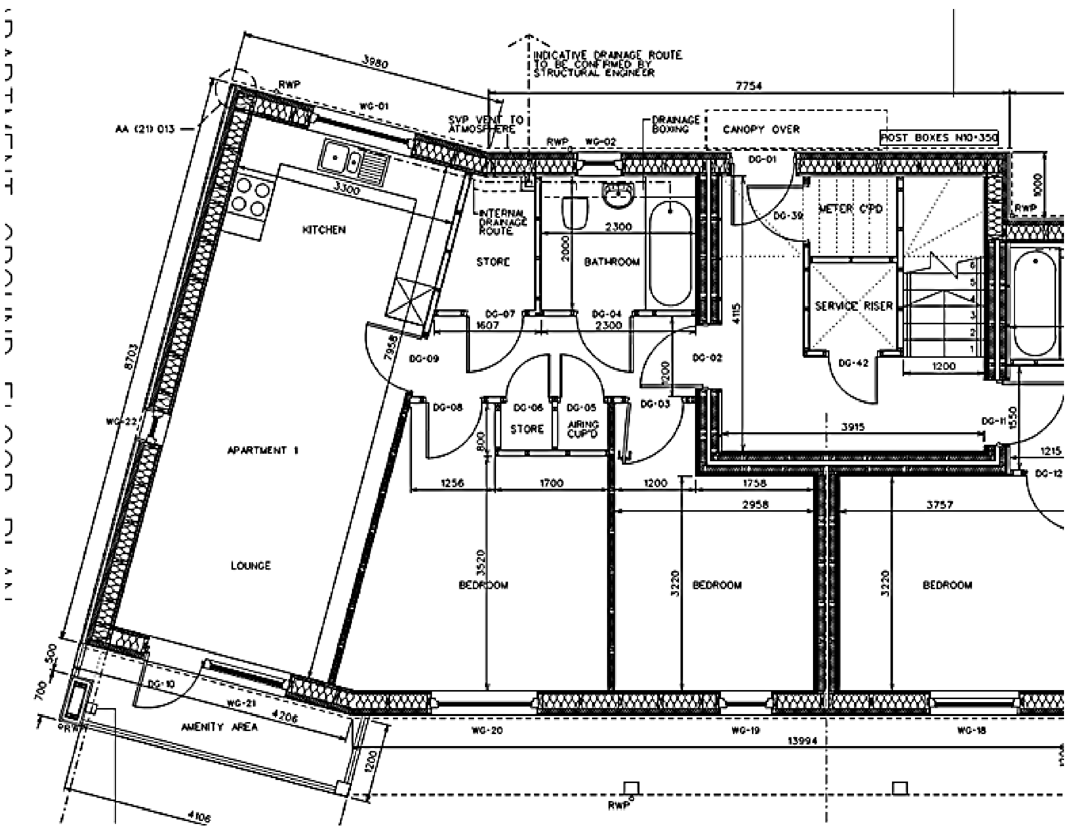


Figure 59 – Plan Drawing of Apartment (Dwelling B)



Dwelling A and B both have an open-plan living room with kitchen. The house (dwelling A) also has a sun-space area on the south side of the building, although the sun-space is inside the thermal envelope. The orientation and exposure of the two test dwellings are summarised in Table 57. The common stairwell in the apartment block is heated using electric panel heaters (approx. 1.5 kW), and therefore the apartment walls to the common area are treated as zero-heat loss elements.

Table 57 – Orientation and Exposure of Monitored Dwellings

Dwelling Code	No of Floors	Orientation of Main Glazed Facade	Fully Exposed Elements	Elements Exposed to Heated Common Spaces	Party Elements
Dwelling A	2	South	7 external walls, floor, ceiling	None	1 party wall
Dwelling B	1	South/South West	5 external walls, floor	2 walls	Ceiling, 1 party wall

The key dimensions of the two monitored dwellings are summarised in Table 58.

Table 58 – Dimensions of Monitored Dwellings

Dwelling Code	Floor Area (m^2)	Internal Volume (m^3)	Room Height (m)	Envelope Area (m^2)	Glazed Area (m^2)	External Wall Area (m^2)	Total Exposed Area (m^2)
Dwelling A	107.1	279	2.5	350	22.2	115.3	243.9
Dwelling B	66.5	166	2.5	220	12.8	66.5	129.7

The fabric, ventilation and total heat loss coefficients for the two monitored dwellings are given in Table 59. The heat loss parameter for the house and flat are very low at 0.59 W/m^{2}K and 0.51 W/m^{2}K respectively.

Table 59 – Predicted SAP 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)	Heat Loss Parameter (W/m^{2}K)
Dwelling A	47.6	15.2	62.8	0.59
Dwelling B	25.0	9.0	34.0	0.51

The demographics of the two households are summarised in Table 60. The residents of the house are a 5-person household, with 2 adults and 3 children. The residents of the apartment are a retired couple.

Table 60 – Details and Demographics of Monitored Households

Dwelling Code	Normal No. of Residents	Tenure	Household Description	Typical Daytime Occupation Pattern
Dwelling A	5	Rented	Family with 1 working adult	Occupied most days
Dwelling B	2	Rented	Retired Couple	Occupied most days

7.1.1 Data Integrity

See Section 12.2 - Site Monitoring Observations, page 139 for additional information.

Prior to data analysis, all datasets were checked for completeness and consistency. Where appropriate, spurious data points were removed and missing data were substituted with estimated or extrapolated values as detailed below. In the case of the dwelling temperature, humidity and CO_2 data, some sensor transmissions to the Eltek data logger were lost due to transmission clashes. This was a particular problem during the first four or five months of the monitoring period. This was found to be related to the fact that the initial sensor transmission rate (5 minute intervals) was insufficient for the 5 minute logging rate and the fact that data from the house had to be transmitted through the whole of the terrace to the plant room. The situation was resolved by installing a dipole aerial on the logger and by reducing the transmission interval to less than 5 minutes. A temporary fix to improve data quality issues caused by the transmission clash problem was attempted during the early monitoring stages by increasing the logging interval to 15 minute intervals. This means that the data for the period between 23/3/13 and the 16/5/13 was recorded at 15 minute intervals rather than the 5 minute interval required under the Technology Strategy Board BPE programme.

Temperature (Temp), relative humidity (RH) and CO_2 data lost due transmission clashes were substituted by data from the adjacent time periods without affecting significantly the integrity of the dataset or subsequent analysis. The data logger uses a cumulative pulse metering system and so no energy data were lost due to transmission clashes.

It was noted during the monitoring period that the real time clock on the data logger had become out of sync with actual time. The total time difference had reached 7 days by February 2013. Subsequent analysis of the data showed that the data logger was randomly stopping logging during a logging period. The amount of time the logger was stopped varied from 5 minutes to more than a day. It was necessary to manually identify these periods in the data (using the signal shown by the accumulated energy data) and insert the appropriate number of 5 minute intervals to bring the time back into line. Where the time period inserted was small (a few hours or less) the missing temperature, humidity, weather and CO_2 data were substituted from adjacent data. Where the missing data were for more than an hour, the missing data were left blank (see Table 61 for summary of missing datasets due to the logger timing fault and logger memory issues).

The total amount of time where all data are missing due to logger memory issues was 40 days. The amount of time where only dwelling temperature, humidity, weather and CO_2 data are missing and were not substituted was 4 days.

Table 61 – Missing Datasets

Dataset	Time Period of Missing Data	Comment
Dwelling A & B: Temp/RH/CO_2/Weather/Energy	1/6/13 to 17/6/13	Logger out of memory
Dwelling A & B: Temp/RH/CO_2/Weather/Energy	3/7/13 to 9/7/13	Logger out of memory
Dwelling A & B: Temp/RH/CO_2/Weather/Energy	5/9/13 to 20/9/13	Logger out of memory
Dwelling A & B: Temp/RH/CO_2/Weather/Energy	18/10/13 to 18/10/13	Logger out of memory
Dwelling A & B: Temp/RH/CO_2/Weather	24/12/13 to 25/12/13	Logger timing fault
Dwelling A & B: Temp/RH/CO_2/Weather	22/1/14 to 23/1/14	Logger timing fault
Dwelling A & B: Temp/RH/CO_2/Weather/Energy	26/1/14 to 27/1/14	Logger out of memory
Dwelling A & B: Temp/RH/CO_2/Weather	30/1/14 to 1/2/14	Logger timing fault
Dwelling A & B: Temp/RH/CO_2/Weather	10/2/14 to 10/2/14	Logger timing fault
ESCo total heat data for *plot #5*	1/12/12 to 22/1/14	Faulty heat meter – missing data substituted
Dwelling A: Kitchen Temp/RH	22/1/14 to 31/5/14	Faulty sensor
Dwelling B: Living Room Temp/RH	2/4/14 to 31/5/14	Faulty sensor
Dwelling B: Living Room CO_2	19/11/13 to 31/5/14	Faulty sensor

Two of the temperature/humidity sensors developed faults towards the end of the monitoring programme. These were the kitchen sensor in dwelling A and the living room sensor in dwelling B. The living room sensor in the flat also included the CO_2 sensor, so this data was also lost. The sensors were removed from the dwellings but not replaced. Table 61 gives the time periods of missing data for these two sensors.

When the data for the dwelling kWh sub-meters were correlated against the ESCo utility meter data and physical meter readings, some inconsistencies were identified. It was found that the sum of the electricity use given by the sub-meters was less than that of the utility meter. In addition, an analysis of the usage patterns of some of the kWh sub-meters did not match the designation as provided by the installer. A summary of the usability of the kWh sub-meter data for both test dwellings is given in Table 62. A comparison of the ESCo utility meter data with the sub-meter data was used to calculate annual data for the sub-meter circuits.

Table 62 – Usability of Data from kWh Sub-meters

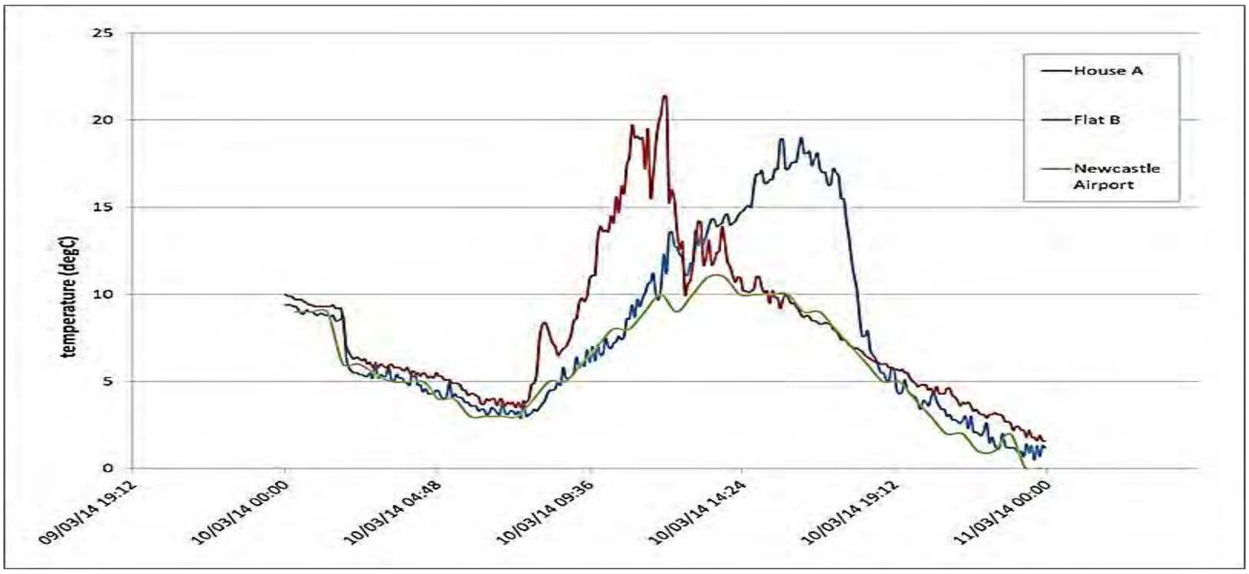
Dwelling A kWh sub-meter	Data usability and action taken
Downstairs lighting	Data useable
Upstairs lighting	Data useable
MVHR	Data useable
Immersion heater	Data useable
Heating controls	Data do not match heating/DHW patterns: designated as unknown
Main socket circuit	Data useable
Kitchen socket circuit	Intermittent fault on kWh meter: difference between ESCo data and sum of sub-meters assigned to kitchen socket circuit
Cooker circuit	Data useable
Dwelling B kWh sub meter	**Data usability and action taken**
Lighting	Data useable
MVHR	Data do not match MVHR pattern: designated as "other" and added to socket circuits. MVHR assumed not to be one of sub-meters and calculated using ESCo data
Immersion heater	No immersion use on circuit: designated as "other" and added to socket circuits. Immersion assumed not be part of sub-meter set
Heating controls	Data useable
Main socket circuit	Data useable
Kitchen socket circuit	Data useable
Cooker circuit	Data useable

The external temperature sensors on both house and flat were found to be affected by solar radiation. This effect can be seen in Figure 61 which shows external temperature data for the two test dwellings and that from the hourly Met Office weather station at Newcastle airport for a sunny day in March 2014. It can be seen that the airport temperature does not exceed 10°C. By comparison, the temperature recorded by the sensors on the dwellings peaks at around 20°C. This is likely due to the Stephenson radiation screen supplied with the sensors being ineffective for south, east or west facing locations (Figure 60). This issue means that the external temperature and relative humidity data collected on site are not useable as the data will be biased on sunny days.

Figure 60 – Logging Equipment, Dwelling B – External Temperature (°C) and Relative Humidity (RH%)

An alternative set of temperature data was sourced from the Weather Underground public weather station database for a weather station located in Billingham (Weather Underground 2014), which is around 30 miles south from the development in South Shields. Whilst not ideal, a comparison of the data showed a similar temperature profile for non-sunny days; and the data was relatively unaffected by sunny weather.

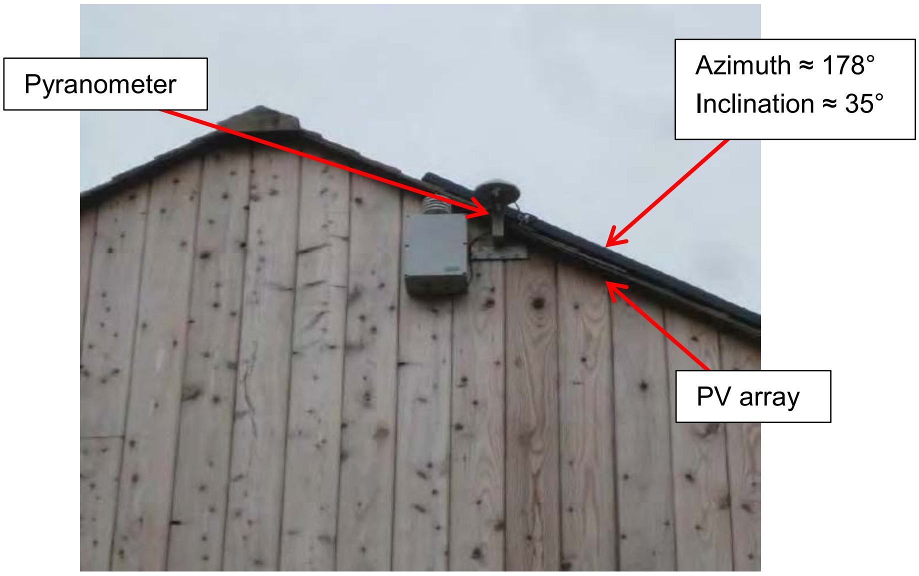
Figure 61 – Comparison of External Temperature Data with Met Office Data for Newcastle Airport (10/3/14)



The two monitoring heat meters on the space heating and domestic hot water circuits in dwelling B were found not to give reliable data and did not match the ESCo billing meter data. Inspection of the installation showed that the hot-side temperature sensors for the two meters had been transposed. This means that the in-use monitoring heat meter data for the flat is not useful for analysis purposes. Problems were identified with a large proportion of the ESCo heat meters on the domestic hot water circuits. Consequently, these data were not used in any analysis of the performance of the district heating system.

The solar PV array was installed at an azimuth ≈ 178° at an inclination of ≈ 35°. The solar pyranometer was installed horizontally and therefore was not in the same plan as the solar PV array (Figure 62). This would mean it would not have been possible to obtain the annual value of solar insolation to assess the efficiency of the solar PV array. In any case, such a comparison would not have been possible due to the 44 days of missing weather data caused by the logger faults.

Figure 62 – Pyranometer and Solar PV Array [located on roof of dwelling A]



It was found that the details of one of the biomass-fuel deliveries to the plant room over the monitoring period was missing from the information provided by the housing association from their financial records. It is believed that this was due to a change in supplier that occurred at this time; which resulted in the delivery not being recorded on the system. This missing delivery was for a 6 week period in September and October 2013. In order to account for the missing biomass-fuel data in the analysis, it has been assumed that there was a delivery of 5 tonnes at this time. This amount of biomass-fuel material is in line with the actual records of deliveries for the previous and subsequent months.

7.1.2 Weather

Analysis of the weather over the monitoring period is limited to the external temperature data obtained from the alternative weather station at Billingham. A graph of the mean daily temperature over the monitoring period from March 2013 to May 2014 is shown in Figure 63. Annual degree days over the monitoring period were calculated by integrating 5 minute temperature data using a base temperature of 15.5°C and were compared to official published degree day data for the SAP Borders region (Table 63).

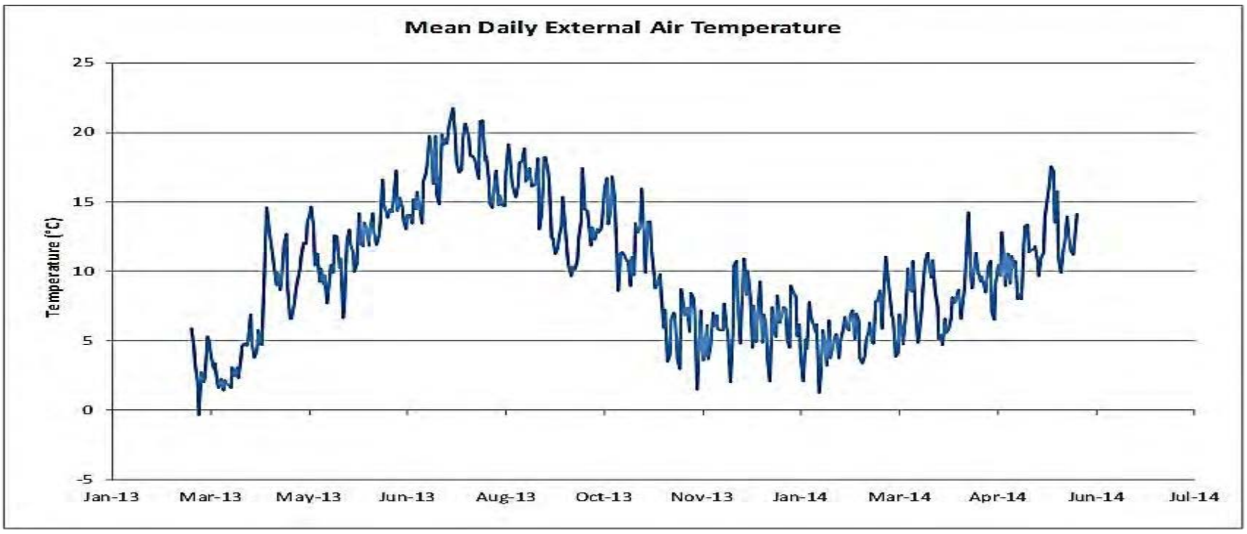
Table 63 – Annual Degree Days during Monitoring Period

Monitoring Period	Degree Days (integrated from Billingham 5 minute temperature)	Official Degree Days for Borders Region
April 2013 to March 2014	2049	2155
May 2013 to April 2014	1996	2059
June 2013 to May 2014	1962	2002

It can be seen that the Billingham data gives slightly lower annual degree days than that for the published Borders region values. The reason for the difference will be mostly due to the fact that the published regional degree day data will be calculated using the British Gas approximation method; and as such will tend to give a higher result that the more accurate integration method.

