Technology Strategy Board
Driving Innovation

Building Performance Evaluation

Final report

Domestic Buildings

Phase 2: In-use performance and post occupancy evaluation

Technology Strategy Board BPE ref no:	450069
Project title:	Monitoring of an estate near Rotherham
Lead organisation name:	Verco
Number of properties as part of BPE:	4

Date:	19/08/2014
Version:	Final report (2 year monitoring period)
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Contents

1 Glossary

A glossary of acronyms used is provided below, for reference:

ACH	Air changes
ASHP	Air source heat pump
BREDEM	Building Research Establishment Domestic Energy Model
BUS	Building User Survey
COP	Coefficient of performance
CSH	Code for Sustainable Homes
dd	Degree days
DomEARM	Domestic Energy Assessment and Reporting Methodology
ECD	Enhanced construction details
FF	First floor
GF	Ground floor
GNC	Guinness Northern Counties
LDC	Local data concentrator
LED	Light-emitting diode
LZC	Low or zero-carbon
M&E	Mechanical and Electrical (with reference to engineering)
MVHR	Mechanical ventilation with heat recovery
PV	Photovoltaic
SAP	Standard Assessment Procedure
SHW	Solar hot water
TGP	The Guinness Partnership
TSB	Technology Strategy Board
UFH	Under-floor heating

2 Introduction and overview

This study focuses on four properties forming part of the first phase of redevelopment of an estate near Rotherham. This phase of development comprises 24 properties with 2, 3 or 4 bedrooms, of which 22 are constructed to Code level 3 of the Code for Sustainable Homes and two are constructed to Code level 5 and Lifetime Homes standards. This development focuses on the two Code 5 properties, and an adjacent pair of Code 3 properties which feature a near identical size and layout, but differ substantially in terms of construction and services design.

Image ref:	1	Floor:	n/a	Room:	n/a
					
Front of the two Code 5 properties (Property 5B on the left, Property 5A on the right) with one of the Code 3 properties (Property 3A) in shot in the background (left).					

Image ref:	2	Floor:	n/a	Room:	n/a
					
Rear of Property 5A					

The study buildings are located on the southern edge of the estate, and passive solar design features heavily, with extensively glazed suspended steel bays featuring on the south elevation and much smaller window openings to the North. Across the wider development, the client (The Guinness Partnership (TGP), formerly Guinness Northern Counties) was keen to trial technologies which were new to their development team such as green roofs, rainwater harvesting, and heat pumps.

This Technology Strategy Board Building Performance Evaluation Project (no. 450069) was carried out by Verco (project lead; design review, walkthroughs, analysis of monitoring data and building testing) supported by TGP (owner of the properties; building user survey, occupant interviews). The design team comprised Lovell (the lead design & build contractor) and AA design (Architect). The project is a post-occupancy review, and assesses the performance of the buildings over a 2 year period after the initial occupation. The project comprises a combination of detailed energy and environmental monitoring (equipment/remote monitoring provided by t-mac technologies) fabric tests (including air tightness, U-value and thermal imaging), occupant and design team walkthroughs and interviews, a Building User Survey, and a review of the design and construction phase.

During the course of the project, TGP compensated the occupants in the properties for their time and inconvenience through the award of vouchers, and for any direct on-costs (e.g. excess energy costs occurring as a result of the monitoring equipment). The tenants are generally open to participation in the project and showed an interest in the possibility of energy cost savings as a result of the study. TGP is also in the process of compensating some tenants for high energy bills relating to heating system problems identified through the study.

The key lessons from the project are that the more complex servicing arrangement in the Code 5 homes is not delivering the intended net zero carbon operation; in fact these houses generally have poorer energy, carbon and energy cost performance than the Code 3 properties. Metering data from one Code 5 property shows that the heat pump's efficiency is comparable to expectations at design stage, but the heat output is far greater than the property should require, which correlates with observed high internal temperatures. Complexity of the controls system and hot water storage design combined negatively with the lack of an effective handover, significantly limiting the tenant's ability to control their energy consumption.

Fabric testing has shown that, whilst the U-values of the properties where tested exceeded the specification, the air tightness measured one and three years down the line from practical completion is poor, with the Code 3 property underperforming by 56%, and the Code 5 property underperforming by 83%. Examination of leakage paths shows the degradation of internal sealing (e.g. mastic) at wall/floor, wall/ceiling and window junctions as well as poor sealing around window and door units to be a significant factor. While this method of sealing remains common in the UK house-building industry, it is clear that this is not a viable long term means of delivering air tightness.

Settling of the buildings post-construction (including differential movement between the steel bay and main building structures) is viewed to be a possible factor in the degradation of seals and mechanical solutions to air tightness should be considered in future. The design team highlighted the steel bays as a particularly challenging element of the project during design and construction.

Meeting the Code 5 energy performance requirements in theory (achieving net zero carbon in the SAP calculations) was considered relatively straightforward, however in practice design and installation of the heat pump/solar hot water system was complex and a challenge for the design team – compounded by the complex control system which made commissioning and subsequent maintenance & remediation more complex. Functionality issues with the heat pump in one Code 5 property were ongoing throughout the project, and the BPE team believe this to be the lead factor in the tenant's exceptionally high bills (over £2,500 in year 1 and £2,000 in year 2).

Ongoing maintenance for the less familiar technologies was also overlooked - for example, no maintenance schedule was put in place for MVHR, PV or SHW systems, and only the original plumber was able to explain the operation of the heat pump system. If the same properties were designed against SAP 2009 instead of 2005, the design team would have used a gas boiler/PV/MVHR solution instead, due to the higher electrical carbon factor and more favourable treatment of boiler systems in the new version. Based on the evidence from this study, it is anticipated that this strategy would perform better in-use.

There was some inconsistency or omission between the details in the final drawings/specification and the values input into the SAP calculations. In most cases the impact of these would be minor, but one issue (the failure to update the declared energy loss factor of the hot water/heating buffer vessel following a specification change) has a significant knock on effect on the outcome of the SAP calculation and consequently the compliance of the design with the Code for Sustainable Homes level 5 target. Our own SAP modelling indicates that the property does not achieve the net zero carbon requirement (EI=> 100) and would therefore not qualify as a Code 5 property in this regard. In order to meet the requirement, approximately a further 0.6kWp of PV could be required – which could not be accommodated on the roof.