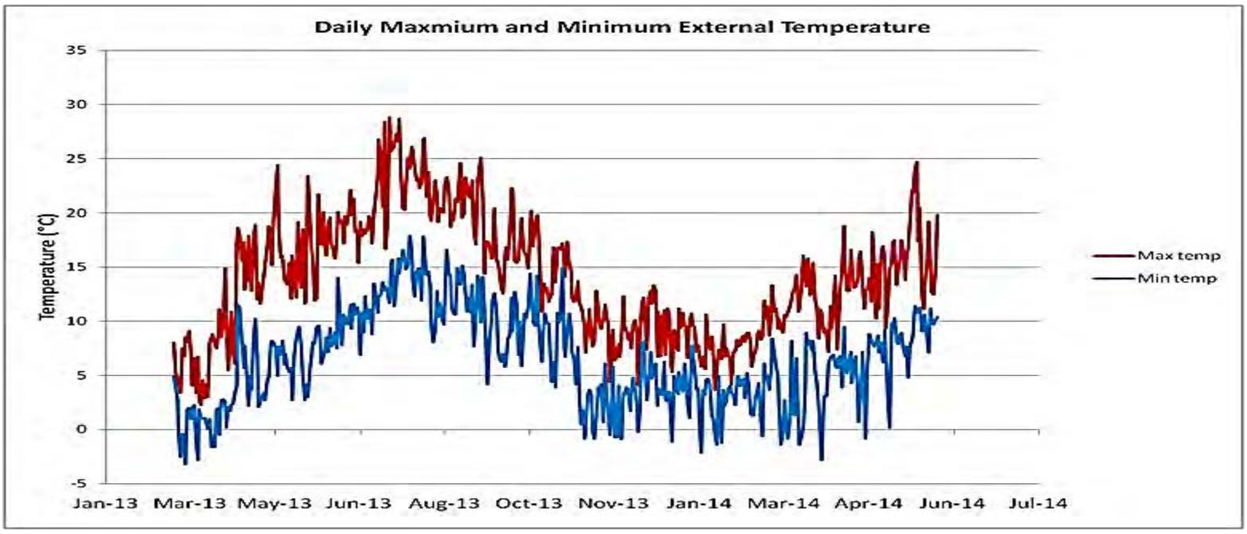
The default annual heat demand used in SAP calculations at 15.5°C base temperature is 2130 degree days. The actual annual heat demand over the monitoring period based on the Billingham data was therefore of the order 100 to 200 degree days lower than that assumed in the SAP calculation. The relatively low annual degree days for the period are a reflection of the very mild winter of 2013-14. The design data showed that there was no significant tendency to overheat in the living rooms: However, the measured temperatures did indicate overheating in the bedrooms in both dwellings during the summer however this may have been due in part to the relatively high summer temperatures in the UK in 2013; where the monthly maximum and minimum internal temperatures in the monitored dwellings are shown by the graph in Figure 63. This shows that peak internal temperatures ranged from 25°C in winter to 35°C in summer 2013.

Figure 63 – Graph of Mean Daily External Temperature



The daily maximum and minimum external temperatures over the monitoring period are shown in Figure 64. The peak summer temperatures occurred during the monitoring period [July 2013] at around 28°C. The relatively high maximum external temperatures for the period can therefore be considered as contributing to summer overheating.

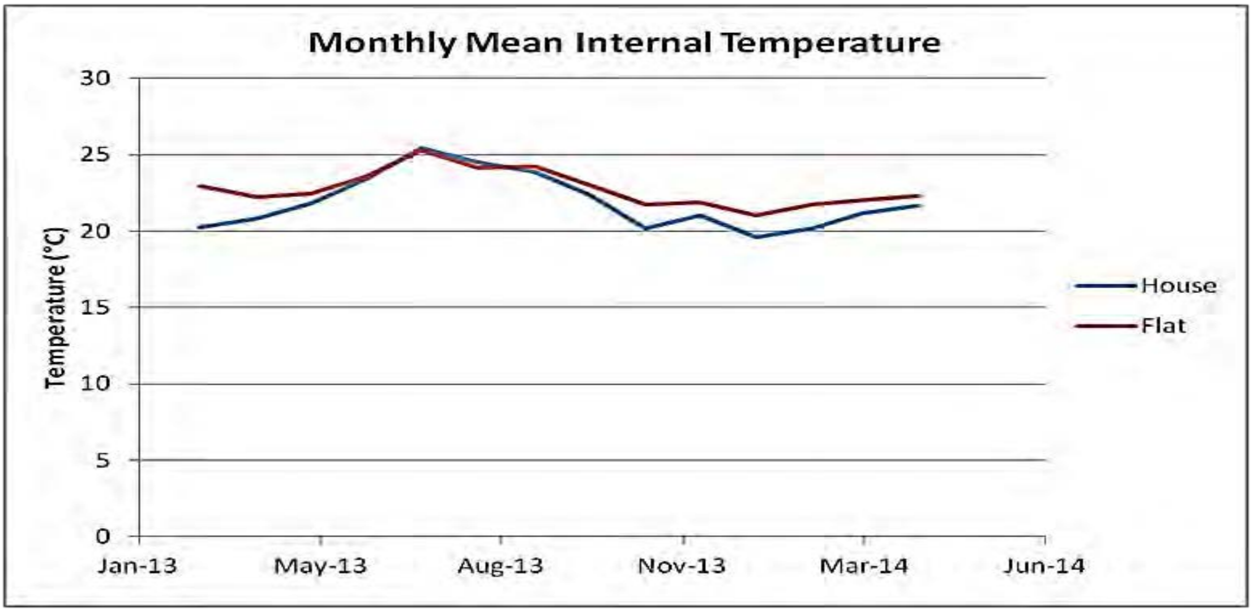
Figure 64 – Daily Maximum and Minimum External Temperature during Monitoring Period



7.2 Internal Temperature

A graph of mean monthly internal temperatures for the two monitored dwellings is shown in Figure 65.

Figure 65 – Monthly Mean Internal Temperature for Monitored Dwellings



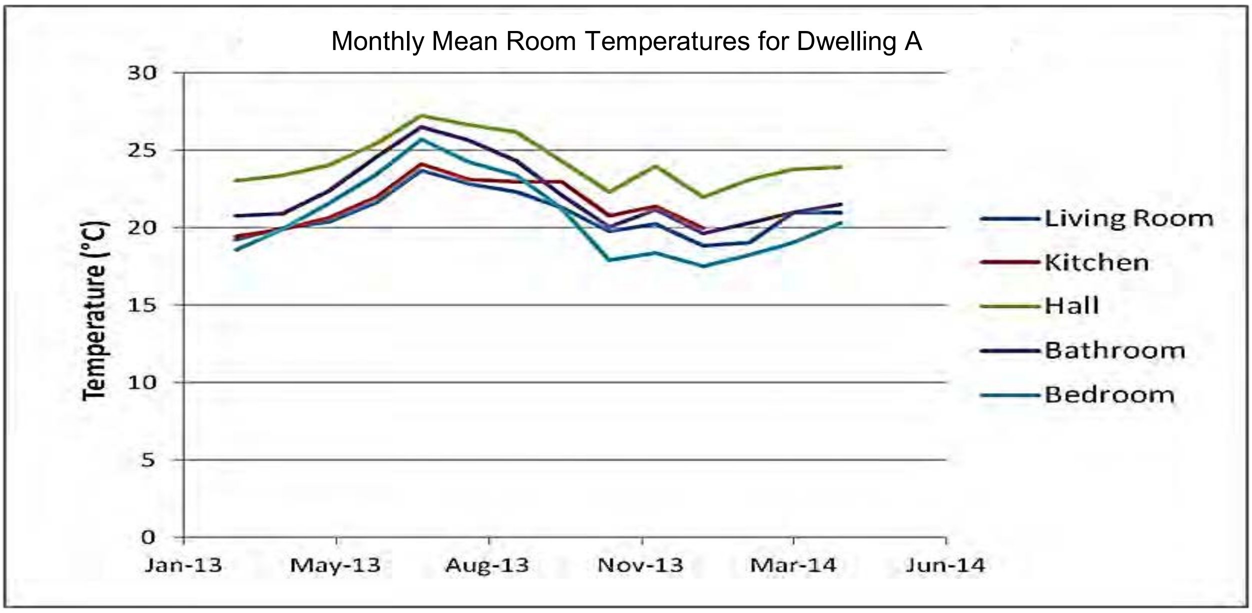
The trend in mean monthly temperature was similar for both dwellings, with the main difference being slightly higher temperatures in dwelling B during winter (around 21 to 22°C) compared to dwelling A (around 20 to 21°C). Mean temperatures in the summer were of the order 24 to 25°C in both dwellings. The winter temperatures were higher than that assumed by the two-zone model in the SAP calculations [SAP mean temperatures were 19.3°C for the house and 19.3°C for the apartment.] The SAP model will therefore underestimate the actual heating load. The conclusion is that the Sinclair Meadows residents are living at higher internal temperatures in winter than is typical for the UK. There are implications for both national energy policy and modelling inputs if occupants of low carbon low energy dwellings heat their dwellings to higher internal temperatures than is generally assumed.

The Sinclair Meadows mean internal temperatures are higher than those in a recent study of 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.

The mean monthly room temperatures for dwelling A are shown in Figure 66. It can be seen that there is around 5°C temperature variation between rooms, with the highest temperatures in the hall and the lowest temperatures in the bedroom. At first sight this would appear somewhat surprising, as one would have expected differences between rooms to be low in a well-insulated dwelling with MVHR. However, it is known that the MVHR system in dwelling A was not working properly (see Section 6, Installation and commissioning checks of services and systems, services performance checks and evaluation, page 65 for additional information).

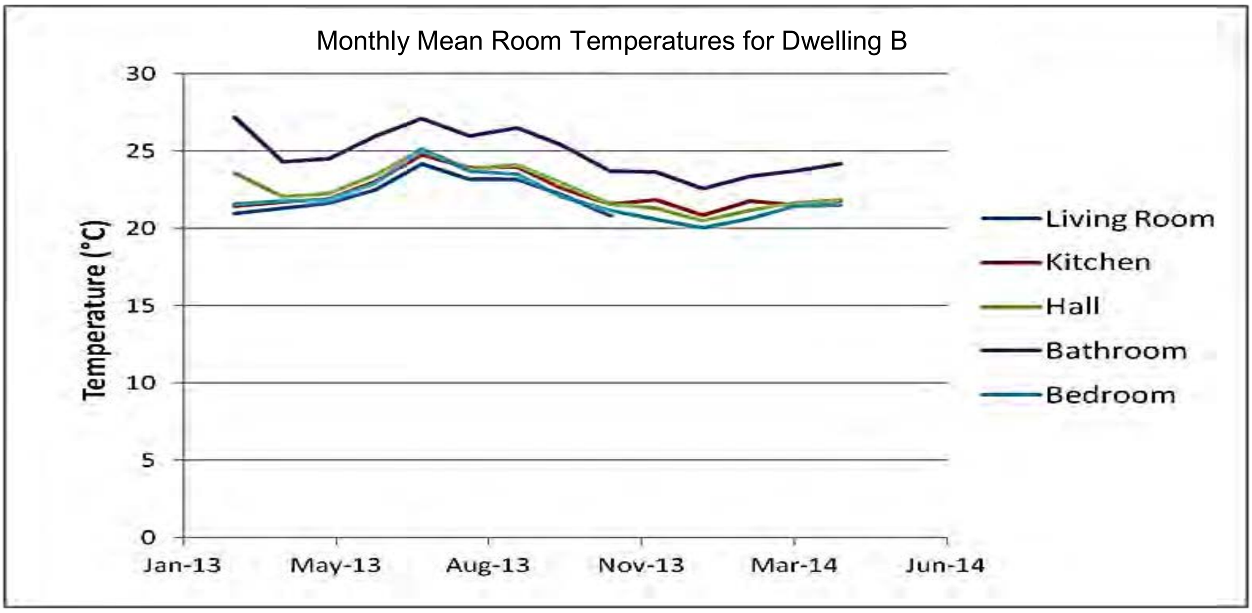
The high temperature in the hallway can be explained in part by heat gains due to losses from the district heating primary pipe work which runs adjacent to the hall in the cupboard under the stairs.

Figure 66 – Monthly Mean Room Temperatures for Dwelling A



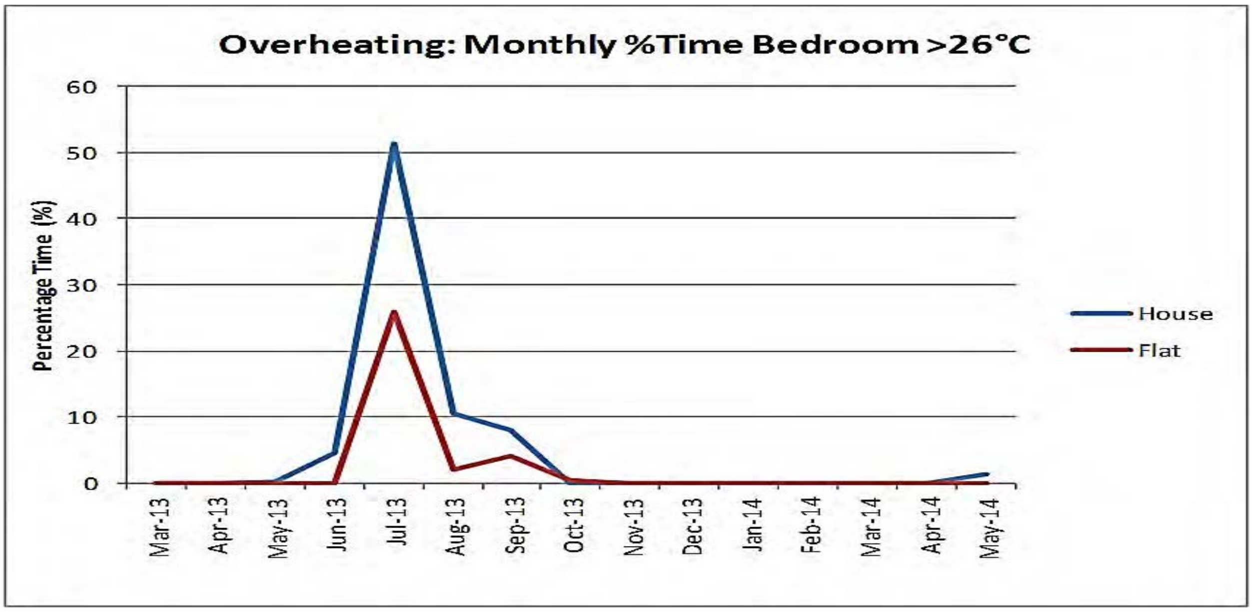
The mean monthly room temperatures for dwelling B are shown in Figure 67. With the exception of the bathroom, the room temperatures are very similar across the year. The bathroom temperature is around 2 to 3°C higher than the other rooms. There are some potential issues with the temperature measurements in dwelling B as it is known that the residents moved some of the sensors from their original locations; although it is not known when this occurred.

Figure 67 – Monthly Mean Room Temperatures for Dwelling B



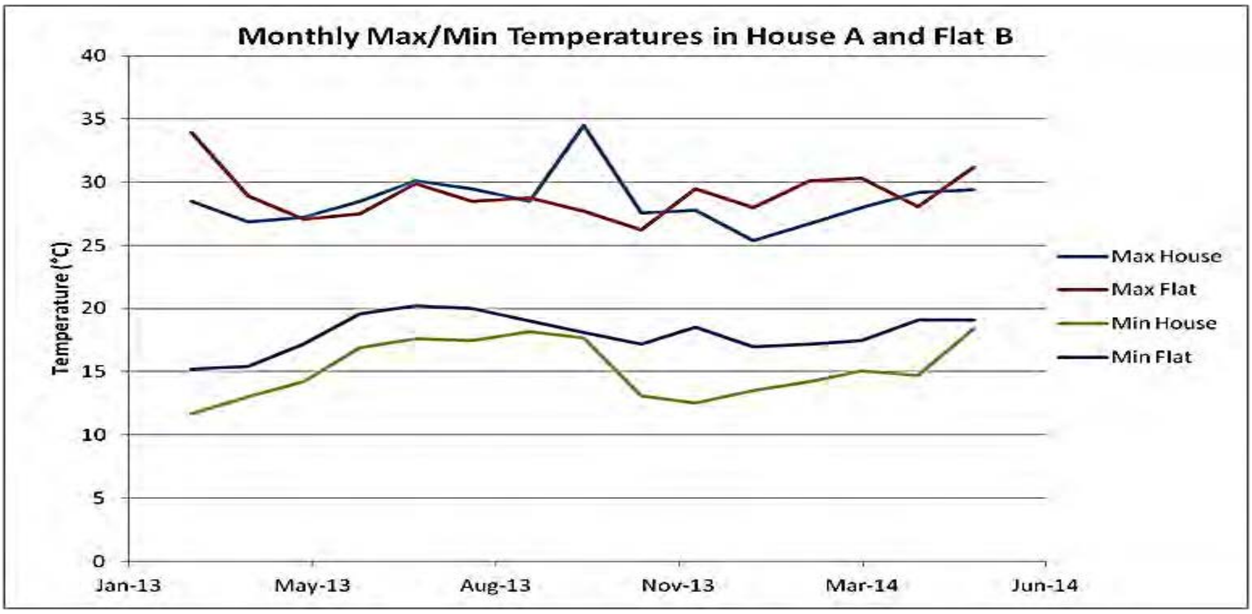
Overheating in the monitored dwellings was assessed using the CIBSE guidance of a maximum of 1% of time annually above the threshold temperatures of 28°C in the living room and 26° in bedrooms. The data showed that there was no significant tendency to overheat in the living rooms. However, the measured temperatures did indicate overheating in the bedrooms in both dwellings during the summer (Figure 68). Annually, the percentage time above 26°C in the bedroom for the period June 2013 to May 2014 was 5.7 per cent for dwelling A and 2.4 per cent for dwelling B.

Figure 68 – Monthly Bedroom Overheating: % Time above 26°C



The monthly maximum and minimum internal temperatures in the monitored dwellings are shown by the graph in Figure 69. This shows that peak temperatures ranged from 25°C in winter to as high as 35°C in summer. Minimum internal temperatures were lower in the house than in the flat, falling as low as 11 or 12°C in the winter. The lowest temperatures were in the living room in the house during winter; which indicates that the residents were opening windows, perhaps as a result of perceived stuffiness.

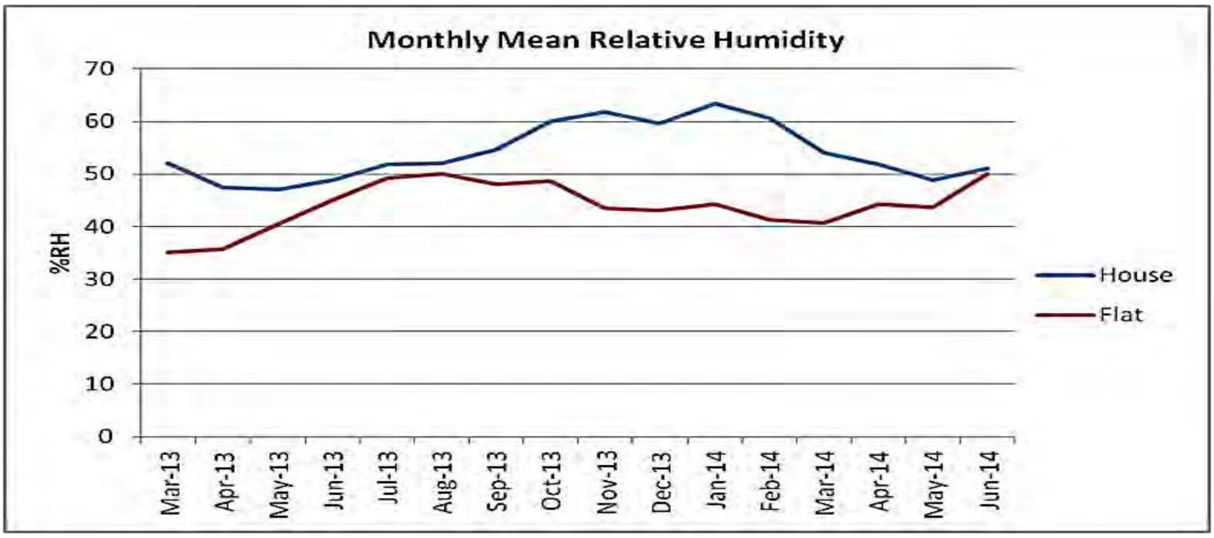
Figure 69 – Monthly Maximum and Minimum Temperature in House A and Flat B



7.3 Relative Humidity

A graph of monthly mean relative humidity for the monitored dwellings is shown in Figure 70.