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

2.1 Introduction

The study buildings were built as part of the on-going development of the estate near Rotherham. This phase of the development concentrated on an area of 0.79 hectares according to the planning application. A total of 24 properties were developed consisting of several unit types, as summarised in Table 0-1

Table 0-1: Summary of units in development

Unit Type	No. of properties	Code rating	No. of study buildings
Two Storey Two Bedroom	8	Code 3	None
Three Storey Three Bedroom	9	Code 3	None
Three Storey Four Bedroom	5	Code 3	2
Three Storey Three Bedroom	2	Code 5	2

Outside of the Code targets adopted, there were no further specific energy or sustainability targets at planning stage, but specific sustainable technologies were trialled in the development e.g. green roofs, rainwater harvesting, MVHR, heat pumps.

A discussion of the study buildings and surrounding environment is included in the Appendix (Section 10.1).

It should be noted that two properties had a change of tenants during the study period. One Code 5 property (Property 5A) and one Code 3 property (Property 3B) had tenant changeovers in July 2013 and September 2013 respectively. This has been accounted for in our subsequent analysis.

The properties in this study have been made anonymous, using the following property codes:

- Property 5A (the Code Level 5 property that was monitored in detail)
- Property 5B (the Code Level 5 property that was monitored for the main incomer meters)

- Property 3A (the Code Level 3 property that was monitored in detail)
- Property 3B (the Code Level 3 property that was monitored for the main incomer meters)
- Property 3C (the Code Level 3 property that was not monitored but had a thermal imaging study done)

2.2 Design review

A comprehensive design review has been undertaken (see Appendix Section 10.1). The study buildings consist of both two Code 5 properties and two of the Code 3 properties, located on the southern edge of the development, as shown in Figure 0-1. Each building is a three storey construction and all have very similar floor plans. The Code 3 properties are 3 or 4 bed (option of a 4th bedroom or study), whilst the Code 5 properties are 3 bedroom with an additional family space instead of a 4th bedroom. Both the Code 5 properties are semi-detached (adjoined to each other) and we have the chosen two end-terrace Code 3 properties from a terrace of three, to best replicate the semi-detached Code 5 properties in built form. The original design layout of the properties does not reflect how the rooms in the properties are now being utilised.

Figure 0-1: Study properties. Property 5B and Property 5A are Code 5, whereas Property 3B, Property 3C, Property 3A are Code 3

A key feature of the architectural design for all the study properties was to exploit the south facing frontage to achieve excellent day-lighting, benefit from passive solar gain in the winter and maximise the potential for the use of solar renewable energy technologies. This resulted in an unusual cross section featuring a suspended bay construction to the upper two floors of the properties, which is described in more detail below.

In terms of material selection, all the study buildings were initially designed to use a wood framed construction, with a mixture of Hardie plank cladding, render and exposed brickwork to the external faces of the properties. The Code 3 dwellings were subsequently switched to a traditional cavity wall construction during value engineering in the detailed design stage, driven by the economic instability of 2009. The external cladding and finishes were heavily proscribed by the conditions of the planning submission and saw little alteration.

The overall approach to achieving Code 5 included improved fabric specifications – but it is really technology led. The Code 5 houses use air source heat pumps (ASHP) as the main heat source for heating[1] and incorporate both solar photovoltaic (PV) and solar hot water (SHW) panels.

The site of the development was previously poor quality scrub land. The phase of the development containing the study properties is located on a slight slope running downhill from South to North. It is bordered by existing properties within the estate which run parallel to the North and East, with an active farming field to the South and West – making the study properties somewhat exposed to southerly winds.

2.3 Procurement and delivery model

The development was delivered through a partnering scheme. The planning stage was led by the Architect, AA Design, in conjunction with GNC's development team. Lovell was brought on board once planning was achieved.

The partnership arrangement was widely praised as allowing an effective collaborative approach to the project and the designers, architect and TGP. All felt that this delivered a high quality end product.

[1] Selection was of ASHP significantly favoured by the low electricity carbon factor (0.422 kgCO_2/kWh) in SAP 2005

2.4 Construction review

A comprehensive construction review has been undertaken (see Appendix Section 10.2).

A summary of the key technical specifications of the Code 3 and Code 5 properties is presented in the table below:

Item	Code 5 property	Code 3 property
Air permeability	Target: 3 $m^3/m^2/hr$; measured one year later at 5.37 $m^3/m^2/hr$ & 3 years later at 5.48 $m^3/m^2/hr$ Fabric testing suggests that the increase in air permeability is due to differential movement and degradation of mastic sealing at junctions, and poor sealing of some door/window units.	Target: 5 $m^3/m^2/hr$; measured one year later at 7.78 $m^3/m^2/hr$ Fabric testing suggests that the increase in air permeability is due in part to settling of the building causing differential movement at floor/wall junctions. Degradation of mastic sealing at junctions was observed, and poor sealing of some door/window units was seen in thermography testing
Wall construction	Proprietary pre-fabricated wood framed construction; U-value 0.14 W/m^2k	Traditional brick/block construction/ 75mm Kingspan TW50 insulation; U-value 0.19-0.21 W/m^2k depending on cladding (brick/render/Hardie plank).
Roof construction	Asymmetric roof to maximise space for PV; Insulated at rafters, U- value 0.11 W/m^2k	Asymmetric roof to match Code 5; U- value 0.11 W/m^2k
Floor construction	Mix of insulated screed and UFH; 0.15 W/m^2k	Insulated screed; 0.15 W/m^2k
Windows & Doors	Double glazed windows & high specification UPVC doors, U value 1.0 W/m^2k	Double glazed windows & high specification UPVC doors, U value 1.4 W/m^2k (window) 1.2 W/m^2k (doors
Heating / DHW	NIBE Fighter F2015 heat pump (6kW) – manufacturers COP circa 3.1 @ 50^oC flow temp. Tank-in-tank hot water tank (150l) inside heating buffer vessel	Baxi Megaflo System HEA15 system boiler & 210l spray foam insulated hot water cylinder

	(300l) -intended to minimise heat losses.	
Heat emitters	Polypipe underfloor heating to ground floor; radiators elsewhere	Radiators
Ventilation	ITHO HRU Eco 4 MVHR system; mix of flexible ducting (loft) and rigid letterbox ducting (within property)	ITHO HRU Eco 4 MVHR system; mix of flexible ducting (loft) and rigid letterbox ducting (within property)
Renewables	Viridian Clearline SHW system 2.6kW PV system; Amerisolar 185W panels and Mastervolt inverters (3 units of 2.0, 0.3 & 0.3kW respectively)	None

A number of key aspects of the design were challenging to construct robustly:

- Rear steel bays were difficult to detail and construct – this required significant technical insight although this was helped and supported by the partnering approach used. Accounting for differential movement between the steel and wooden frame on the Code 5's was especially difficult (see Figure 8-6 in Appendix section 0). It was noted that all parties agreed that this part of the design and construction process was extremely satisfying to complete and the finished result was universally well received for its impact on the look and feel of the properties.