Figure 70 – Monthly Mean Relative Humidity



It can be seen from Figure 70 that there is a significant difference in the level of relative humidity in the house compared to the flat, despite the fact that the internal temperature are similar. This difference is most pronounced in the winter; with the mean relative humidity in the house exceeding 60%RH; whereas the humidity in the flat is around 40 to 45%RH. This would indicate a significant difference in the ventilation rates of the two dwellings; with the house having a much lower level of ventilation in the winter. It can also be seen that the mean relative humidity in the flat falls below 40%RH for some periods. This dry air in winter is a common issue in dwellings with MVHR.

CIBSE define an acceptable range of relative humidity to be from 40 to 70%RH (CIBSE 2006). These criteria were used calculate the % time for each month in each room that the humidity was below 40%RH, between 40 to 70%RH and above 70%RH. The annualised time in these ranges for the period June 2013 to May 2014 in the living room, bedroom and kitchen are given in Table 64. It can be seen that the humidity in the bathroom in the flat was below 40%RH for 36% of the time. However, this is mainly a result of the high internal temperatures in the bathroom compared to the rest of the apartment.

The house data shows that the humidity in the bathroom and living room exceeded 70%RH for between 5 and 10% of the year. This would increase the risk of condensation and associated mould growth in these rooms. Observations in the ceilings in the bathroom of the house indicate the presence of damp/mould, which is consistent with the humidity data (see Figure 38 – Evidence of Damp/Mould Growth, Dwelling A, Bathroom Ceiling, page 52).

Table 64 – Annualised %Time within CIBSE Humidity Thresholds (June 2013 to May 2014)

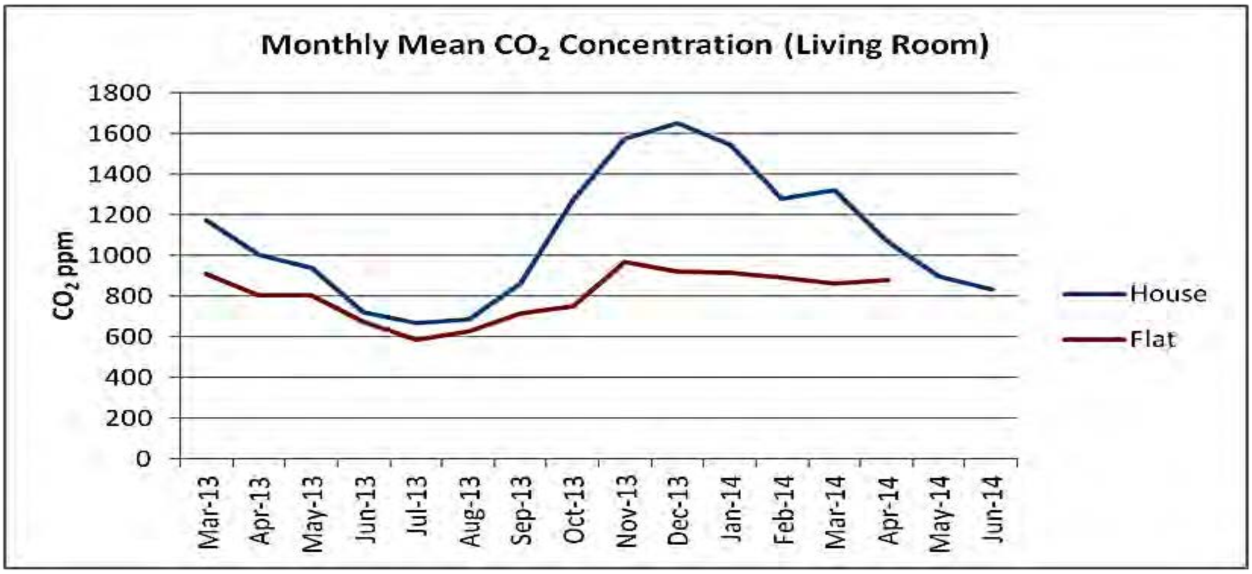
	Dwelling A	Dwelling B
Bedroom <40%RH (% year)	0.2	4.8
Bedroom 40-70%RH (% year)	99.2	95.2
Bedroom >70%RH (% year)	0.6	0.0
Living Room <40%RH (% year)	0.5	3.8*
Living Room 40-70%RH (% year)	90.3	96.2*
Living Room >70%RH (% year)	9.2	0.0*
Bathroom <40%RH (% year)	0.0	36.0
Bathroom 40-70%RH (% year)	85.7	63.6
Bathroom >70%RH (% year)	5.3	0.4

* Note that the flat living room data was only available to November 2013

7.4 Carbon Dioxide Concentration

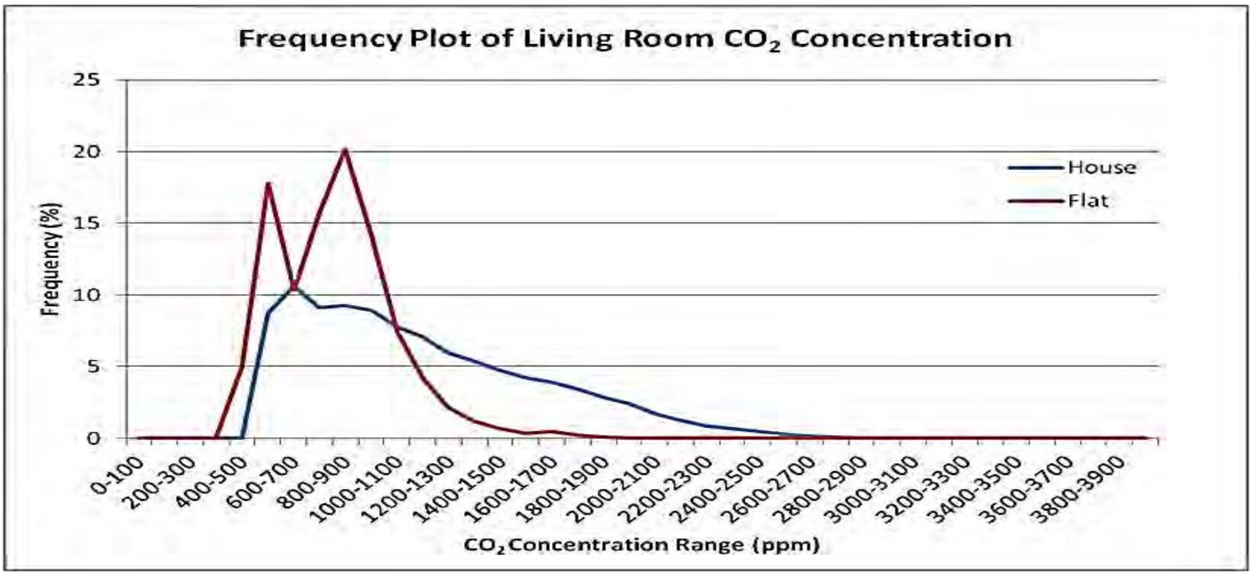
The internal concentration of carbon dioxide in the dwellings was used as a proxy for general internal air quality. A plot of the monthly mean living room CO_2 concentration for both monitored dwellings is shown in Figure 71. This demonstrates that there is a significant difference in the CO_2 levels between the dwellings, with the mean winter-time CO_2 in the house (1200 to 1600 ppm) being around twice that in the flat (800 – 900 ppm). This indicates that the ventilation rate in the house is less than that in the flat and supports the view that the MVHR system in the house is not working effectively. The maximum recorded level of CO_2 in the house was 3750 ppm compared to 3000 ppm in the flat.

Figure 71 – Monthly Mean CO_2 Concentration for Dwelling A (House) and B (Flat) [Living Room]



A frequency plot of CO_2 concentration over the monitoring period is given in Figure 72. This shows a bimodal normal distribution for the flat but that the distribution for the house is significantly skewed to high concentrations.

Figure 72 – Frequency Plot of CO_2 Concentration in House A and Flat B



The mean CO_2 concentration over the annual period May 2013 to April 2014 was 1133 ppm for the house and 800 ppm for the flat. A recent meta-analysis of peer reviewed research into the effects of ventilation and air quality on health (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. The bar charts in Figure 73 and Figure 74 show the monthly CO_2 levels for different ranges for the house and flat respectively. The high levels of CO_2 in the house are likely related to issues with the MVHR system with residents keeping windows closed to stop draughts and maintain thermal comfort.

Figure 73 – Dwelling A: Monthly % Time CO_2 in Ranges <800ppm, 800-1000ppm, > 1000ppm

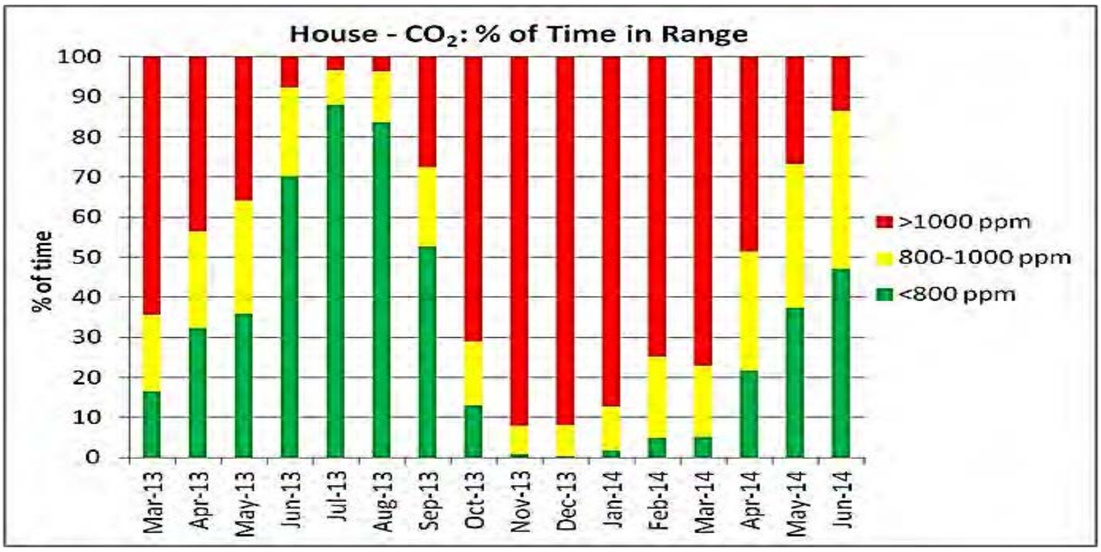
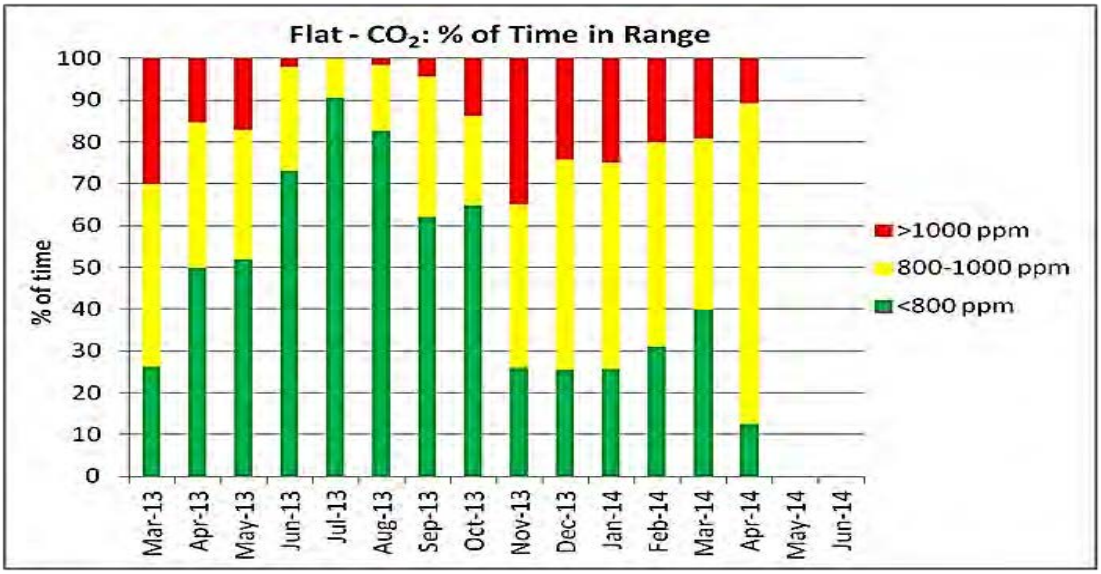


Figure 74 – Dwelling B: Monthly % Time CO_2 in Ranges <800ppm, 800-1000ppm, > 1000ppm



7.5 Monitored Dwelling Electricity Use [including DomEARM]

The total and sub-metered annual electricity consumption for dwelling A is summarised in Table 68. Total electricity use ranged from 4191 kWh.a to 4346 kWh.a for the 2 years during the monitoring period. This compares to an assumed electric use in the SAP2005 calculations of 3722 kWh.a. Taking into account the additional electricity use for immersion heat of around 200 kWh.a, actual electricity consumption was therefore around 300 to 400 kWh higher than assumed by SAP. The NEED database (DECC 2013a) gives the median electricity use for an end-terrace housing association dwelling as 3300 kWh.a in 2011 and for a three bedroom dwelling with 2 adults as 3700 kWh.a. The measured annual consumption of the dwelling A is therefore of the order 500 to 1000 kWh higher than a similar dwelling in England and Wales. The graph in Figure 75 compares the average annual energy use of dwelling A with UK Average, Part L Compliance, CfSH Level 4 and CfSH Level 6.

Figure 75 – Dwelling A - Annual energy performance compared with benchmarks (DomEARM)

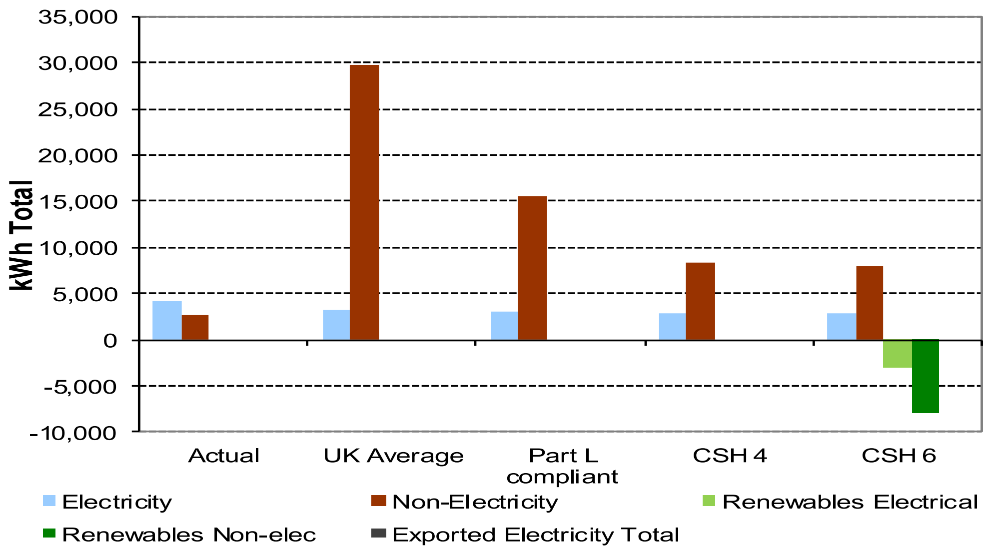


Table 65 is the annual energy performance compared with benchmarks for dwelling A [Domestic Energy Audit and Reporting Methodology (DomEARM), developed by Arup]; where the data have been colour coded and where red is for data higher than the relevant benchmark and green is for data lower than the relevant benchmark.

- Electrical use (4260 kWh.a) with the UK average (3190 kWh.a) [+34%; which represents the percentage difference between actual and benchmark], Part L Compliance (3061 kWh.a) [+39%], CfSH Level 4 (2931 kWh.a) [+45%] and CfSH Level 6 (2931 kWh.a) [+45%]

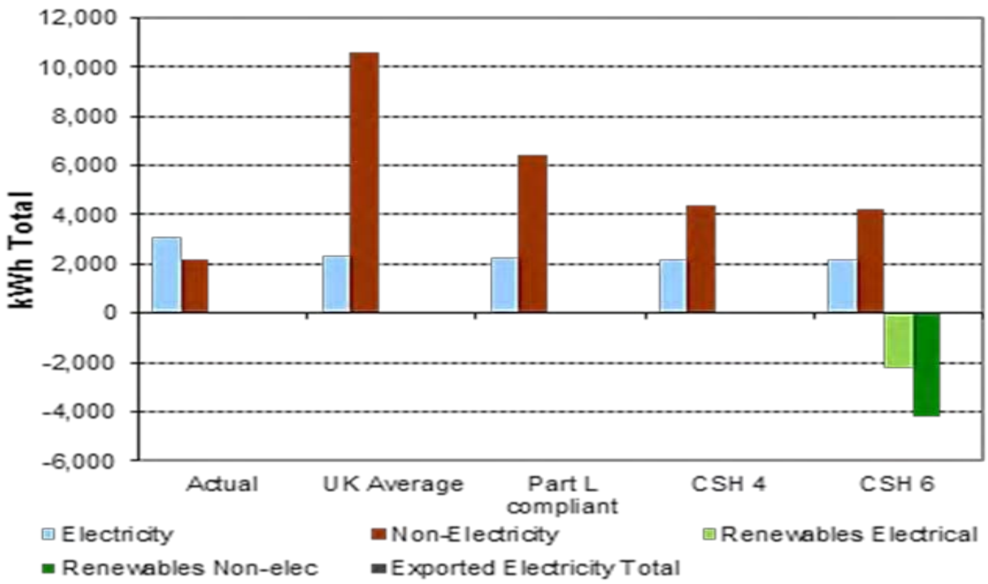
- Non-Electrical [Heat] use (2673 kWh.a) with the UK average (29848 kWh.a) [-91%], Part L Compliance (15613 kWh.a) [-83%], CfSH Level 4 (8317 kWh.a) [-68%] and CfSH Level 6 (7991 kWh.a) [-67%]

Table 65 – Dwelling A - Annual energy performance compared with benchmarks (DomEARM)

Primary Energy Source	Actual Average Energy Use (kWh.a)	UK Average Electricity Use (kWh.a)	Part L Compliant (kWh.a)	CfSH Level 4 Average Electricity Use (kWh.a)	CfSH Level 6 Average Electricity Use (kWh.a)
Electricity kWh Total	**4260**	**3190**	**3061**	**2931**	**2931**
% Difference between actual and benchmarks		**+34**	**+39**	**+45**	**+45**
Non-electricity kWh Total	**2673**	**29848**	**15613**	**8317**	**7991**
% Difference between actual and benchmarks		**-91**	**-83**	**-68**	**-67**

The graph in Figure 76 compares the average annual energy use of dwelling B with UK Average, Part L Compliance, CfSH Level 4 and CfSH Level 6.

Figure 76 – Dwelling B - Annual energy performance compared with benchmarks (DomEARM)



Note: Benchmark figures include appliance energy use. Data includes number of occupants, weather correction and year of construction.

Table 66 is the annual energy performance compared with benchmarks for dwelling B; where:

- Electrical use (3115 kWh.a) with the UK average (2365 kWh.a) [+32%; which represents the percentage difference between actual and benchmark], Part L Compliance (2289 kWh.a) [+36%], CfSH Level 4 (2212 kWh.a) [+41%] and CfSH Level 6 (2212 kWh.a) [+41%]
- Non-Electrical [Heat] use (2168 kWh.a) with the UK average (10579 kWh.a) [-80%], Part L Compliance (6443 kWh.a) [-66%], CfSH Level 4 (4387 kWh.a) [-51%] and CfSH Level 6 (4221 kWh.a) [-49%]

Table 66 – Dwelling B - Annual energy performance compared with benchmarks (DomEARM)

Primary Energy Source	Actual Average Energy Use (kWh.a)	UK Average Electricity Use (kWh.a)	Part L Compliant (kWh.a)	CfSH Level 4 Average Electricity Use (kWh.a)	CfSH Level 6 Average Electricity Use (kWh.a)
Electricity kWh Total	3115	2365	2289	2212	2212
% Difference between actual and benchmarks		+32	+36	+41	+41
Non-electricity kWh Total	2168	10579	6443	4387	4221
% Difference between actual and benchmarks		-80	-66	-51	-49

All dwellings at Sinclair Meadows were provided with energy-efficient white goods and electrical appliances (Table 67) however tenants were not prevented from purchasing additional appliances. This was particularly noticeable in dwelling A where the tenants confirmed via the DomEARM survey that they had supplemented the housing association approved electrical appliance list with other equipment including toaster, microwave, food processor, toasted sandwich maker, electric whisk and hair dryer and straightener. Additionally electrical equipment used for leisure and entertainment including television(s) [2 of], sky box, PC laptop and tablet, phone and phone charger have also been used.

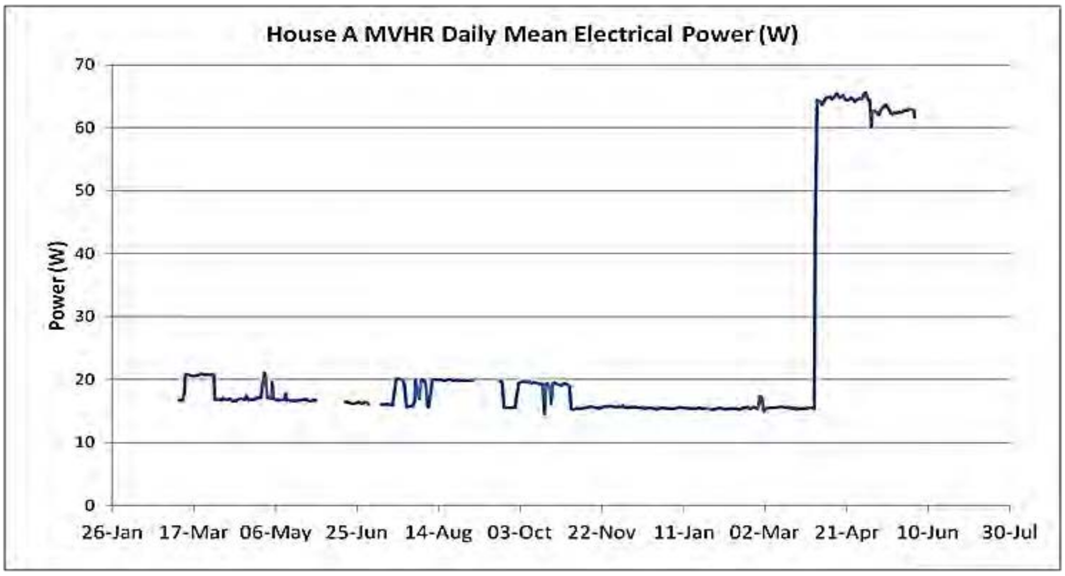
Table 67 – Standard list of energy-efficient white goods and appliances and Typical Energy Consumption (kWh)

Product	Manufacturer	Product Type	Typical Energy Consumption (kWh)*
Washing machine	Electrolux	EWG12450W	0.45 / 2.1
Dishwasher	Electrolux	ESL63010	0.1 / 2.0
Fridge Freezer	Electrolux	ERN29600	0.87/24h / 318kWh.a
Oven	Electrolux	EOB53000X	3kW rating
Hob	Electrolux	EHE6002X	7kW Rating
Cooker Hood (Dwelling B)	Electrolux	EFC60001	No data
Cooker Hood (Dwelling A)	Zanussi	ZHT630X	No data

The electricity use for fixed lighting was around 240 kWh.a. This compares to the assumption in CfSH for all lighting using 100% low energy bulbs of 481 kWh.a [this assumes 50% plug-in lighting use and 50% fixed lighting use]. The lighting use for fixed luminaries is therefore comparable.

The electricity use for MVHR was of the order 195 kWh.a averaged over the monitoring period. This is equivalent to about 22 W load for the fan unit. The mean daily power consumption of the MVHR unit is shown in Figure 77.

Figure 77 – Dwelling A [House]: Daily Mean MVHR Electrical Power



It can be seen that, prior to April 2014 the MVHR power was at ~16 W or 20 W. It is expected that the 16 W reflects the system in trickle mode and the 20 W may be where the resident has switched on the boost but has forgotten to turn it off. A load of 16 W equates to a Specific Fan Power (SFP) of 80 W/l/s [based on the measured total duct flow rate (0.2 l/s)]. This indicates that the MVHR system is not working properly and consuming excessive electricity for the amount of air flowing through the system. On the 2nd April 2014, the MVHR power increased to 65 W, which corresponds by an intervention by the MVHR specialist test engineer.

The total and sub-metered annual electricity consumption for dwelling A is summarised in Table 68. Total electricity use ranged from 4346 kWh.a to 4191 kWh.a for the 2 years during the monitoring period.

Table 68 – Dwelling A [House]: Annual Electricity Consumption

Annual Period	Lighting (kWh.a)	MVHR (kWh.a)	Immersion (kWh.a)	Appliances + other (kWh.a)	Cooker (kWh.a)	Total Electric (kWh.a)
Apr-13 to Mar-14	234.4	147.8	191.2	3186.9	430.7	4191
May-13 to Apr-14	240.1	184.4	195.1	3199.1	422.3	4241
Jun-13 to May-14	254.1	223.0	196.8	3258.8	413.3	4346

As expected, fixed lighting energy in dwelling A varies across with the year, with highest use in winter (~30 kWh/month) and lowest in summer (~5 kWh/month).

The total and sub-metered annual electricity consumption for dwelling B is summarised in Table 69. Total electricity use ranged from 3069 kWh.a to 3174 kWh.a for the 2 years during the monitoring period. This compares to an assumed electric use in the SAP2005 calculations of 2814 kWh.a. Monitored use is therefore around 200 to 300 kWh.a higher than the SAP assumption. By comparison, the NEED database (DECC 2013a) gives the median electricity use for an purpose-built housing association apartment as 2300 kWh.a in 2011 and for a 2 bedroom dwelling with 2 adults as 3100 kWh.a.

Table 69 – Dwelling B [Apartment]: Annual Electricity Consumption

Annual Period	Lighting (kWh.a)	MVHR (kWh.a)	Pumps/ Controls (kWh.a)	Immersion (kWh.a)	Appliances + other (kWh.a)	Cooker (kWh.a)	Total Electric (kWh.a)
Apr-13 to Mar-14	76.1	204.7	58.1	16.6	2628.6	190.1	3174
May-13 to Apr-14	77.9	204.8	54.4	16.6	2552.2	198.1	3104
Jun-13 to May-14	78.9	201.1	54.1	16.6	2517.1	201.3	3069

The electricity use for fixed lighting was very low at around 78 kWh.a. This compares to the assumption in CfSH for all lighting using 100% low energy bulbs of 307 kWh.a [this assumes 50% plug-in lighting use and 50% fixed lighting use]. It is not known what proportion of the appliance use in the flat was due to plug-in lighting. The electricity use for MVHR was of the order 205 kWh.a. This is equivalent to 24 W load from the fan unit over the monitoring period. A load of 24 W equates to a SFP of 12.6 W/l/s based on the measured total duct trickle supply flow rate (1.9 l/s). The SFP is therefore significantly higher than that assumed in SAP (0.48 W/l/s) based on the Appendix Q data and SAP in-use factors. SAP assumes an annual consumption of 115 kWh.a in the flat for rigid ducting. The measured consumption is around twice this.

The heating/hot water circulation pump and controls used around 55 kWh.a but SAP takes no account of pump energy for dwellings where heat is provided by a district heating system. As expected, fixed lighting energy in dwelling B varies across with the year; with highest use in winter (~10 kWh/month) and lowest in summer (~1 kWh/month).

7.5.1 Monitored Dwelling Heat Energy Use

The annual heat consumption data for dwelling A are summarised in Table 70. Total annual heat use ranged from 2814 to 3022 kWh.a. The NEED database (DECC 2013a) gives the median gas use for an end-terrace housing association dwelling as 11,500 kWh.a in 2011 and for a three bedroom dwelling with 2 adults as 13,800 kWh.a. The house at Sinclair Meadows therefore consumes around 30% of the delivered energy for heating and hot water compared to the equivalent type of house from the stock.

This indicates that the building fabric of dwelling A is performing well.

Table 70 – Dwelling A [House]: Annual Delivered Heat Energy

Annual Period	ESCo Total Heat (kWh.a)	ESCo DHW (kWh.a)	Monitoring Space Heat (kWh.a)	Monitoring DHW (kWh.a)	Monitoring Total Heat (kWh.a)	HIU Efficiency (%)
Apr-13 to Mar-14	2814	2118	362.8	2287.4#	2650.2	94.2
May-13 to Apr-14	2879	2171	356.8	2338.1#	2694.9	93.6
Jun-13 to May-14	3022	2278	357.5	*	*	*

* Monitoring DHW heat data for May-14 unreliable
# Monitoring DHW data adjusted for missing data in June-13, July-13 and Sep-13

The SAP calculation estimated total delivered heat requirement was 4207 kWh.a, which comprised 894 kWh.a space heating and 3313 kWh.a domestic hot water. The actual delivered total heat consumption at around 2900 kWh.a is less than that predicted, mainly as the actual amount of hot water supplied by the DH system was only of the order 2200 kWh.a.

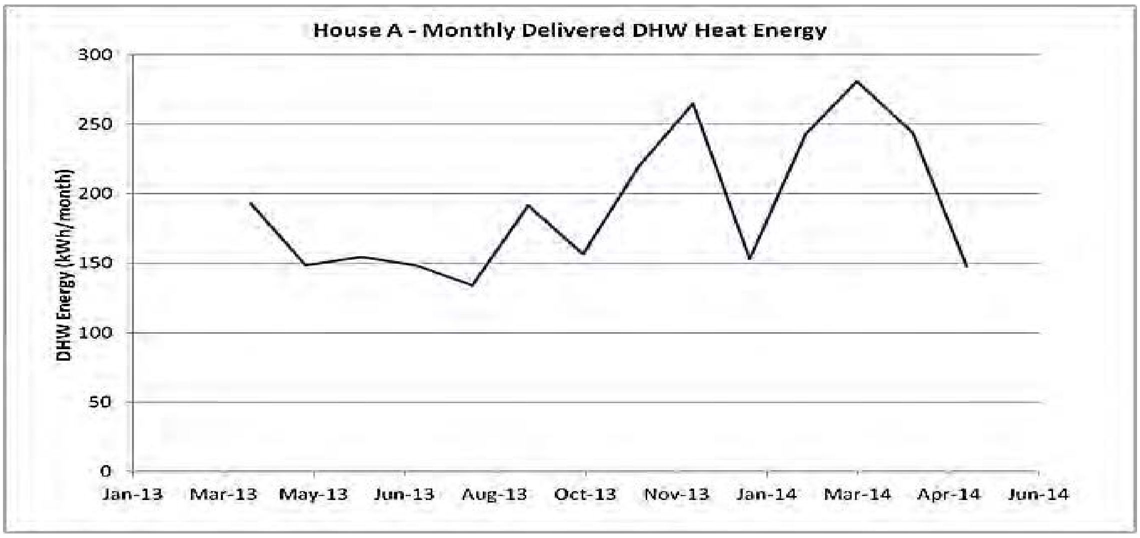
The amount of actual space heating was very low compared to the SAP estimate (360 kWh.a measured vs. 894 kWh.a predicted). This is likely a result of the relatively mild winter and heat gains from the district heating primary pipe work that are not accounted for in the SAP model.

The difference between the sum of the space heat and DHW monitoring heat meters and the ESCo total heat meter can be used to estimate the efficiency of the heat exchanger in the heat interface unit (HIU). The calculated HIU efficiency is around 94 per cent; although it should be noted that this value would include the effect of losses from the small sections of insulated pipe between the HIU and monitoring heat meters.

Current and past versions of SAP take no account of potential HIU heat exchange inefficiencies in the calculation of heat requirement for dwellings with district heating systems.

The amount of energy required for DHW varies over the year as shown by the graph in Figure 78, with highest use in winter (~270 kWh/month) and lowest in summer (~150 kWh/month). This difference is in line with the extra energy required to heat colder mains water in winter [note that Jan 2014 is artificially low due to the fault with the district heating system at this time].

Figure 78 – Dwelling A [House]: Monthly DHW delivered to Cylinder from District Heating



The only reliable data for heat input to dwelling B during the monitoring period is the total ESCo heat input (see Table 71). Total heat energy ranged from around 2000 kWh.a to 2350 kWh.a. The NEED database (DECC 2013a) gives the median gas use for a purpose-built housing association apartment as 6,900 kWh.a in 2011 and for a two bedroom dwelling with 2 adults as 10,900 kWh.a.

This demonstrates the enhanced efficiency of the fabric of the Sinclair Meadows apartments compared to the typical stock. The SAP calculation estimated total delivered heat requirement was 3125 kWh.a; which comprised 428 kWh.a space heating and 2697 kWh.a DHW.

The actual delivered is therefore less than the prediction. This level difference is small and would be expected, despite the higher internal temperatures, due to the mild winter, problems with the district heating system and gains from district heating primary pipe not accounted for in the SAP algorithms.

Table 71 – Dwelling B [Apartment]: Annual Delivered Heat Energy

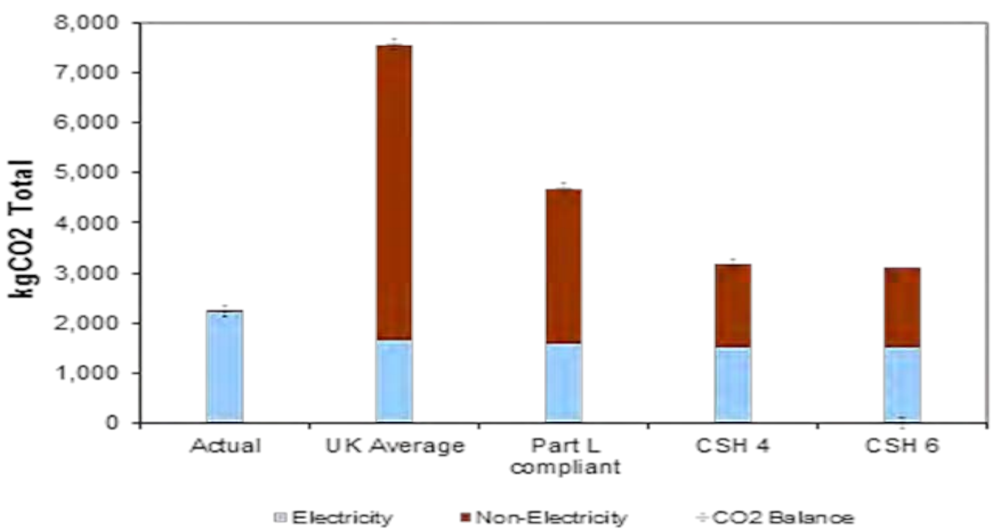
Annual Period	ESCo Total Heat (kWh.a)
Apr-13 to Mar-14	2352
May-13 to Apr-14	2177
Jun-13 to May-14	1975

7.5.2 Monitored Dwelling Carbon Emissions [including DomEARM]

See also Section 7.8 - Overall Carbon Emissions for Development, page 106. The graph in Figure 79 compares the average annual carbon emissions of dwelling A with UK Average, Part L Compliance, CfSH Level 4 and CfSH Level 6. The graph in

Figure 80 compares the average annual carbon emissions of dwelling B with UK Average, Part L Compliance, CfSH Level 4 and CfSH Level 6.

Figure 79 – Dwelling A - Annual emissions compared with benchmarks (DomEARM)



Note: Benchmark figures include appliance energy use. Data includes number of occupants, weather correction and year of construction.

The data shows that the annual emissions derived from electricity consumption for dwelling A are higher than the benchmarks for UK Average, Part L, CfSH4 and CfSH6. Annual emissions derived from non-electricity consumption are significantly lower than the relevant benchmarks [as would be expected for a district heating system]. These data are represented in Table 72 – Dwelling A - Annual emissions compared with benchmarks (DomEARM), where the data have been colour coded and where red is for data higher than the relevant benchmark and green is for data lower than the relevant benchmark.

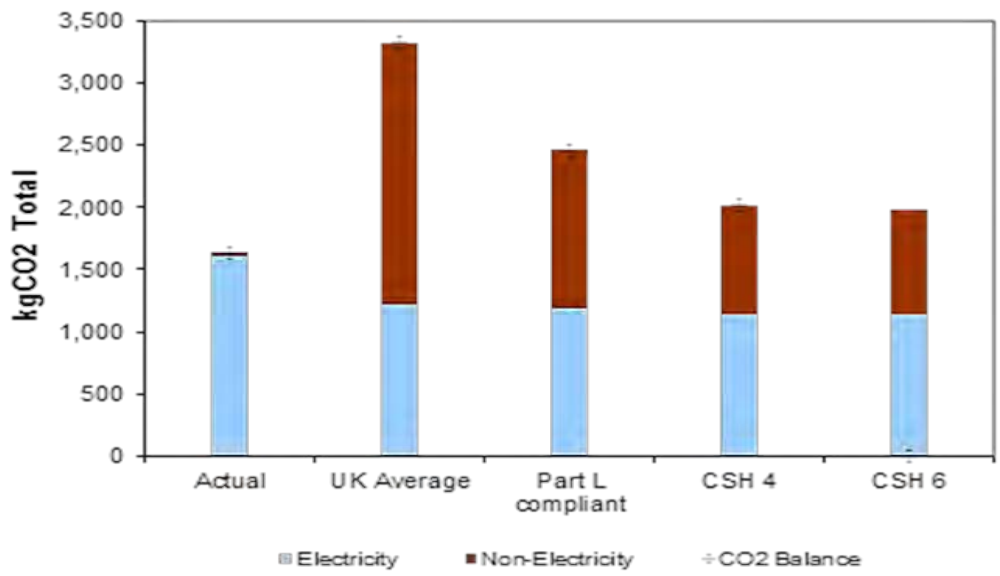
Table 72 is the annual emissions compared with benchmarks for house dwelling A; where:

- Electrical use (2202 kgCO_2/a) with the UK average (1649 kgCO_2/a) [+34%; which represents the percentage difference between actual and benchmark], Part L Compliance (1582 kgCO_2/a) [+39%], CfSH Level 4 (1515 kgCO_2/a) [+45%] and CfSH Level 6 (1515 kgCO_2/a) [+45%]
- Non-Electrical use (35 kgCO_2/a) with the UK average (5910 kgCO_2/a) [-99%], Part L Compliance (3091 kgCO_2/a) [-99%], CfSH Level 4 (1647 kgCO_2/a) [-98%] and CfSH Level 6 (1582 kgCO_2/a) [-98%]

Table 72 – Dwelling A - Annual emissions compared with benchmarks (DomEARM)

Primary Energy Source	Actual Average Emissions (kgCO_2/a)	UK Average Emissions (kgCO_2/a)	Part L Compliant (kgCO_2/a)	CfSH Level 4 Average Emissions (kgCO_2/a)	CfSH Level 6 Average Emissions (kgCO_2/a)
Electricity kgCO_2 Total	**2202**	**1649**	**1582**	**1515**	**1515**
% Difference between actual and benchmarks		**+34**	**+39**	**+45**	**+45**
Non-electricity kgCO_2 Total	**35**	**5910**	**3091**	**1647**	**1582**
% Difference between actual and benchmarks		**-99**	**-99**	**-98**	**-98**

Figure 80 – Dwelling B - Annual emissions compared with benchmarks (DomEARM)



Note: Benchmark figures include appliance energy use. Data includes number of occupants, weather correction and year of construction.

The data shows that the annual emissions derived from electricity consumption for dwelling B are again higher than the benchmarks for UK Average, Part L, CfSH4 and CfSH6. Annual emissions derived from non-electricity consumption are again significantly lower than the relevant benchmarks [as would be expected for a district heating system].