- Acoustics – an acoustics specialist was added to the team as the party wall was built off the steel structure. An improvement in sound transference of 8-9dB was achieved through careful consideration of acoustic issues. This correlated with the BUS surveys indicating that noise from other properties was low.

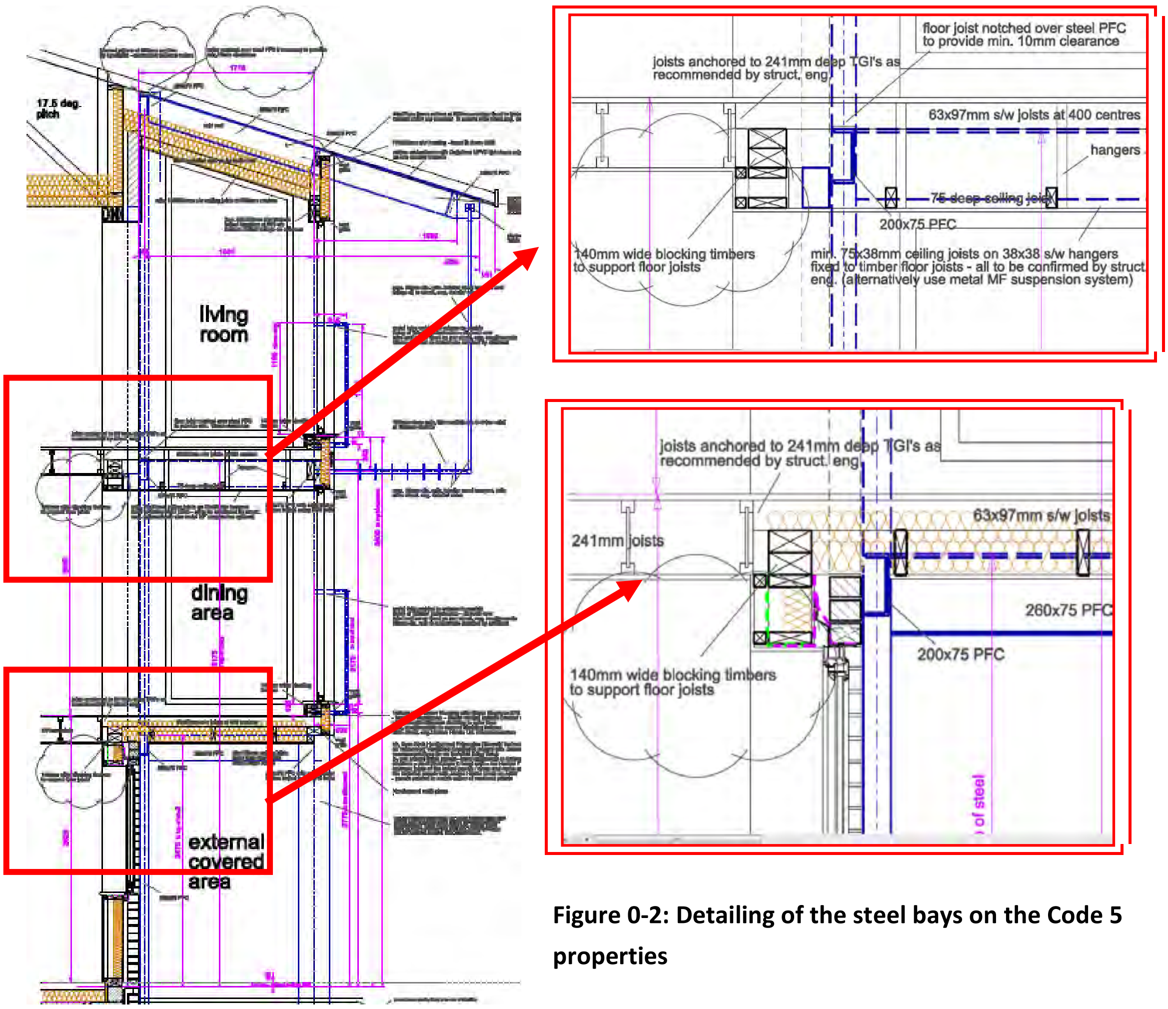


Figure 0-2: Detailing of the steel bays on the Code 5 properties

- There were a number of new features which were unfamiliar to some members of the design team on the Code 5 properties e.g. UFH / heat pumps / air permeability 3.0 $m^3/m^2/hr$ which added a degree of challenge. Leaks occurred in the UFH system; in future testing would be carried out with air to better identify small leaks.
- Cladding the vertical steelwork in a watertight manner was difficult as it was difficult to find locations to attach the cladding in a robust manner (e.g. locating fixings was difficult due to the presence of insulation around junctions)
- Detailing the floor junction between the house and the steel bay was a particular challenge due to the differential movement

2.5 Conclusions and key findings for this section

Economic conditions had a very large impact on this development, as the economic instability of 2009 occurred during the design phase – delaying delivery substantially. The three Code 3 study properties were initially intended to be Code 5, but were downgraded to Code 3 for financial reasons. This resulted in Code 3 and Code 5 properties with near identical layouts (with different wall constructions), offering an ideal study opportunity. Despite this there were relatively few changes between planning and design stage on the Code 5 units which were retained as a flagship "eco-prototype" for TGP. There were considerable changes between concept stage designs and planning stage. The concept stage design incorporated a raft of sustainable design features (stack vent, wind turbine, thermal massing, rear balconies, and green roof), each of which might have been feasible individually. However, it was speculated that the combination of features was unlikely to be cost effective or technically practical on a single dwelling and the planning stage design omitted all the features aforementioned, only retaining the solar thermal system and passive solar design from the concept.

The Code 5 properties cost £117,088 per unit to construct, and the Code 3 properties cost £92,334 per unit - a price premium of over 25% on the code 5 properties compared to the simpler code 3 properties. Much of this price premium is likely to be associated with the servicing arrangement (heat pump, UFH, PV panels and solar hot water) in the code 5 units compared to the gas boiler, radiators & MVHR servicing arrangement in the code 3 units.

Unfortunately, the architect is no longer available to comment further (due to emigration), so absolute clarification on the criteria used for decision-making during the design stage, is not possible.

Some key architectural aspirations of the study properties were retained (extensive day-lighting and suspended bays on south side) despite the economic stress – however comments from the design team suggest this was partly driven by retained planning restrictions on external appearance and further value engineering would have been carried out if the planners had allowed this.