Table 73 – Dwelling B - Annual emissions compared with benchmarks (DomEARM), is the annual emissions compared with benchmarks for dwelling B; where:

- Electrical use (1610 $kgCO_2/a$) with the UK average (1223 $kgCO_2/a$) [+32%; which represents the percentage difference between actual and benchmark], Part L Compliance (1183 $kgCO_2/a$) [+36%], CfSH Level 4 (1144 $kgCO_2/a$) [+41%] and CfSH Level 6 (1144 $kgCO_2/a$) [+41%]
- Non-Electrical use (28 $kgCO_2/a$) with the UK average (2095 $kgCO_2/a$) [-99%], Part L Compliance (1276 $kgCO_2/a$) [-98%], CfSH Level 4 (871 $kgCO_2/a$) [-97%] and CfSH Level 6 (836 $kgCO_2/a$) [-97%]

Table 73 – Dwelling B - Annual emissions compared with benchmarks (DomEARM)

Primary Energy Source	Actual Average Emissions ($kgCO_2/a$)	UK Average Emissions ($kgCO_2/a$)	Part L Compliant ($kgCO_2/a$)	CfSH Level 4 Average Emissions ($kgCO_2/a$)	CfSH Level 6 Average Emissions ($kgCO_2/a$)
Electricity $kgCO_2$ Total	**1610**	**1223**	**1183**	**1144**	**1144**
% Difference between actual and benchmarks		**+32**	**+36**	**+41**	**+41**
Non-electricity $kgCO_2$ Total	**28**	**2095**	**1276**	**871**	**836**
% Difference between actual and benchmarks		**-99**	**-98**	**-97**	**-97**

7.5.3 Overall Energy Use of Dwellings on Development

The electricity consumption for all 21 dwellings on the Sinclair Meadows development was obtained from the ESCo billing data. The annual total electricity consumption ranged from 57188 kWh.a (Dec-12 to Nov-13) to 61380 (Jun-13 to May-14) (Table 74).

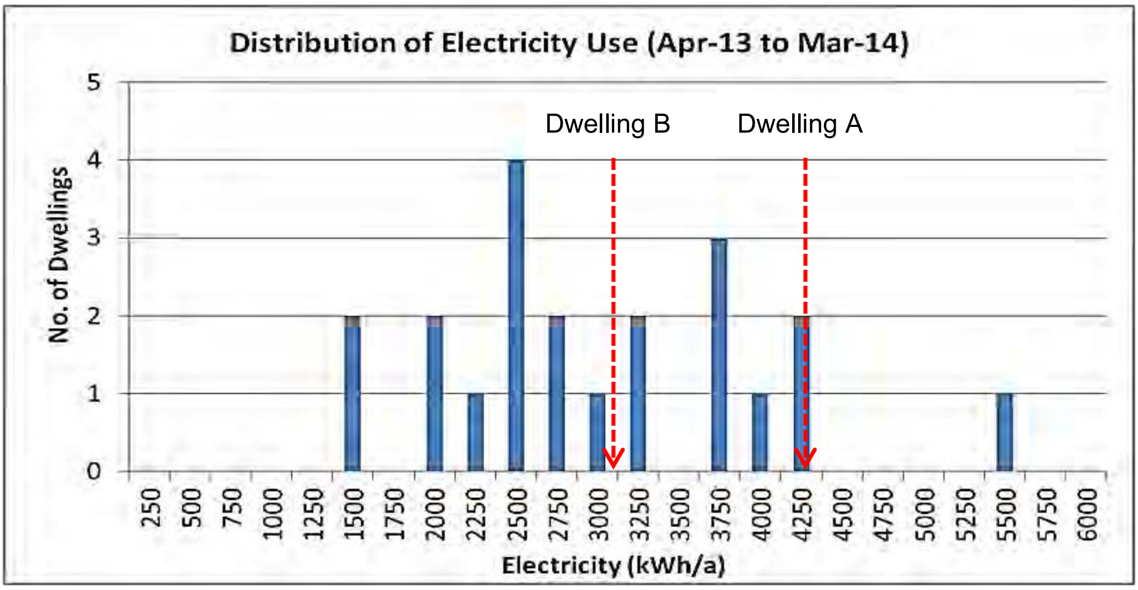
Table 74 - Overall Annual Electricity Consumption for Development

Period	Total Electricity Use (kWh.a)	Mean Electricity Use per Flat (kWh.a)	Mean Electricity Use per House (kWh.a)
1/12/12 to 30/11/13	57188	2321	3259
1/1/13 to 31/12/14	57887	2325	3332
1/2/13 to 31/1/14	59385	2345	3472
1/3/13 to 28/2/14	60525	2370	3565
1/4/13 to 31/3/14	60747	2359	3604
1/5/13 to 30/4/14	61212	2365	3648
1/6/13 to 31/5/14	61380	2338	3702

The higher annual consumption for the later part of the monitoring periods is believed to be related in part to the use by householders of immersion heat and fan heaters during the times when the communal heating system was not working properly. It is interesting to note that the mean electricity use in the apartments was fairly stable at around 2350 kWh.a over the monitoring period; whereas the mean electricity use in the houses increased from 3250 kWh.a to 3700 kWh.a towards the end of the monitoring period [when the communal heating system was off most often]. This suggests that the additional use of immersion heat, fan heaters and other electrical appliances and equipment was concentrated mainly in the houses. This is likely to be related to the higher level amount of hot water use in the houses due to the larger number of occupants per dwelling.

The variation in annual electricity consumption between dwellings is shown by the frequency plot given in Figure 81 for the period April 2013 to March 2014. The lowest use is in the range 1250-1500 kWh.a, with the highest use in the range 5250-5500 kWh.a.

Figure 81 - Distribution of Annual Dwelling Electricity Use (Apr-13 to Mar-14)



The annual delivered heat energy from the communal heating system to all 21 dwellings on the Sinclair Meadows development was obtained from the ESCo billing data. The annual total electricity consumption ranged from 62,600 kWh.a (Dec-12 to Nov-13) to 53,765 (Jun-13 to May-14) (Table 75).

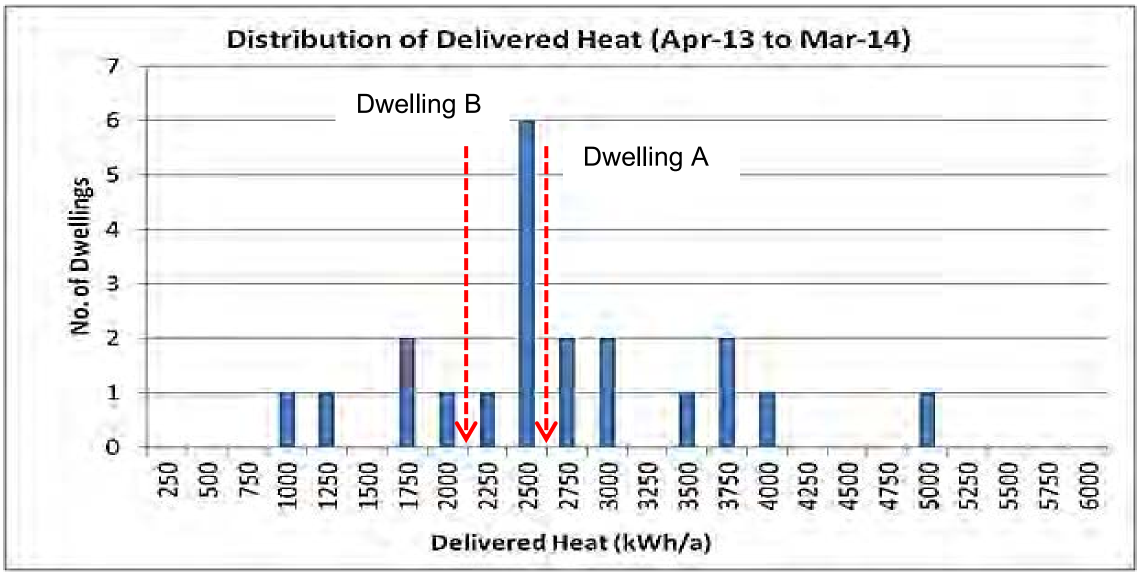
Table 75 - Overall Annual Heat Delivered to Dwellings from District Heating System

Period	Total DH Heat Use (kWh.a)	Mean DH Heat Use per Flat (kWh.a)	Mean DH Heat Use per House (kWh.a)
1/12/12 to 30/11/13	62601	2803	3218
1/1/13 to 31/12/14	60983	2716	3155
1/2/13 to 31/1/14	58621	2623	3016
1/3/13 to 28/2/14	57069	2587	2892
1/4/13 to 31/3/14	54197	2481	2714
1/5/13 to 30/4/14	53993	2465	2712
1/6/13 to 31/5/14	53765	2433	2730

The reduction will be partly due to problems with the communal heating system towards the end of the monitoring period and also to a reduction in space heat demand due to the mild winter of 2013-14. Perhaps surprisingly, the mean heat delivered to the houses (2700 to 3200 kWh.a) is only marginally higher than that for the flats (2400 kWh.a to 2800 kWh.a) despite the houses having higher occupancy and around 50 per cent bigger floor area than the flats.

The variation in annual delivered heat between dwellings is shown by the frequency plot given in Figure 82 for the period April 2013 to March 2014. The lowest heat use was in the range 750-1000 kWh.a, with the highest in the range 4750-5000 kWh.a.

Figure 82 - Distribution of Annual Heat Delivered to Dwellings (Apr-13 to Mar-14)



The trend in total delivered heat to the dwellings is shown in Figure 83 for the overall period of ESCo data. Ignoring periods when the communal system was not working properly, the minimum daily heat demand was during the summer months at around 75 kWh/day. The minimum heat demand in winter was of the order 400 kWh/day. There is no measured data on peak load on the district heating system. However, if we assume that the daily demand was concentrated over a four hour period (2 hours in the morning and 2 hours in the evening), then the minimum 75 kWh/day equates to a load of 19 kW and the maximum 400 kWh/day and a load of 100 kW. This would indicate that the biomass-fuelled boiler sizing of about 110 kW is of the right sort of order for the expected demand from the dwellings.

Figure 83 - Trend in Total Daily Delivered Heat (Dec-12 to May-14)

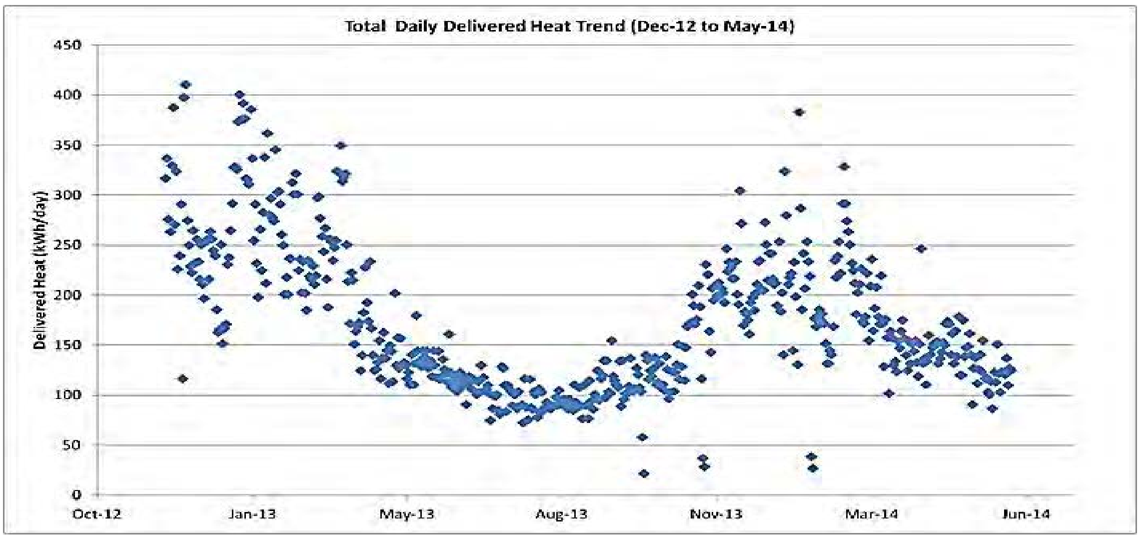


Table 76 gives the comparison between average annual electricity and heat use for all dwellings onsite with extrapolated average annual electricity and heat use for the monitored properties. The average electricity use for all houses onsite was 3512 kWh.a and the average electricity use for the apartments was 2346 kWh.a.

The extrapolated average electricity use for dwelling A was 4260 kWh.a. The extrapolated average electrical use for dwelling B was 3115 kWh.a. The average heat use for all houses was 2920 kWh.a and the average heat use for all apartments was 2587 kWh.a. The extrapolated average heat use for the dwelling A was 2673 kWh.a. The extrapolated average heat use for dwelling B was 2168 kWh.a.

Table 76 – Comparison between all dwellings and monitored dwellings

Dwelling Type	Average Electricity Use [All Dwellings] (kWh.a)	Average Electricity Use [Monitored Dwelling] (kWh.a)	Average Heat Use [All Dwellings] (kWh.a)	Average Heat Use [Monitored Dwelling] (kWh.a)
House	3512	4260	2920	2673
Apartment	2346	3115	2587	2168

7.6 Performance of Sinclair Meadows Solar Photovoltaic (PV) Arrays

The annual output from the solar PV arrays of the houses and flats on the Sinclair Meadows development was obtained from the ESCo data. The annual total electricity output from the arrays ranged from a high of 87,594 kWh.a (Feb-13 to Jan-13) to a low of 72,964 kWh.a (Mar-13 to Feb-14) (Table 77). The variation in output was mainly due to technical issues with one of the arrays on the houses rather than differences in annual solar radiation. The latest ESCo data indicate that technical issues have now been resolved and it would be expected that the annual output from the solar PV arrays will increase in future years; as long as there are no further problems with the operation of the system.

The total predicted annual output for the overall 85 kWpeak array based on the inputs to the SAP2005 assessments for the dwellings was 70,845 kWh.a. The measured output from the array is therefore higher than the predication; even for years where there were technical issues. It should be noted however that SAP is relatively conservative in its calculation of solar PV performance, and the SAP algorithm applies a factor of 80 per cent to account for the system efficiency. The measured data from Sinclair Meadows indicate that system efficiency factor is of the order 90 per cent or better.

Table 77 - Total Annual Output from Solar PV Arrays

Period	Total PV Output Use (kWh.a)	Total PV Output from Flat Array (kWh.a)	Total PV Output from House Arrays (kWh.a)
1/12/12 to 30/11/13	86059	40299	45760
1/1/13 to 31/12/14	86731	40429	46302
1/2/13 to 31/1/14	87594	40702	46892
1/3/13 to 28/2/14	72964	40914	32050
1/4/13 to 31/3/14	75062	41709	33353
1/5/13 to 30/4/14	74153	40881	33272
1/6/13 to 31/5/14	74597	40652	33945

7.7 Performance of District Heating System

The calculated efficiencies for the district heating system are given in Table 55.

The overall performance of the district heating system was assessed using ESCo data and biomass-fuel delivery data for the period 25th March 2013 to the 24th March 2014. This period was chosen to match with biomass-fuel deliveries that took place on both these dates and therefore minimises any potential variability caused by the periodic nature of the deliveries. The performance data for this period used to calculate the efficiency of the district heating system are given in Table 78. The calculated efficiencies for the district heating system are given in Table 79.

Table 78 - District Heating System Performance Data for Period 25/3/13 to 24/3/14

Energy from Biomass Deliveries (kWh.a) (Based on net calorific value)	254976
Heat Energy Output from Biomass Boiler (kWh.a)	209618
Total Heat Delivered to Dwellings (kWh.a)	55016
Total Parasitic Electric Use DH Pumps, Controls & Buffer Immersion (kWh.a)*	15466
Total Immersion Heat to Buffer Tank (kWh.a)	5504

*Corrected for missing data due to logger faults

Table 79 - District Heating System Calculated Efficiencies for Period 25/3/13 to 24/3/14

Efficiency of Biomass Boiler (%) (Based on net calorific value)	82.2
District Heating System Distribution Efficiency Biomass Heat Only (%)	26.2
District Heating System Distribution Efficiency All Heat (including buffer immersion heat) (%)	25.6
Parasitic Electricity as Function of Delivered Heat (%)	28.1
District Heating System Overall System Efficiency (%)	20.3

The overall system efficiency for delivery of heat to the dwellings was 20.3 per cent. This is perhaps an indication that the use of district heating for small scale low energy developments such as Sinclair Meadows may be inappropriate due to the lack of a sufficiently large heat demand to offset the system inefficiencies and distribution losses. Recent research carried out by the National Energy Foundation on a number of district heating schemes in London found similarly poor system efficiencies. This is an area that requires further industry research.

The net efficiency of the biomass boiler was 82.2 per cent. This is based on the net calorific value for biomass-fuel wood pellets of 4,800 kWh/tonne [as specified by the biomass supplier (Verdo 2014)]. This compares to the manufacturers' quoted boiler efficiency of 93.6 per cent. The reason for the under-performance of the boiler is unknown.

The parasitic electricity used to run the communal system (pumps, boiler controls, buffer tank immersion) was very high at 28.1 per cent as a function of delivered heat. This factor increases to as high as 40 per cent later in the monitoring period; where the use of immersion heat is higher due to the failure of the biomass-fuelled boiler in April 2014.

The distribution efficiency of the heat via the district heating system was 26 per cent. This compares to the assumption used in the SAP calculation of 95 per cent [although it should be noted that the SAP 2005 protocol is based on a nominal figure for distribution efficiency and does not require detailed calculation of pipe losses]. It is generally recognised that this SAP figure is unrealistic and requires revision.

The average distribution loss for delivered heat was of the order 19 kW (Figure 84). An estimate of the expected losses from the system is of the order 17kW (Table 80) and is therefore compared to the measured losses of 19 kW. This includes losses from the external main, buffer tanks or from inside the dwellings and communal area.

Figure 84 - District Heating Daily Distribution Loss in kW

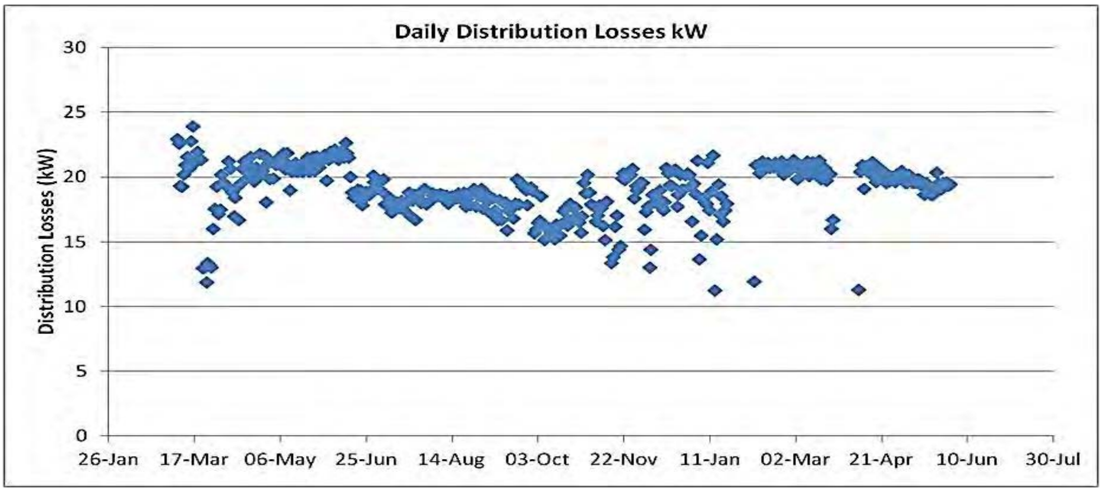


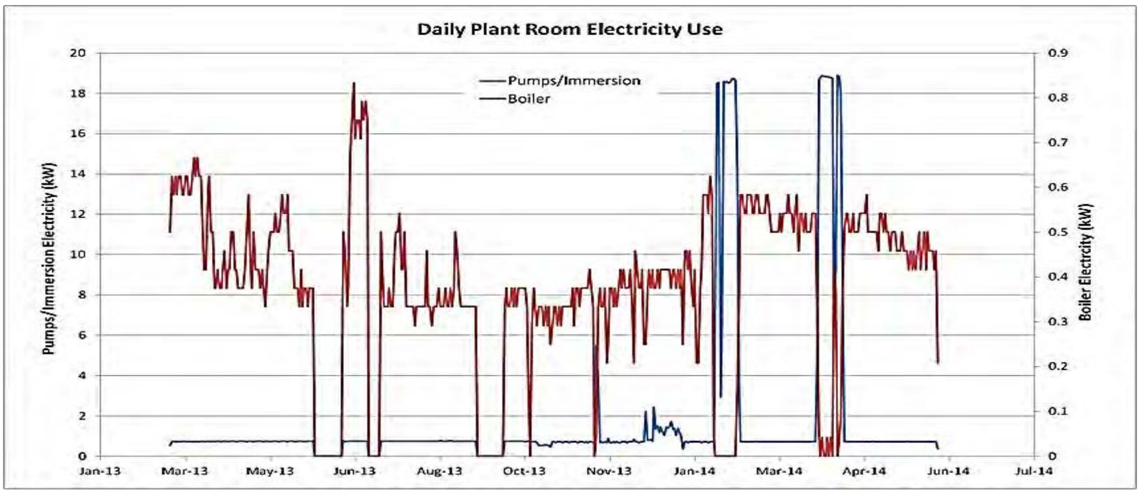
Table 80 - Estimated District Heating Distribution Losses

Source of Loss	Heat Loss (kW)
External Heat Main in Ground (180 m at 22.5 W/m)*	4.1
2000 litre Buffer Storage Vessel (7.2 W/K for vessel)	0.4
District Main inside Houses (0.5 kW per house)	4.5
District Main inside Flats (0.5 kWh per flat)	6.0
District Main in Apartment Block Common Areas	2.0
Total Losses	**17.0**

* Calculated using manufacturers heat loss data for Uponor Ecoflex Thermo Twin pipe as used on development (Uponor 2014)

The calculated heat density for the Sinclair Meadows communal heating system is only 0.4 MWh.a. A plot of the daily plant room parasitic electric load for pumps, buffer tank immersion and boiler controls is shown in Figure 85. The base load for the pumps is around 750 W. This is consistent with the specification of the two main circulation pumps. When the immersion heaters are in use in at the start of 2014 the output is of the order 18 kW. This is slightly lower than that given in the M&E specification of 24 kW. The apparent biomass-fuelled boiler electricity use varies from 300 to 600 W, but as the boiler is switching on and off during the day this will not reflect the instantaneous load.

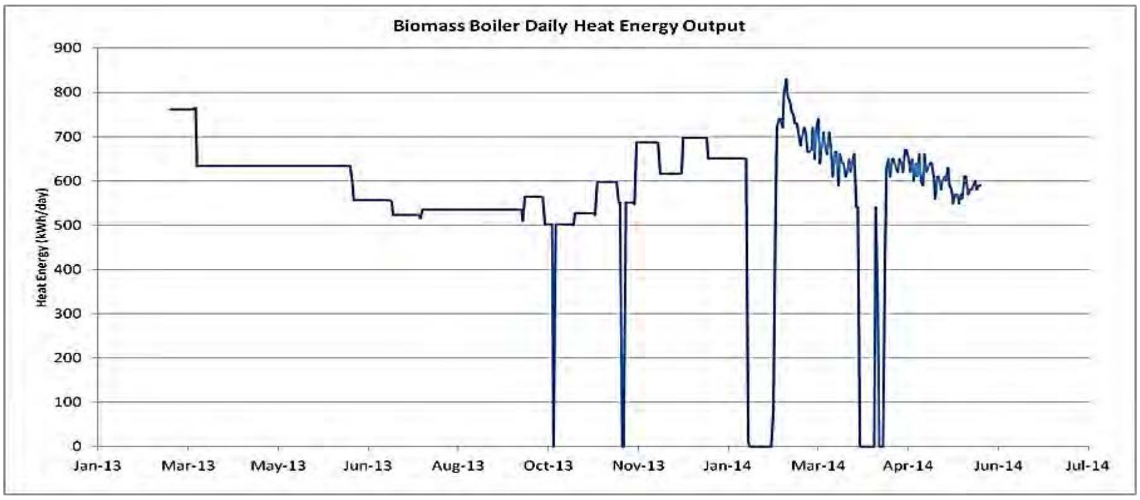
Figure 85 - Daily Plant Room Parasitic Electric Load



The graph in Figure 86 shows that daily heat energy output from the biomass boiler over the monitoring period.

Note: The data for the first 10 months are averages based on manual meter readings.

Figure 86 - Biomass Boiler Daily Heat Energy Output



The minimum output over the summer was around 500 kWh/day and the peak output in the winter was up to 800 kWh/day. The periods when the biomass-fuelled boiler was non-operational can be seen where the daily output falls to zero. It can be calculated that the boiler was non-operational for a total of 32 days over the monitoring period; which is the equivalent to 9 per cent of the time on a yearly basis.

7.8 Overall Carbon Emissions for Development

Carbon emissions for the development were calculated using the measured data for the period 25/3/13 to 24/3/14, the carbon intensity figures for delivered energy as given in SAP 2005.

Table 81 - Delivered Fuel Carbon Intensity Factors in SAP2005

Energy Source	SAP 2005 Carbon Intensity Factor ($kgCO_2/kWh$)
Electricity Imported from Grid	0.422
Electricity Exported to Grid	0.568
Mains Natural Gas	0.194
Biomass Wood Pellets	0.025

The carbon intensities for delivered heat from the communal heating system calculated using the measured system efficiencies are shown in Table 82. The overall carbon intensity of delivered heat was 0.328 $kgCO_2/kWh$ [when the effect of the parasitic plant room electricity use was included]. This is around seven times the predicted carbon intensity of 0.044 $kgCO_2/kWh$ calculated using the nominal SAP inputs of 93.6 per cent for boiler efficiency and 95 per cent distribution efficiency. SAP 2005 does not have any inputs for parasitic electrical loads.

In cases when there is excess solar PV output, the solar PV energy could be offset against the electric parasitic loads to reduce the effective carbon intensity of delivered heat.

Table 82 - Measured Carbon Intensities for District Heating System

Energy Definition	Carbon Intensity ($kgCO_2/kWh$)
Delivered Heat (excluding communal system parasitic electricity for pumps, boiler controls and buffer immersion)	0.181
Parasitic Electricity for Communal System (at 28.1% of Heat)	0.147
Delivered Heat including Parasitic Electricity	0.328

The annual overall carbon emissions for the development were calculated for the period 25th March 2013 to the 24th March 2014 to coincide with the biomass-fuel delivery dates. The data used in the carbon calculation are given in Table 83. Total emissions from the development for the period were 10.3 tonnes of CO_2 per annum. This is equivalent to 5.65 $kgCO_2/m^2$.a based on the total floor area of the 21 dwellings at Sinclair Meadows of 1825 m^2. These data show that the development is currently not "carbon negative" as originally intended at the design stage. Nonetheless, the carbon emissions are still very low compared to dwellings built to current regulatory standards.

Table 83 - Sinclair Meadows Annual Energy Data for Period 25/3/13 to 24/3/14 (using SAP2012 factors)

Energy Source	Annual Energy (kWh.a)	Carbon Emissions ($kgCO_2/a$)
Biomass Delivered	254976	9944.1
Electric Used by Dwellings	60596	
Electric Used by Communal Heating System	15466	
Electric Generated by solar PV Arrays	75349	
Net Electric Imported from Grid	713	372.1
Total Carbon Emissions		**10316**

The carbon emission calculations shown in Table 83 do not include the effect of electricity used in communal areas or other use on the site such as external lighting and pressurisation for the district heating system. This use is not sub-metered by the housing association so it is not possible to calculate this energy directly.

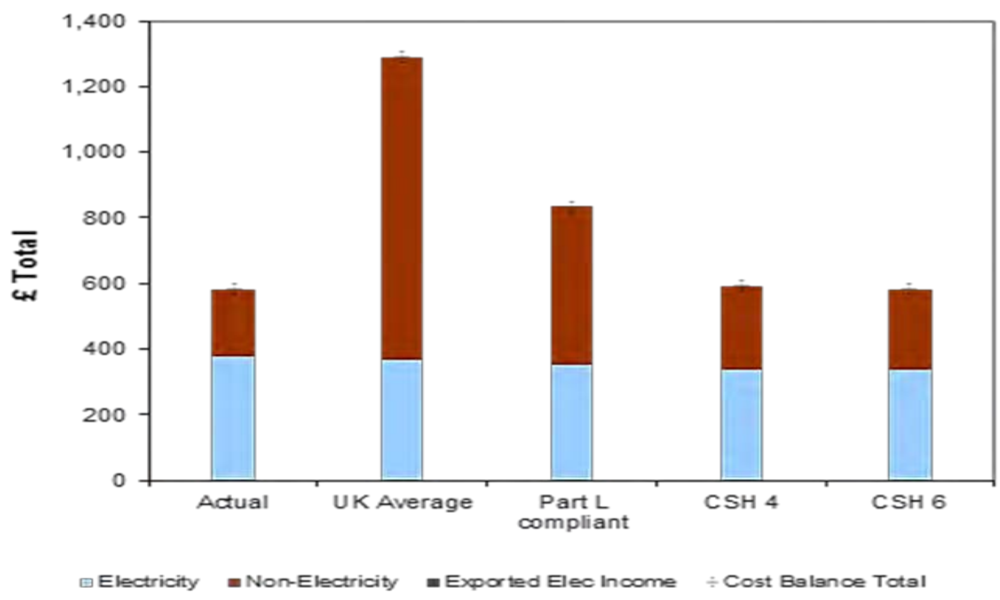
The energy used in the communal areas in the apartment block can be approximated from the charge levied by the housing association as part of the annual service charge. The residents of the flats are charged £3 per week each for communal area electricity use. This equates to 17,476 kWh.a at the current rate charged to residents for electricity of 10.71 p/kWh; this seems rather high and would be the equivalent of an extra 9,122 tonnes of CO_2 per annum on the developments carbon emissions (see Section 12.6 - Residents Energy Costs, page 204 for additional detail).

7.9 Monitored Dwelling Annual Energy Costs [including DomEARM]

The graph in Figure 87 compares the average annual energy costs of dwelling A with UK Average, Part L Compliance, CfSH Level 4 and CfSH Level 6.

The graph in Figure 88 compares the average annual energy costs of dwelling B with UK Average, Part L Compliance, CfSH Level 4 and CfSH Level 6.

Figure 87 – Dwelling A - Annual energy costs compared with benchmarks



Note: Benchmark figures include appliance energy use. Data includes number of occupants, weather correction and year of construction.

Table 84 is the annual energy costs compared with benchmarks for dwelling A; where:

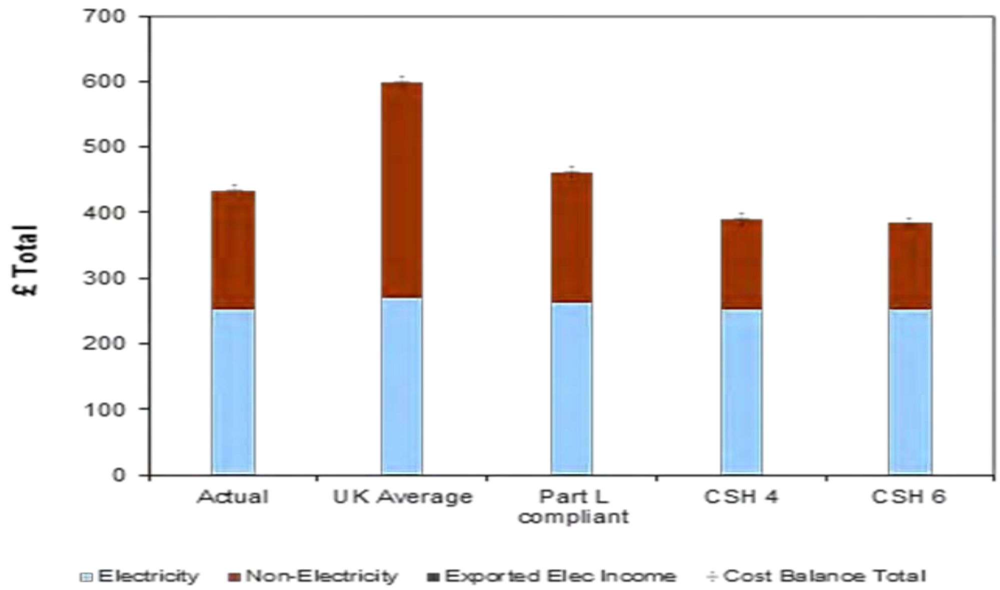
- Electrical energy cost (376 £/a) with the UK average (366 £/a) [+3%; which represents the percentage difference between actual and benchmark], Part L Compliance (351 £/a) [+7%], CfSH Level 4 (336 £/a) [+12%] and CfSH Level 6 (336 £/a) [+12%]

- Non-Electrical energy cost (206 £/a) with the UK average (952 £//a) [-78%], Part L Compliance (484 £/a) [-57%], CfSH Level 4 (258 £/a) [-20%] and CfSH Level 6 (248 £/a) [-17%]

Table 84 – Dwelling A - Annual energy costs compared with benchmarks (DomEARM)

Primary Energy Source	Actual Average Costs (£/a)	UK Average Costs (£/a)	Part L Compliant Costs (£/a)	CfSH Level 4 Average Costs (£/a)	CfSH Level 6 Average Costs (£/a)
Electricity £ Total	**376**	**366**	**351**	**336**	**336**
% Difference between actual and benchmarks		**+3**	**+7**	**+12**	**+12**
Non-electricity £ Total	**206**	**952**	**484**	**258**	**248**
% Difference between actual and benchmarks		**-78**	**-57**	**-20**	**-17**

Figure 88 – Dwelling B - Annual energy costs compared with benchmarks



Note: Benchmark figures include appliance energy use. Data includes number of occupants, weather correction and year of construction.

Table 85 is the annual energy costs compared with benchmarks for dwelling B; where:

- Electrical energy cost (251 £/a) with the UK average (271 £/a) [-7%; which represents the percentage difference between actual and benchmark], Part L Compliance (262 £/a) [-4%], CfSH Level 4 (254 £/a) [-1%] and CfSH Level 6 (254 £/a) [-1%]

- Non-Electrical energy cost (183 £/a) with the UK average (328 £/a) [-44%], Part L Compliance (200 £/a) [-9%], CfSH Level 4 (136 £/a) [+34%] and CfSH Level 6 (131 £/a) [-40%]

Table 85 – Dwelling B - Annual energy costs compared with benchmarks (DomEARM)

Primary Energy Source	Actual Average Costs (£/a)	UK Average Costs (£/a)	Part L Compliant Costs (£/a)	CfSH Level 4 Average Costs (£/a)	CfSH Level 6 Average Costs (£/a)
Electricity £ Total	**251**	**271**	**262**	**254**	**254**
% Difference between actual and benchmarks		**-7**	**-4**	**-1**	**-1**
Non-electricity £ Total	**183**	**328**	**200**	**136**	**131**
% Difference between actual and benchmarks		**-44**	**-9**	**+34**	**+40**

7.10 Conclusions and key findings for this section

7.10.1 Monitored Data

A fundamental part of the BPE programme is the continuous and ongoing analysis of the monitored data, the highlighting of any issues encountered to the relevant programme coordinators; and the speedy resolution of any identified problems. Analysis of the monitored data at Sinclair Meadows showed that not all of the BPE data gathering methodology worked as predicted and that this shortcoming significantly affected both the robustness and quality of some of the extracted data. It was 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.

Additionally towards the end of 2013 it was found that the ongoing analysis of the monitored data had been completed incorrectly by someone inexperienced with BPE methodology. Once it was identified that this had occurred the inexperienced operative was replaced with a specialised resource, someone more experienced and knowledgeable with BPE programmes.

However forensic data analysis in early 2014 found that:

- The ESCo utility meter data for electricity and total heat match the physical meter readings and could be used with a high degree of confidence
- The ESCo data for DHW could not be used
- There was a problem with the installation of the monitoring heat meters for space heating and DHW in the apartment; likely due to the cold side temperature sensors being transposed; and it was not possible to correct the data
    - o This problem suggested the need for a more rigorous commissioning process for such meter installations at the start of the monitoring programme. It would also be useful in the case of multiple installations to have better labelling of cables between meters, sensors and transmitters and that all cables should be labelled at both ends
- In the case of the heat metering in the house, it was possible to calculate a long term system efficiency of heat delivery from the HIU using both the ESCo data and monitoring data.
- It is recommended that, for future monitoring projects, readings of all utility meters, heat meters and sub-meters are taken at the start and end of the monitoring period. This then will make it easier to cross check monitoring data with physical meter readings.
- A standard commissioning process should be adopted to check the validity of energy meter data at the start of monitoring. For example, in the case of electricity sub-meters, this would involve activating individual circuits in turn (i.e. by turning on a device on the circuit) so that they can be identified in the monitoring data. Ideally, each circuit would be activated so that it was the only energy consuming device for one timed monitoring interval. The same process should be applied to heat meters on heating and hot water circuits and to any flow meters on cold water or hot water pipework.

7.10.2 Relative Humidity and Condensation

There was a significant difference in the level of relative humidity in the house compared to the flat, despite the fact that the internal temperatures were similar. This would indicate a significant difference in the ventilation rates of the two dwellings; with the house having a much lower level of ventilation in the winter. It can also be seen that the mean relative humidity in the flat fell below 40%RH for some periods. This dry air in winter is a common issue in dwellings with MVHR.

The house data shows that the humidity in the bathroom and living room exceeded 70%RH for between 5 and 10% of the year. This would increase the risk of condensation and associated mould growth in these rooms. Observations in the ceilings in the bathroom of the house indicate the presence of damp/mould, which is consistent with the humidity data.

7.10.3 Carbon Dioxide Concentration and M&E Installations

The internal concentration of carbon dioxide in the dwellings was used as a proxy for general internal air quality. A plot of the monthly mean living room CO_2 concentration for both monitored dwellings indicated that the ventilation rate in the house was less than that in the flat and supported the view that the MVHR system in the house was not working effectively.

It was reported 0that commissioning of the various M&E installations was very fragmented and that in essence statutory certification had taken place rather than commissioning. Additionally there was no opportunity to stress test the various M&E installations. It is therefore recommended that the definition of commission needs to be clearer and understood by all parties involved and that M&E installations need to be stress tested prior to occupation to ensure correct performance.

7.10.4 Appliance Audits [DomEARM]

In order to minimise the disruption to the residents the Appliance Audit [DomEARM] surveys were completed and returned to the housing association by the residents themselves; and this was due in part because it was reported that the residents had expressed displeasure with the constant disruption that this and other studies had caused.

However analysis of the returned information showed that specific dataset necessary to complete the DomEARM study to level 3 had not been recorded by the residents and that this had resulted in the DomEARM studies being completed only to level 2. As a consequence DomEARM level 2 assessment data have been included in this report. It is therefore recommended that Appliance Audit [DomEARM] on future programmes be completed by either the housing association (in conjunction with the relevant programme manager) or by the programme manager only.

Additionally a better understanding of the wishes and views of the residents must be included and take higher prominence when considering future programme and task scheduling.

8 Other technical issues

8.1 Post construction project review

This section was completed using the notes of a post construction project review meeting held on Monday 12th May 2014. This meeting was attended by members of the project team. In the spirit of the partnership agreement under which this project was delivered, the notes of the meeting are confidential. However, the following general themes and lessons learned were discussed and agreed by those present. Performance reviews are expressly omitted from this report.

The objective of the post construction project review meeting was to constructively reflect on the Sinclair Meadows development and to identify, agree and discuss the main learning points that could be taken away from the project. It is a key element of the process which is used to inform the design and construction of future developments.

8.2 Lessons learned

It was agreed that the project had been successful in a number of significant areas, most notably in the ultimate delivery of the development. There had been minimal building defects since handover within a number of ongoing issues in respect of the more specialised M&E systems included in the project.

8.2.1 Celebrate More

It was agreed that those involved in this project should celebrate the ultimate success of this project. Whilst this project has perhaps not received the national recognition it deserves, the project team were hopeful that it would do so in the future. It was felt that the Sinclair Meadows development will stand apart from other (similar) projects for a long time

The project was listed in the Top 50 Affordable Housing Development of 2013 by Inside Housing and has won several awards including; Best New Affordable Housing Scheme at the Housing Excellence Awards 2013 and the Innovation Award at both the North East and National Construction Excellent Awards 2013.

It was felt by the project team that the project could achieve Passivhaus status quite easily, given the impressive U-values and airtightness achieved. Indeed, the team were impressed with the overall performance of the dwellings.

Everyone involved in the project has gone above and beyond to deliver this unique project. It was acknowledged by the review team that that the main consultants had committed throughout the duration of the project despite any issues encountered and, in general, the design team had worked well together on a long, innovative and complex project

All parties present agreed that they would undertake the project all over again.