Meeting the Code 5 energy performance requirements in theory (the SAP calculations) was relatively straightforward. However in practice design and installation of the heat pump/solar hot water system was complex and a challenge for the design team – this also added significant complexity to the controls and commissioning and is a potential maintenance issue further down the line (for example, no maintenance schedule was put in place for MVHR or SHW systems, and only the original plumber was able to explain the operation of the heat pump system). If the same properties were designed against SAP 2009 instead of 2005, the design team would have used a gas boiler/PV/MVHR solution instead, due to the higher electrical carbon factor and more favourable treatment of boiler systems in the new version.

The suspended steel bays to the rear of the properties were particularly difficult to detail and construct. This extended the build time to 28 weeks and added substantial design complexity. It will be especially interesting to see how air tightness varies over time on the Code 5 properties, where some settlement of the wood frame is expected.

There was some inconsistency or omission between the details in the final drawings/specification and the values input into the SAP calculations. In most cases the impact of these would be minor, but one issue (the failure to update the declared energy loss factor of the hot water/heating buffer vessel following a specification change) has had a significant knock on effect on the outcome of the SAP calculation and correspondingly the compliance of the property with the Code for Sustainable Homes level 5 target.

Our own SAP modelling indicates that the property does not achieve the net zero carbon requirement (EI=> 100) and would therefore not qualify as a Code 5 property in this regard. In order to meet the requirement, approximately a further 0.6kWp[2] of PV would be required – which could not be accommodated on the roof.

Despite the difficulties and key limitations related to ventilation, hot water and heating (as illustrated in this section and later on in sections 3.2, 5 and 6), the improved look and feel of the properties over a 'standard' social housing product was viewed as a great success by the design team, the developer and the tenants, and key elements (like the fabric first approach to U-values and air tightness targets exceeding building regulations requirements) have been carried on to other projects to be absorbed into "standard practice". It is important that TGP ensure the reasons for degrading air permeability values are designed out on future projects.

[2] Lovell's own investigations indicated that a smaller quantity would have sufficed at around 0.3 or 0.4kWp

3 Fabric testing (methodology approach)

3.1 Introduction

A range of fabric testing methodologies have been used to assess the performance of the as-built specifications to the design performance specifications.

3.2 MVHR testing & review

The MVHR testing was conducted by Chris Knights from BSRIA (Building Services Research and Information Association) on 18/09/2013.

Access could not be gained to the kitchen extract terminal in Property 5A; hence extract rate comparisons were made against the design flow rates for the three bathrooms only. This is a major limitation and impacts heavily on the confidence on conclusions for whole house extract ventilation at this property. However, variation from design values in individual room extract rates were observed in this property & at this level concerns have been raised.

Table 3-1: Comparison of extract ventilation rates: design values and tested values

	Low rate (l/s)	High rate (l/s)
Property 3A	32.1 (-4%*)	36.3 (+9%*)
Property 5A (Kitchen extract was inaccessible to test equipment due to terminal being located above a kitchen unit.	16.4 (-19%*) vs. target of 20.3	24.2 (+19%*) vs. target of 20.3
Requirement for building regulations	33.4	33.4

* Percentage difference from building regulations requirement

Table 3-2: Comparison of supply ventilation rates: design values and tested values

	Low rate (l/s)	High rate (l/s)
Property 3A measured values	20.2 (-40%*)	25.6 (-24%*)
Property 5A measured values	28.2 (-16%*)	36.7 (+10%*)
Requirement for building regulations	33.4	33.4

* Percentage difference from building regulations requirement

Key conclusions from the testing were as follows:

- Both properties presented significant variations from the target ventilation rates required under the building regulations which are of concern. At the time on site commissioning tests of flow rate were not mandatory; commissioning reports cannot be traced indicating that this may not have been carried out.

- The general trend was for insufficient ventilation at the constant ventilation rate for the MVHR units – this was particularly evident in the air supply ventilation in both properties, and in the partial assessment of extract at Property 5A. This is a serious issue – if the properties were to meet and maintain the target levels of air tightness this would lead to a significant lack of fresh air and extraction capacity with knock on impacts on health and air quality.

- As both properties Air Tightness testing results fell short of the design targets (see the following section of the report), in this specific case the additional infiltration may go some way to offset the shortfall in fresh air ventilation rates, but this cannot be presumed for the future, and re-commissioning is essential, especially if action is taken by TGP or the tenants to remedy air tightness issues. In the BUS results, the tenants did not report any stuffiness in the properties – but observations and comments during the interviews indicate that tenants also open windows during the heating season as they have not been trained in how to maximise benefit from the MVHR.

- On closer inspection, the supply & extract rates to individual rooms showed a wide variation from substantial over-ventilation to severe under-ventilation. (See Figure 0-8 and Figure 0-9 in section 14.5.2 of the appendix for further detail) It should be noted that under-ventilation can lead to mould formation, so a solution should be implemented by TGP.

- The cause of the deviation from design targets could be due to a combination of distribution and terminal issues (i.e. poor commissioning, tenant interference with unlocked terminals, excess resistance in certain air pathways), and a central issue (i.e. main unit fan underperformance, or the excess ductwork in the loft space not being factored into the design calculations).

- The MVHR system was noted to be excessively noisy, during the tenant walkthrough of the Code 5 properties (Property 5B and Property 5A – see Section 5.3.1). It may be the case that the systems were out of balance between the various inlets and outlets, as this can cause excessive noise. The worry here is that residents may resort to switching the system off altogether to deal with the noise issue.

- If the air is dry and still, due to incorrect MVHR function and balancing, the tenants may feel hotter, exacerbating any sense of overheating so MVHR commissioning issues may be impacting on comfort. .
- Installation issues were noted in both properties during the testing:
    - A notable level of excess flexible ductwork in loft space
    - One unit not connected to backboard & supported only by flexible ducting
    - Some elements of the rigid ducting in the loft spaces were left un-insulated presenting a condensation risk. This could lead to damp and mould formation & result in a health risk. TGP should correct this issue to prevent further complications.

It should be noted that subsequent to the design and build phases of this development, BPEC domestic ventilation training courses have been developed for MVHR installation. The National House Building Council (NHBC) now provides a ventilation guide; so industry is better set up for MVHR installation and commissioning. However, better national standards and regulations are needed over and above guidance training, especially for MVHR acoustics.

Note: TGP has now put in place MVHR and heat pump service providers for future support.

3.3 Air tightness testing

Air tightness testing was carried out by BSRIA on one of the Code 5 and one of Code 3 properties, at both the start and the end of the project.

The plots selected for testing were the same plots which received the full complement of metering and monitoring installations –Property 3A and Property 5A.

The initial air tightness tests were carried out on the 20th July 2012 in line with the TSB's specifications for the BPE programme. The dwellings had been in occupation for a little over a year at this point in time.