8.2.2 Cost Control

It was acknowledged by the project team that innovation has an associated increase in costs. Cost control during the project was challenging due to the complex nature of the project.

Value Engineering (VE) is a given for this type of complex project and took place pre-contract to enable the project to proceed on site. This process did have a knock on effect for the consultants, with additional work being necessary. The team accepted that value engineering can create buildability issues on site.

8.2.3 Share Learning

The unique nature of this project required an intensive research and development phase. This was felt to be a positive learning experience by all involved. This was an innovate project, drawing together elements which many of the project team had never worked with before, as such the research and development phase was a long process.

Whilst the project was not particularly complex from a CDM perspective, it was stated that a more user friendly format was required for the Building manual. Separate end-user and technical manuals were also required to cover the unique and innovative elements of the mechanical and electrical installation.

There were some difficulties in translating the unique design concept of this project to a completed building was at times challenging. However, it was acknowledged that this transition is always difficult and that the team have learnt from their experiences of delivering the innovative elements of this project. A valuable method of identifying and resolving issues resulting from this transition was the weekly technical meetings carried out on site involving the full project team.

Regular technical meetings have now been adopted on all development projects.

9 Key messages for the client, owner and occupier

9.1 Conclusions and key findings for this section

Academic research has shown that even low-energy buildings, carefully built to perform well, rarely perform to expectations, either in use, or in the fabric alone. Only a systematic evaluation of the performance of buildings can aid in the diagnosis of the reason or reasons for this, and, assuming that remedies can be applied, can evaluate the effectiveness of the remedies.

Sinclair Meadows was an innovative and leading edge development. During the course of this project it is clear that all of those involved learned an enormous amount and there were a whole range of positive learnings (e.g. the Clerk of Works success together with the design and delivery team engagement). From the outset tenants of the properties were required to be sympathetic to the aims and ethos of the Sinclair Meadows development scheme as well as being in housing need. It was important that these buildings were used in the way that they were designed to be; and in partnership with the local council, Three Rivers Housing Association marketed the properties in an attempt to get prospective tenants in to skills and knowledge training to understand the concept and design of their home. This resulted in prospective tenants being interviewed to determine attitudes towards factors including sustainable living, energy appreciation and natural environment. Subsequently successful applicants were supported by way of an additional 12 month Community Development Programme.

The results from Phase 1 of the behaviour change research programme suggested that the new tenants of Sinclair Meadows were largely willing to engage with carbon-negative lifestyles and become part of new type of community. Despite some initial teething problems, most residents were very pleased with their new homes (in the words of one person, *'I feel like I've won the lottery!'*), and appeared to be willing to enter into the ethos of the development.

While most tenants already displayed at least some pro-environmental attitudes and beliefs, there were areas for potential improvement in their habits and everyday behaviours, e.g. reducing the amount of time spent in the shower, reducing packaging waste, and re-using items. Possible next steps included boosting awareness of the environmental impacts of all types of purchases, and educating people about checking labels on products, 'green' products and the importance of buying local to reduce transportation.

Tenants identified a number of areas in which they would have liked more information and support, with the most common ones being advice about how the heating system and boiler works, composting, bin use and recycling on site, problems with toilets, and information about how Individual Appliance Monitors (IAMs) and Energy Monitors work. Ensuring that people get the information and support they require, and managing potential problem issues such as onsite car parking, was identified as being a potential challenge in the coming months and years.

The primary problem so far has been car parking, which has been a cause of division, rows and ill-feeling involving a number of tenants. In two cases where tenants have left the development after less than six months, their desire to leave arose from disagreements around parking. There is also uncertainty around the future availability of off-site parking due to adjacent land being developed. The parking issue is a threat to the success of Sinclair Meadows in terms of providing a pleasant living environment for its tenants, and in particular to the aim of building a cohesive community. Action needs to be taken to resolve matters and rebuild goodwill between tenants, which has in some cases been lost.

The community development training programme as well as efforts by Three Rivers Housing Association staff to address tenants' concerns and needs, has had a vital role in ensuring that the new community settled in and problems were dealt with. As well as car parking, these issues have included 'teething problems' such as how to use the heating and other technologies, and what to do when things do not work. A great deal of time has been dedicated to ensuring that tenants were supported in the early months in their new homes.

9.1.1 Building Use Survey (BUS) study

To summarise, overall satisfaction at the site appears to be quite high, with residents reporting many positive experiences of their new homes and scores comparing well with benchmark datasets. Satisfaction with the dwellings also appeared to be high, with overall comfort, perceived health and needs all scoring in the 99th percentile. All residents felt that their needs were being met, and the majority are comfortable in their new home. Although toward the end of the BPE programme there was an air of displeasure associated with continuous requests for information, data and access to the properties in order to complete BPE tasks. Going forward it is recommended that in-depth consideration of resident's ongoing needs and requirements is regularly assessed and included into both project and local communication plans.

Additionally it is evident that 85 per cent of respondents of the Building Use Surveys do believe that living in the new development has changed their lifestyle; with a large number of positive comments relating to the ways in which residents have changed their lifestyle, in terms of diet, leisure, travel and work.

9.1.2 Summer Overheating

The design data showed that there was no significant tendency to overheat in the living rooms. However, the measured temperatures did indicate overheating in the bedrooms in both dwellings during the summer; however this may have been due in part to the relatively high summer temperatures in the UK in 2013 [where the monthly maximum temperatures in the monitored dwellings reached 35°C].

Measurements showed that summer overheating in the bedrooms of the monitored dwellings at Sinclair Meadows is a potentially serious issue (see Section 2.3.9 - Summertime Overheating Risk Assessment, page 26 and Section 7.2 - Internal Temperature, page 87 through to Section 7.4 - Carbon Dioxide Concentration, page 91). The exact causes of the overheating at Sinclair Meadows are not fully understood [although as outlined this may have been due in part to the relatively high summer temperatures in the UK in 2013]. However, it is known that issues with the installation, commissioning and operation of the MVHR system operation will have reduced the potential of the ventilation system to minimise overheating (see Section 6, Installation and commissioning checks of services and systems, services performance checks and evaluation, pages 65 through 76 for additional information).

In terms of thermal comfort the flats are performing much better in winter than during the summer. While in the winter the residents seem to appreciate the ability of the flats to retain heat, during warmer periods there appears to be some significant overheating problems with 80 per cent of residents answering that it is too hot in the summer. High levels of natural light combined with limited control over cooling may be causing the flats to overheat. The lack of control over cooling is probably the greatest concern at Sinclair Meadows, with over a third of residents stating that they are unable to control cooling. It is also surprising that the dwellings are reported as too hot during the winter as residents believe that they have full control over heating and therefore would be expected to be able to maintain a comfortable temperature.

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 prevalence of overheating in other dwellings on the development and to check the correct and effective operation of all MVHR units. It is also suggested that residents be provided with additional advice on simple measures that can be implemented to reduce overheating potential.

Another issue may be the limited amount of shading [a design strategy which can be effective in reducing solar gain during summer]. This is something which needs to be investigated further as without remedial action the residents may resort to using electric fans to cool the spaces; which will increase electricity consumption at the site.

9.1.3 MVHR Installations

The MVHR systems at Sinclair Meadows were found to be poorly commissioned and with a range of installation defects evident. 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 Sinclair Meadows are carried out as a matter of urgency. These inspections should include measurements of MVHR flow rate 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. Tenants should be provided with better information and support in the effective operation of the MVHR systems.

9.1.4 Reliability of Biomass Boiler

The plant room monitoring data showed that the contribution of the biomass-fuelled boiler to overall communal heat output was around 20.3 per cent. This had a significant impact on the carbon emissions related to heat delivered by the communal heating network; and this was perhaps an indication that the use of district heating for small scale low energy developments such as Sinclair Meadows may be inappropriate due to the lack of a sufficiently large heat demand to offset the system inefficiencies and distribution losses.

10 Wider Lessons

10.1 Conclusions and key findings for this section

10.1.1 Building Performance Evaluation Methodology

The scope of the Building Performance Evaluation (BPE) project at Sinclair Meadows was limited mostly to the measurement of and the assessment of, in-use performance and post occupancy evaluation. Consequently, it was not possible to relate the measured performance data to procurement, although elements of both the design and construction processes have been assessed. A better understanding of the overall process issues would require a model for BPE that is fully integrated into the design and construction process. An 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).

A fundamental part of the BPE programme is the continuous and ongoing analysis of the monitored data, the highlighting of any issues encountered to the relevant programme coordinators; and the speedy resolution of any identified problems. Analysis of the monitored data at Sinclair Meadows showed that not all of the BPE data gathering methodology worked as predicted and that this shortcoming significantly affected both the robustness and quality of some of the extracted data. It was 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.

Additionally towards the end of 2013 it was found that the ongoing analysis of the monitored data had been completed incorrectly by someone inexperienced with BPE methodology. Once it was identified that this had occurred the inexperienced operative was replaced with a specialised resource, someone more experienced and knowledgeable with BPE programmes.

In-situ transmittance (U-value): In-situ thermal transmittance (U-value) heat flux data showed that the thermal performance of the external walls exceeded the design U-values, although the measurement was carried out in two locations only [and the test carried out in the house was incorrectly completed on a south facing wall for the reasons identified within Section 4, Fabric testing (methodology approach), pages 41 through 59]. This demonstrates the need to carry out tighter and auditable control using the correct and appropriate test methodology.

Thermographic Imaging: Infra-red thermal imaging surveys of both the inside and outside of the dwellings were carried out by a specialist thermal imaging subcontractor on the 2nd April 2014. It was found that image manipulation and post processing of the Thermographic Images had given rise to artefacts and distortions which resulted in it not being possible to draw any conclusions with regard to the thermal performance of the structures. As a consequence this may have wider implication for specialist contractors carrying out Thermographic Imaging surveys.

In this programme the short-coming in data was identified relatively late in the project and this is mainly due to the in-experience of those tasked with analysing the data. However once the issues with the data had been identified, steps were taken to minimise the overall risk to the project; including the sourcing and substitution where necessary of alternate data sources [as detailed in Section 7].

Specifically with regard to this project, this forensic data analysis was completed by a person that was both highly qualified and experienced with BPE programmes; the use of whom enabled the project to be completed in accordance with the scope and objectives of the project.

Again this demonstrated the need to ensure the correct design, installation and test and commissioning of the monitoring equipment at the front end of the project, and to ensure an appropriate minimum level of technical competence in those organisations responsible for conducting BPE programmes. Therefore it is strongly recommended that this fundamental part of the BPE programme is reviewed in conjunction with the lessons learned through other BPE programmes and enhanced for future projects.

10.1.2 Fabric First Approach

From the outset tenants of the properties were required to be sympathetic to the aims and ethos of the Sinclair Meadows development scheme as well as being in housing need. It was important that these buildings were used in the way that they were designed to be; and in partnership with the local council, Three Rivers Housing Association marketed the properties in an attempt to get prospective tenants in to skills and knowledge training to understand the concept and design of their home. This resulted in prospective tenants being interviewed to determine attitudes towards factors including sustainable living, energy appreciation and natural environment. Subsequently successful applicants were supported by way of an additional 12 months Community Development and it is recommended that where possible future exemplar developments such as Sinclair Meadows also adopt this practice.

From the start of the project, the emphasis was placed on the quality of both the building fabric (especially on airtightness and heat loss) and the insistence by Three Rivers Housing Association and the design team of the need to understand and use correct construction techniques. The Sinclair Meadows development was felt by the design and delivery team to have been a success and the team were proud to be part of it.

It was agreed by all participants that there had been reasonable to good co-operation during the project that had been enhanced through the use of weekly on-site meetings. The participants enjoyed the design and delivery feedback process which they perceived as having been useful and productive. There was a general consensus that all would be interested in taking part in similar processes in the future. Achieving CfSH6 and being carbon negative was seen as challenging as CfSH included features that were not specifically related to energy consumption; although it was widely acknowledged by the team that the support provided by the Code Assessor was extremely useful.

The principal adopted from the onset was that by starting with a *high quality* building fabric would mean less energy required to heat/cool the buildings during occupancy. The results showed that a *fabric first* approach to building design and construction can result in significant reduction in energy demand for space heating compared to the building stock.

10.1.3 Errors in SAP Calculations

The evidence from Sinclair Meadows 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 per cent 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 the Technology Strategy Board and the project team with an opportunity to raise them with all relevant stakeholders.

10.1.4 Carbon Emissions from Community Heating

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 Sinclair Meadows show that communal heating systems do not always work as expected, and that emissions can be considerably higher than those calculated using design estimates. Recent research carried out by the National Energy Foundation on a number of district heating schemes in London found similarly poor system efficiencies. This is an area that requires further industry research.

As a matter of interest, it is noted that SAP2005 does not define the how the efficiency of biomass-fuelled boilers should be calculated. By normal convention, the efficiency of biomass boilers is generally taken as the net efficiency (i.e. excluding the latent heat of water content or water of combustion). This differs from the convention for gas boilers in SAP, which uses gross efficiency to take account of the latent heat of combustion water for condensing boilers. Although condensing biomass boilers are uncommon, there are some on the market, so there is potential for confusion. It is therefore suggested that there should be clearer guidance in SAP for biomass-fuelled boilers.

10.1.5 Commissioning of MVHR Systems

The indication from measurements of the performance of the MVHR systems at Sinclair Meadows was that they had not been properly commissioned and/or operated. 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.

10.1.6 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 tenants at Sinclair Meadows were finding and identifying 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 Sinclair Meadows 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 the MVHR systems. 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.

10.1.7 Internal Air Quality

The results of humidity and carbon dioxide measurements in the monitored dwellings at Sinclair Meadows indicate that the internal air quality ranged from satisfactory to poor. 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.

11 Appendices

11.1 References

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11.2 Construction Drawings

Figure 89 – Construction Drawing, External Wall to Party Wall Junction (19 May 2011) page 124, is the construction drawing of the external wall to party wall junction. Figure 90 – Construction Drawing, External Wall Corner Detail Plan (19 May 2011), page 125, is the construction drawing of the external corner detail plan. Figure 91 – Construction Drawing, Apartment External Wall to Party Floor Detail (19 May 2011), page 125, is the construction drawing of the apartment external wall to party floor. Figure 92 – Construction Drawing, Window Sill Detail to Render (19 October 2011), page 126, is the construction drawing window sill to render. Figure 93 – Construction Drawing, Roof Eaves Detail (19 May 2011), page 126, is the construction drawing showing the roof eaves detail. Figure 94 – Construction Drawing, Apartment Eaves Detail (19 May 2011), page 127, is the construction drawing showing the apartment roof eaves detail. Figure 95 – Construction Drawing, Ground Floor to External Wall Detail (19 May 2011), page 127, is the construction drawing showing the ground floor to external wall detail. Figure 96 – Construction Drawing, Party Wall to Ground Floor Junction Detail (19 May 2011), page 128, is the construction drawing showing detail between party wall to ground floor.

Figure 89 – Construction Drawing, External Wall to Party Wall Junction (19 May 2011)

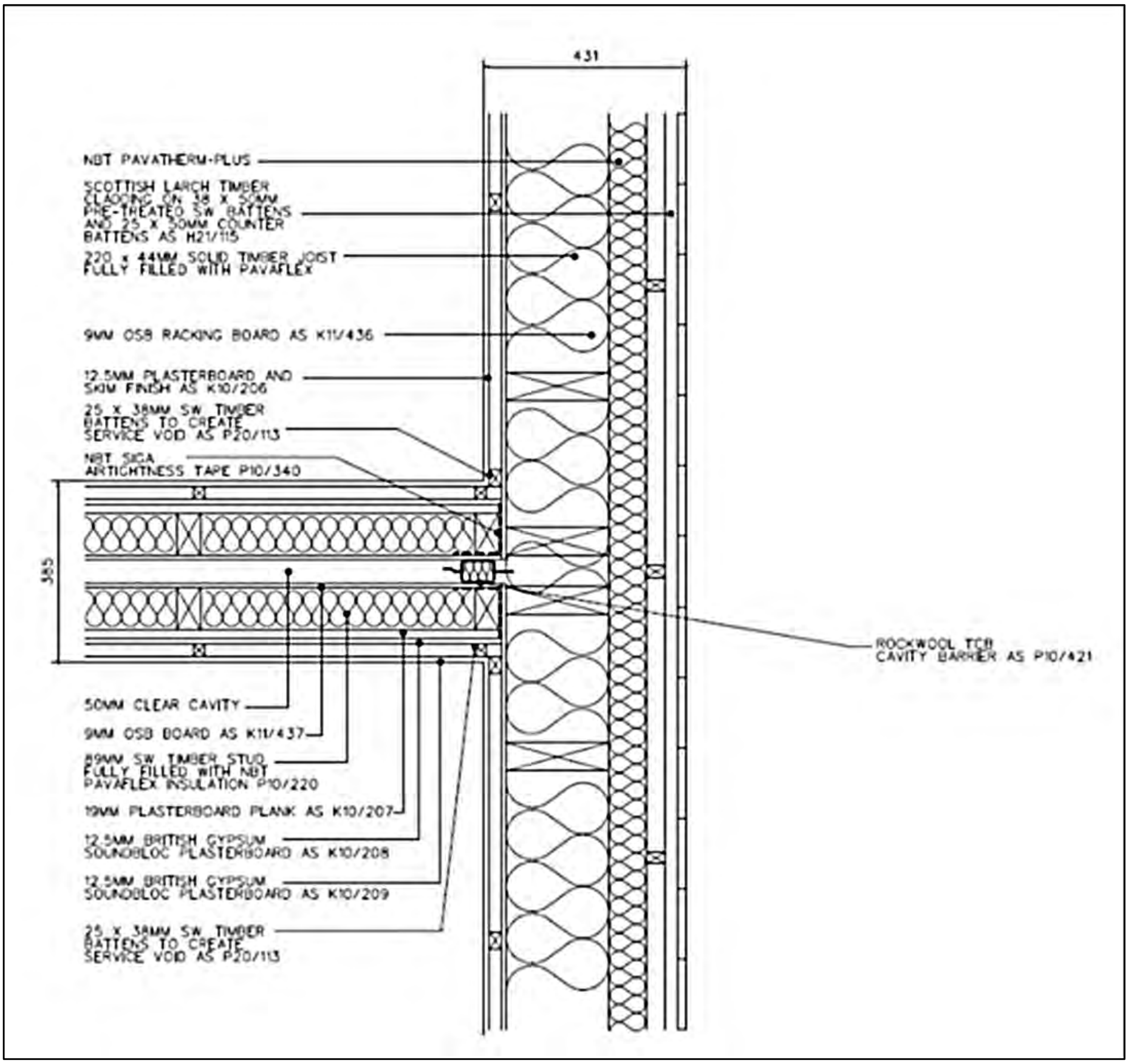

Figure 90 – Construction Drawing, External Wall Corner Detail Plan (19 May 2011)

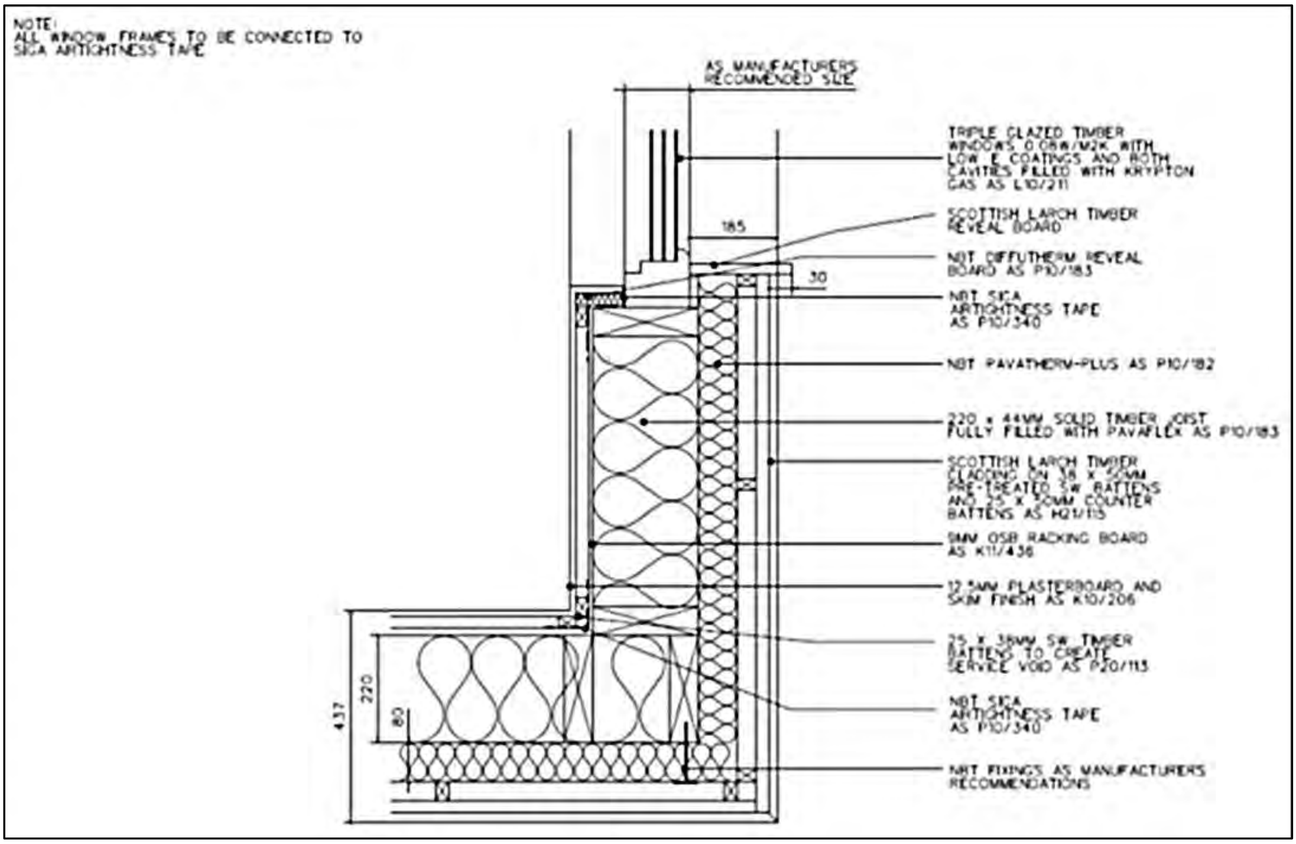

Figure 91 – Construction Drawing, Apartment External Wall to Party Floor Detail (19 May 2011)

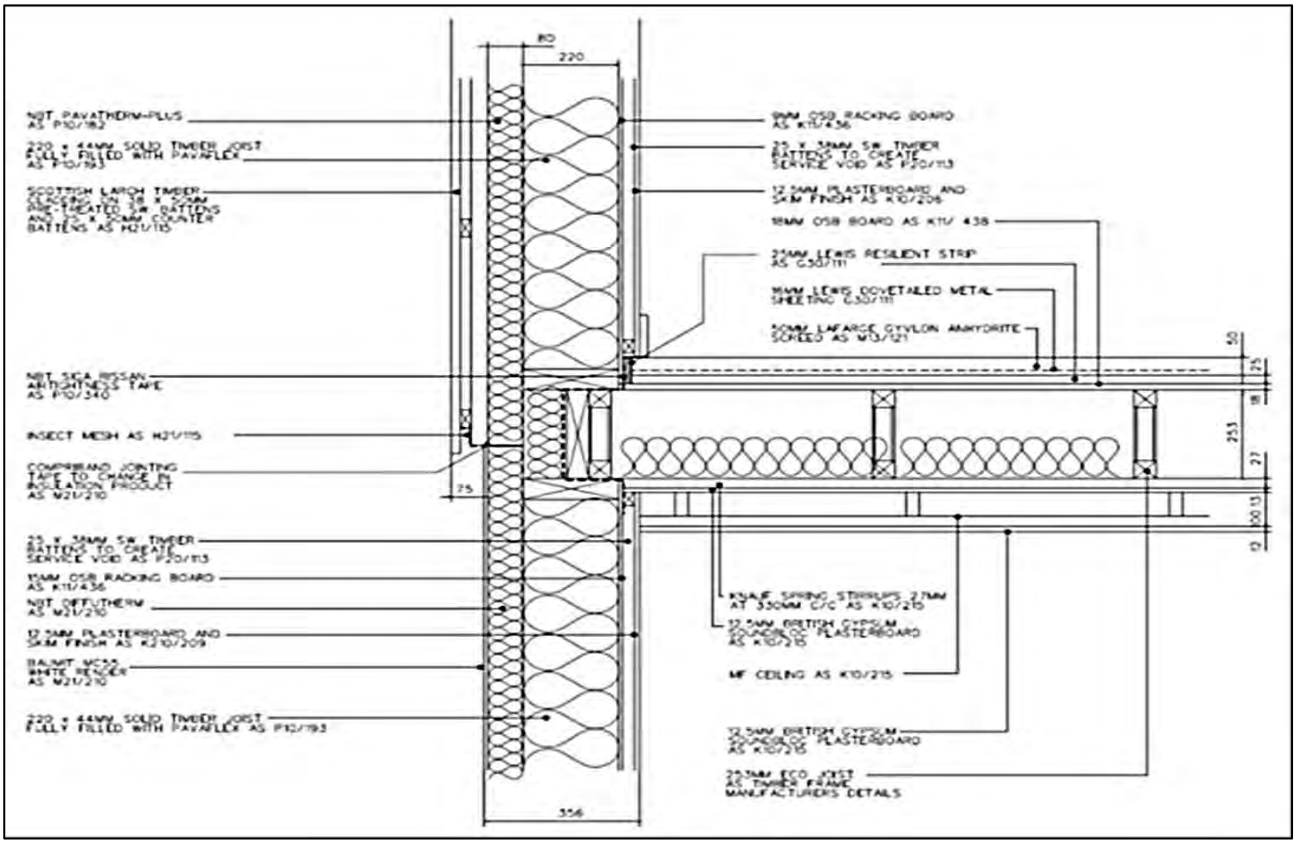

Figure 92 – Construction Drawing, Window Sill Detail to Render (19 October 2011)

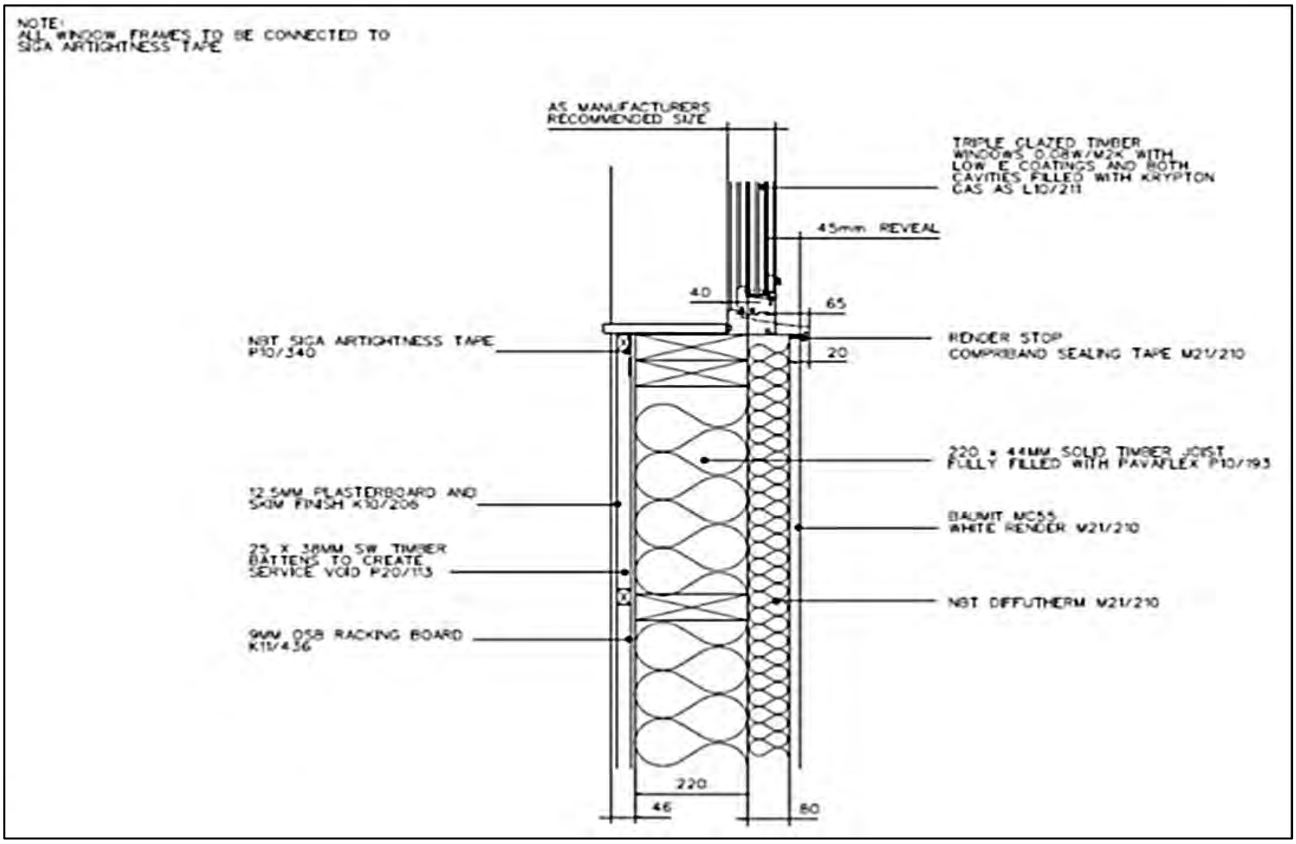

Figure 93 – Construction Drawing, Roof Eaves Detail (19 May 2011)

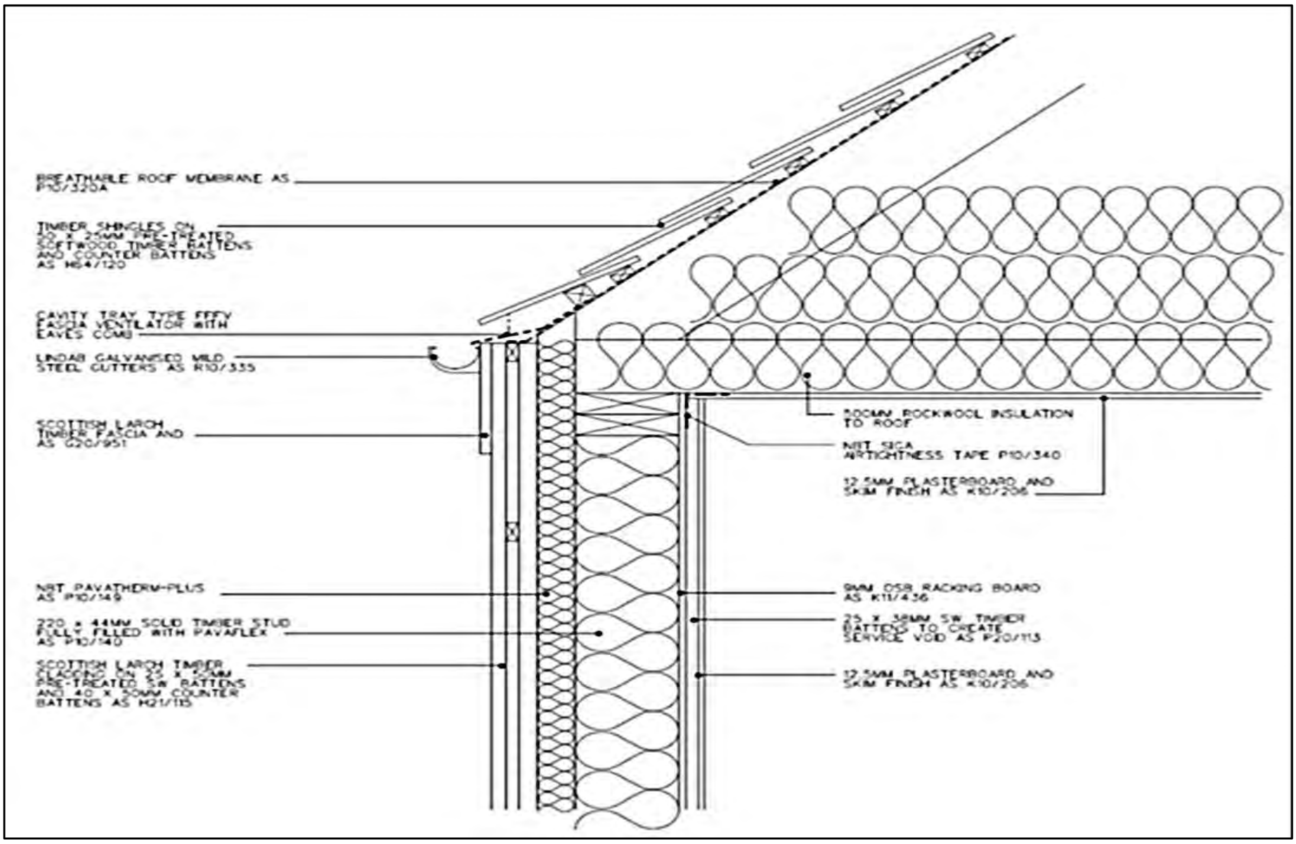

Figure 94 – Construction Drawing, Apartment Eaves Detail (19 May 2011)

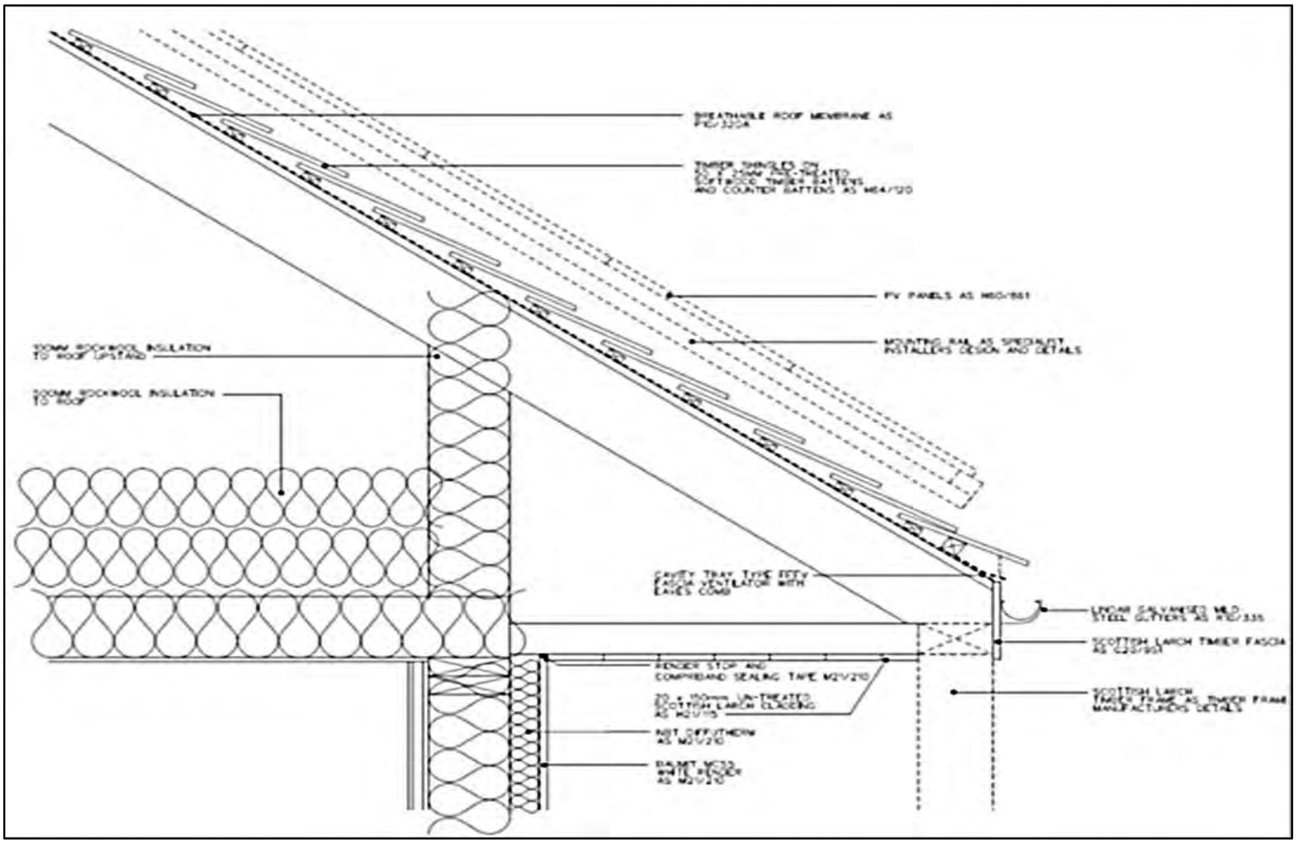

Figure 95 – Construction Drawing, Ground Floor to External Wall Detail (19 May 2011)

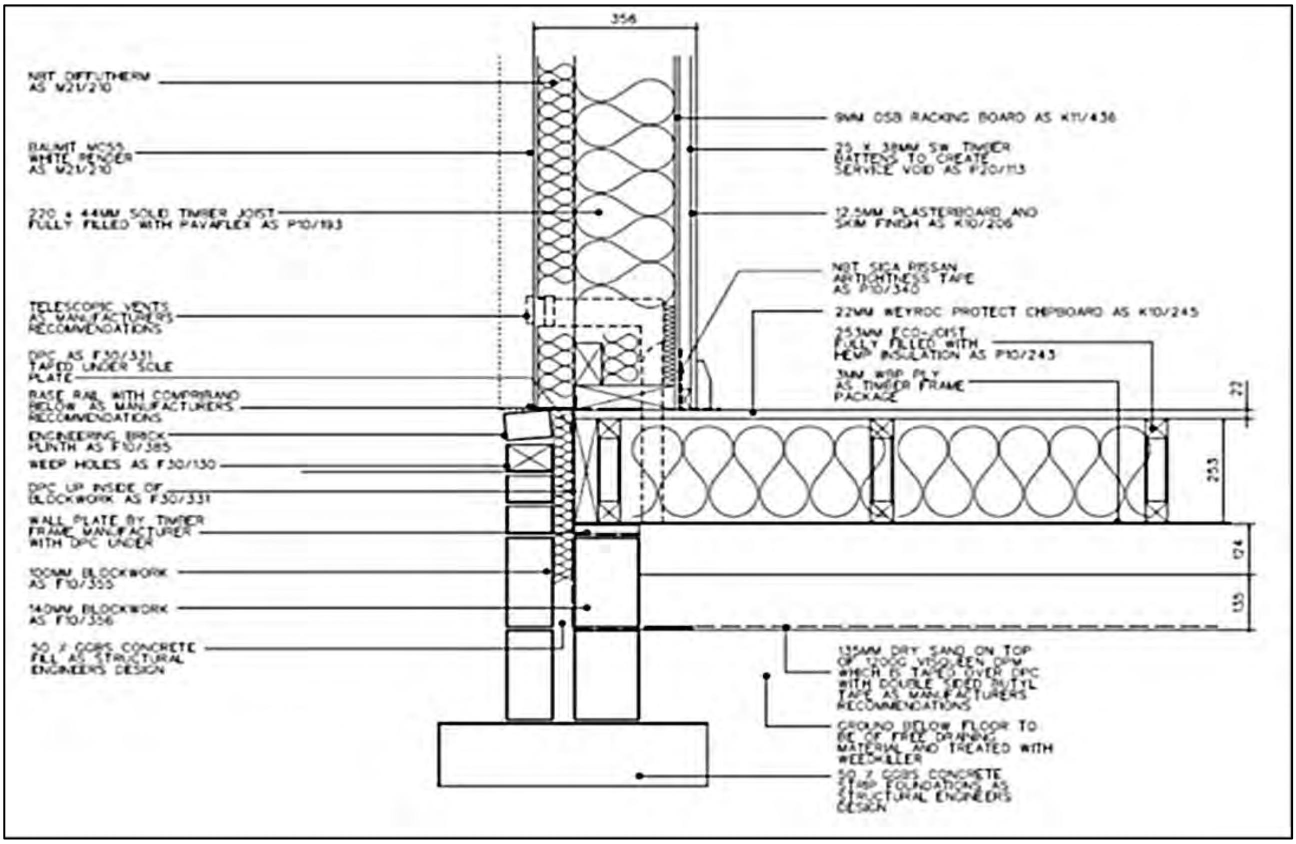

Figure 96 – Construction Drawing, Party Wall to Ground Floor Junction Detail (19 May 2011)