The results of these tests are presented in Table 3-3**Error! Reference source not found.**, and compared with the original design target and the on completion testing results of similar dwellings in the development. Neither of the dwellings selected for the detailed study was tested at the commissioning stage.

Table 3-3: Air tightness test results

Value	Code 3: Property 3A	Code 5: Property 5A
Dwelling target air permeability	5 $m^3/m^2/hr$	3$m^3/m^2/hr$
Test results on construction for other dwellings of same Code level	6 Code 3 dwellings tested: 4.87, 3.03, 5.23, 4.37, 4.58, 4.15 $m^3/m^2/hr$	2.95 $m^3/m^2/hr$ achieved on Property 5B
Initial air permeability under pressurisation: 20th July 2012	7.95 $m^3/m^2/hr$	5.57 $m^3/m^2/hr$
Initial air permeability under depressurisation: 20th July 2012	7.60 $m^3/m^2/hr$	5.16 $m^3/m^2/hr$
Start of project – average value: 20th July 2012	7.78 $m^3/m^2/hr$	5.37 $m^3/m^2/hr$
Final air permeability under pressurisation: 27th March 2014	Access not granted despite two visits.	5.64 $m^3/m^2/hr$
Final air permeability under depressurisation: 27th March 2014		5.32 $m^3/m^2/hr$
End of project – average value: 27th March 2014		5.48 $m^3/m^2/hr$

The air test results for both properties at the start of the project are poorer than the design target, by 3 $m^3/m^2/hr$ for the Code 3 unit, and 2.4 $m^3/m^2/hr$ for the Code 5 unit. The average performance of the properties tested at the time of commissioning met or exceeded the targets in all but one case.

The performance of the sample properties was not tested at the time of construction, as this was not required.[3] Therefore, it is not possible to confirm the exact extent of degradation. However the shortfall in air permeability a year after construction is a disappointing result and smoke testing indicates a number of new leakage paths (cracks in sealant etc.) suggesting that a significant degree of degradation in performance is likely over the first year.

The final air permeability test was conducted on 27th March 2014, to provide further insight into the air tightness degradation over time. Access was arranged with both properties, but

[3] This was standard industry practice at the time of construction; however, current regulations now require all new-build properties to be tested on completion.

on the day, access was not possible for Property 3A. A second visit was arranged, but also aborted due to lack of access. The results for Property 5A show a 2% decrease in air permeability performance (from 5.37 $m^3/m^2/hr$ to 5.48 $m^3/m^2/hr$) over the 20 month period between the initial air permeability testing and the final air permeability testing. The results indicate that the either the majority of the performance deterioration occurred over the first year of occupation, or was present from construction.

Examination of air leakage paths during the testing showed clear evidence of degradation of window unit sealing & internal mastic sealing at window & wall/floor or floor/ceiling junctions which suggests that the air tightness will have degraded in the first year of occupation. Given the number of locations where degradation was identified, it is considered likely that a significant of the shortfall is due to degradation over time.

Key lessons are taken as follows:

- Settling of the building structure can have a major impact on building performance, and mechanically fixed solutions should be stipulated in specifications and design.
- Current standards require that all properties are air tested on-construction, so the specification of robust sealing methods (and the prohibition of methods prone to degradation) is seen as the key action.
- The developer should train their engineering team to understand methods used during construction and ensure vigilance on site to verify that the specifications are adhered to. Where mechanical solutions are used, the developer could specify that the air testing is undertaken before decorative sealing is applied (e.g. decorator's caulk/mastic along junctions) to ensure that the measured result represents a realistic long term value.
- Given the minimal shift in air tightness between 1 year post occupation and 3 years post occupation, Landlords could consider the inclusion of a re-visit after 1-2 years on all new-build properties to check and reapply sealant at junctions – both for aesthetic and energy performance reasons. The TGP tenancy agreement states that residents are responsible for dealing with shrinkage cracks, but tenants would not realise the significance of these in well-sealed properties. Mechanical fixings would avoid the issue entirely.
- Historically (e.g. in the Victorian era), designers/builders would design an overlap for junctions (e.g. wall-to-floor). Modern construction techniques typically use junctions that fit exactly, the fabric elements butting up to each other. Therefore, when there

is differential movement, the reduction in air tightness is greater and happens more easily. It could be argued that the construction industry should not see this reduction in air tightness as 'degradation', rather, it is more appropriate to view it as poor design and poor finishing.

- An air tightness 'Champion' whose role is to ensure air tightness standards are maintained during construction (especially for areas where multiple contractors might be involved, such as seals around plumbed pipes) and in-use phases, would be beneficial in a 'soft-landings' approach to construction.

- Taking a comprehensive "fabric first" approach gives confidence that fabric is stable before focussing on user behaviour – this is essential to eliminate as many variables as possible in an holistic approach to delivering on building performance.

During the site visit on 16th September 2013, the Verco team noted cracks around the sealant along the skirting boards and around the windows in the first floor steel bays, with a cold draft felt coming through. This has been highlighted with TGP as an issue for further investigation.

Smoke tests were conducted on 27th March 2014 during the second air permeability test, to provide additional detail. The following air leakage paths were observed at Property 5A:

- General leakage throughout (see photographs in Figure 3-1):
    - Wall-to-floor detail
    - Electrical outlets (ceiling roses and sockets)
    - Windows – corner details (very slight leakage)
    - Windows – mastic joint to plasterboard
    - Between joints in the floor boards (noticeable where no floor covering was present)
    - Movement cracks between the walls and ceilings
    - Movement cracks between the walls and windows
- Ground floor (see photographs in Figure 3-2):
    - Floor to wall junction – lifting lino in entrance lobby and family space
    - Personnel door to garage

    - Access to hatch to service void in WC

- First floor:
    - Bedroom 1 balcony door
    - Through bath panel
    - Plumbing penetrations to service void
    - Behind kitchen units

- Second floor (see photographs Figure 3-3):
    - WC penetrations to service void
    - Store cupboard to the void above stairs
    - Loft hatch (significant along hinged edge)

The leakage of air to service voids in the WCs indicates leakage in the building envelope and highlights that the general airtightness of the property is reliant on the internal finish (e.g. at plasterboard level) rather than solutions inherent in the building envelope. This is typical for traditional construction methods, however, in this instance, mechanically fixed solutions at the property envelope would clearly provide benefit in long term performance.

The key remedial actions suggested for Property 5A are as follows:

- The skirting board should be re-installed, ensuring the skirting sits flush with the floor level, not the lino flooring finishing level. Currently the skirting board finishes at the level of the lino, and the Mastic is sealed on top of the lino. This has resulted in the lino being able to come away from the floor very easily, which is a major issue for air infiltration.

- Investigate an improvement in the loft hatch insulation and sealing, as heat is currently being lost to the loft (the uninsulated space) unnecessarily.

- Investigate insulation and air tightness measures for the service hatch in WC. The solution here may not be clear-cut, since the air is lost to a service area, which is inside the building insulation envelope. There must therefore be a further leakage path in the building envelope. Improving the sealing of the hatch itself may be the most cost effective solution.

Figure 3-1: General leakage photographs

Leakage through shrinkage cracks

Leakage through shrinkage cracks

Leakage through shrinkage cracks

Leakage through floor joints

Leakage through shrinkage cracks

Figure 3-2: Ground floor leakage photographs

Leakage through personnel door

Leakage under skirting lifting floor covering

Significant leakage through WC access hatch

Figure 3-3: Second floor leakage photographs

Leakage through loft hatch

Leakage to void above stairs

3.4 U-value study

The U-values of the north-facing external walls of Property 3A and Property 5A were measured between the dates of 23rd January 2014 and 3rd February 2014. The results are presented in Table 3-4.

Table 3-4: U-value measurement results for Property 3A and Property 5A

Wall detail	Final averaged U-value W/m^2.K
Property 3A – North facing external wall	0.19
Property 5A – North facing external wall	0.12

The design U-value for the walls was 0.14 W/m^2.K (Code 5) and 0.21W/m^2.K (Code 3, rendered finish), which means that both properties performed better than expected by 0.02W/m^2.K. Anecdotal comments from Chris Knights, the BSRIA engineer, indicated that these were the best results he had seen, in terms of comparing design-stage U-values and in-situ results. This is an excellent result for the construction team. While testing of the roof, window and floor structures would be desirable to confirm the whole building envelope, the detailing of these elements is quite simple in design terms (mineral wool insulation in the loft, insulated floor slabs). The very positive result on the wall testing suggests that air leakage, system control and tenant behaviour are likely to be the main factors contributing to the excess heat demand in the properties.

3.5 Thermographic study

Thermographic studies of the properties at Property 3B, Property 3C, Property 3A, Property 5B, and Property 5A were conducted on 3rd February 2013.

All thermograms are included in the appendices (Section 11.1). The thermograms containing key anomalies are shown in the figures below:

- Property 3B (Figure 3-4): air leakage was noted from a first floor window. Anomalous temperature variations were noted through the ventilated cladding in the front of the property, as well as above the rear door.
- Property 3C (Figure 3-5): air leakage was noted from first and second floor windows. Anomalous temperature variations were noted through the ventilated cladding in the front of the property, as well as above the rear door, and on the underside of the rear bay.
- Property 3A (Figure 3-7): air leakage was noted from the window and door on the first floor.
- Property 5B (Figure 3-8): air leakage was noted from the window and door on the first floor. Localised heating anomalies were noticed at a window on the second floor. There was elevated temperature noted at the meter box.

Property 5A (

Figure 3-6: Property 5A thermography survey

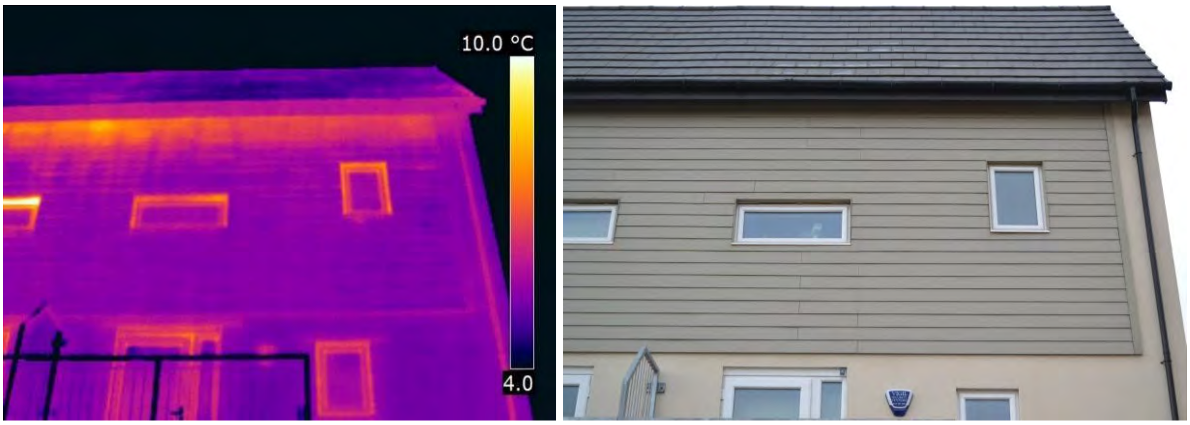


Image 31: Property 5A Front 2nd Floor. Observations: Elevated temperature at top of

cladding. Note: cladding is ventilated

-): Anomalous temperature variations were noted through the ventilated cladding in the front of the property

The key issues highlighted by the thermographic surveys are similar across the properties. These are summarised below:

- The air leakage areas highlighted from windows and doors should receive remedial action. TGP should send a contractor to site to readjust the setting of windows and doors, and check the sills for depressions. Air leakage around openings causes draughts and reduces comfort levels for tenants. This may influence behavioural choices on the level of heating, due to the sensation of reduced internal temperatures in the properties.

- The thermal anomalies seen in the meter boxes should be investigated. Although not a significant issue, it may be the case that as the cables pass into the properties, they are insufficiently insulated or air tight, acting as gaps in the thermal envelope of each of the properties. It is also possible

- The cause of the thermal anomalies seen in the façades of the properties is uncertain, but may indicate air leakage or heat transfer through the wall leading to warm air behind the cladding rising to the top, warming the cladding as it passes. It may be possible to remove the façades to investigate. However, this may not prove conclusive, and would be rather invasive. Remediation of known air leakage paths inside the property may alleviate the issue in a less invasive manner.

Figure 3-4: Property 3B thermography survey

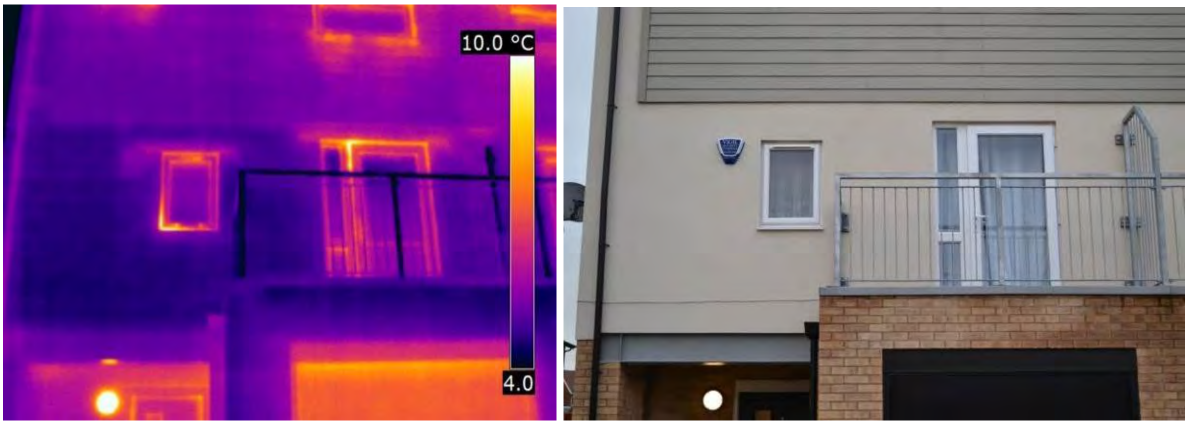


Image 2: Property 3B Front 1st Floor: Observations: leakage to bottom left corner of window and top left of door. Elevated temperature above door as door had been in use.

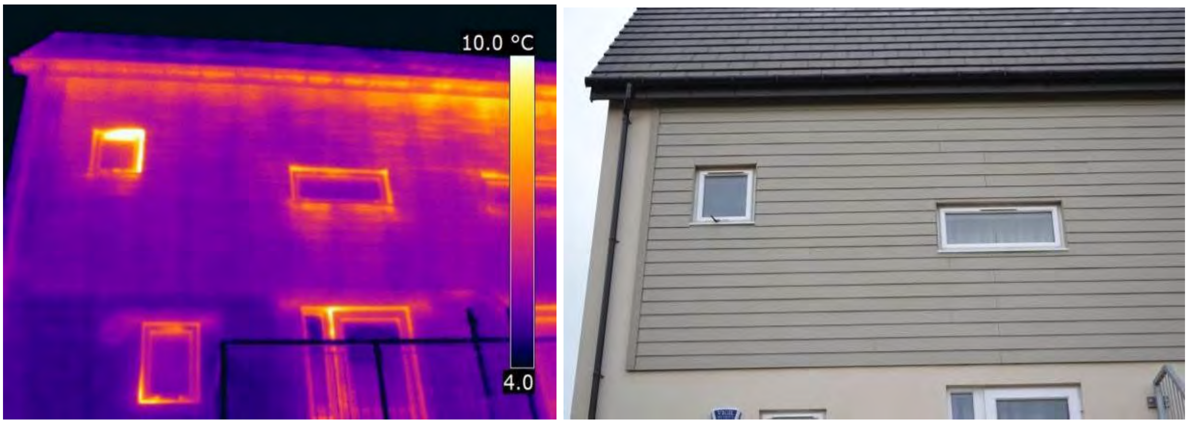


Image 3: Property 3B Front 2nd Floor. Observations: Elevated temperature at top of cladding. Note: cladding is ventilated. Potential leakage at window corners

Image 24: Property 3B Rear Bay (Underside). Observations: localised heating above door.

Figure 3-5: Property 3C thermography survey

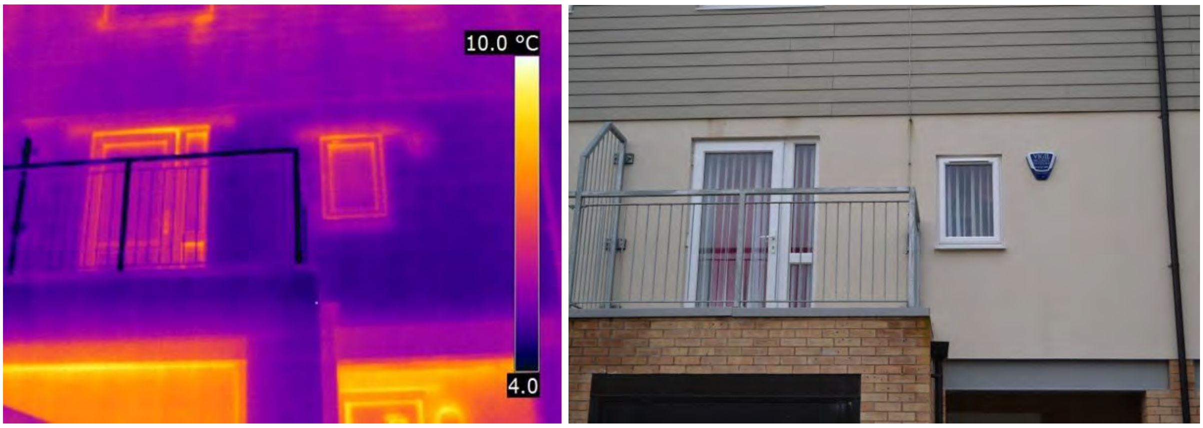


Image 5: Property 3C Front 1st Floor: Observations: Elevated temperatures above windows and door (door had been in use)

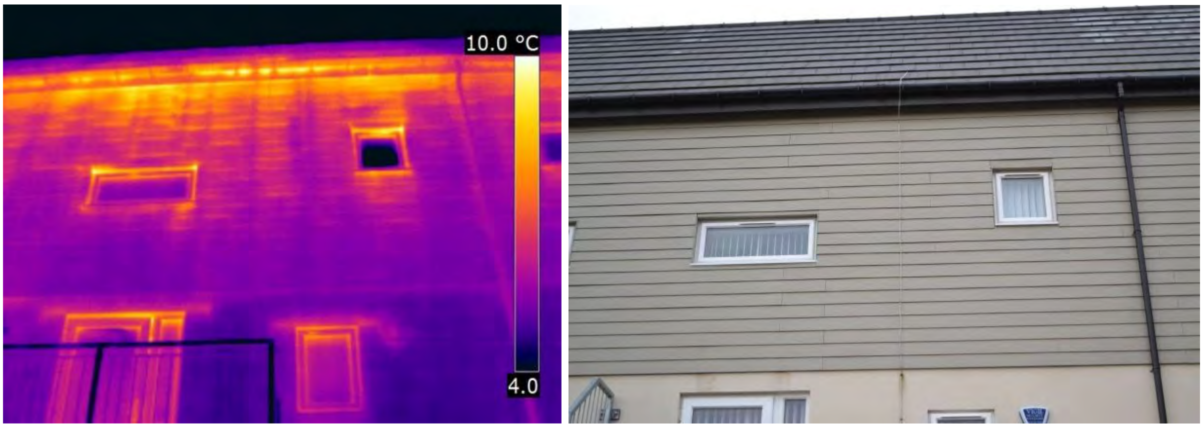


Image 6: Property 3C Front 2nd Floor. Observations: Elevated temperature at top of cladding. Note: cladding is ventilated. Potential leakage at window corners

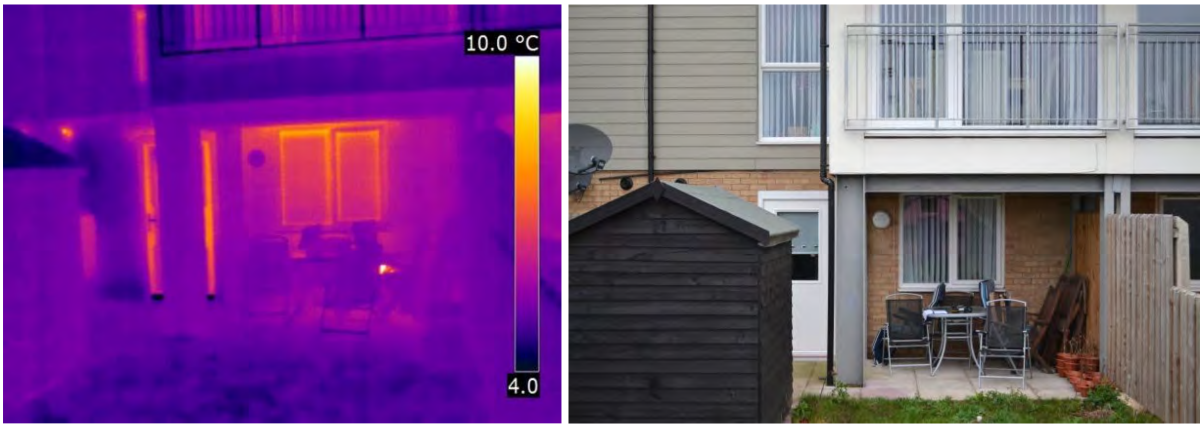


Image 13: Property 3C Rear Ground Floor. Observations: localised temperature elevation above window.

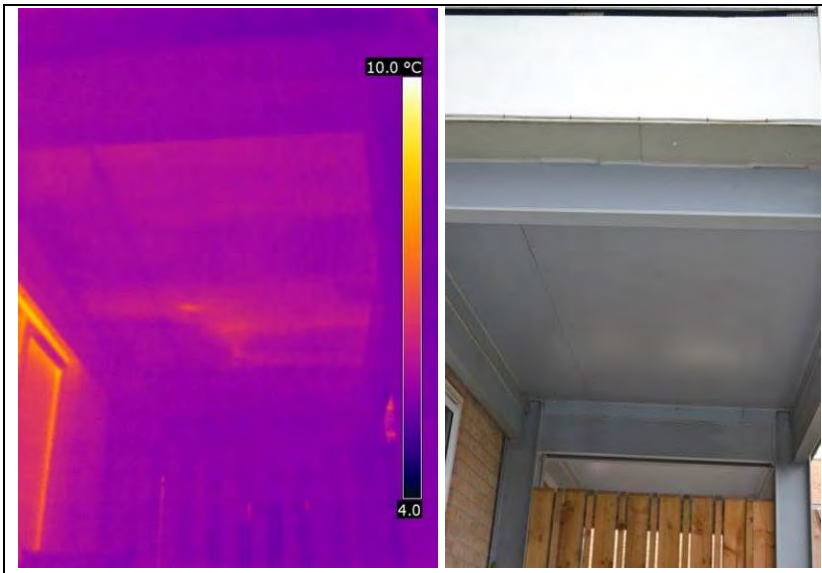


Image 25: Property 3C Rear Bay (Underside). Observations: Small anomaly at centre of panel.

Figure 3-6: Property 5A thermography survey

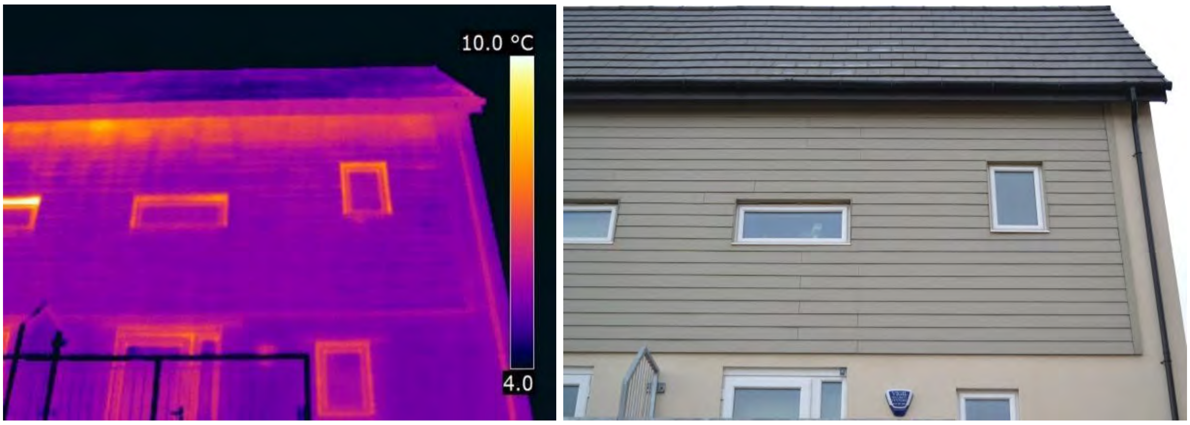


Image 31: Property 5A Front 2nd Floor. Observations: Elevated temperature at top of cladding. Note: cladding is ventilated

Figure 3-7: Property 3A thermography survey

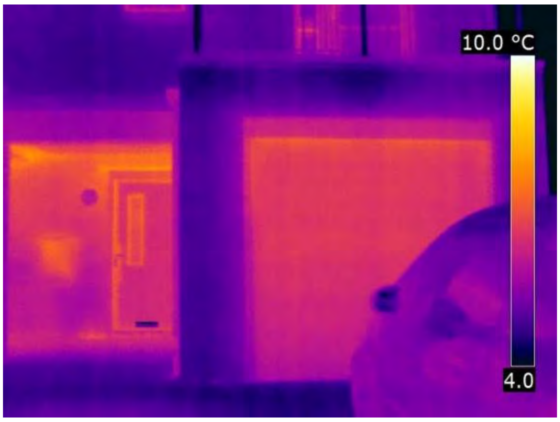


Image 7: Property 3A Front Ground Floor. Observations: Localised temperature elevation at meter box. Porch area temperature elevated, door had been in use.

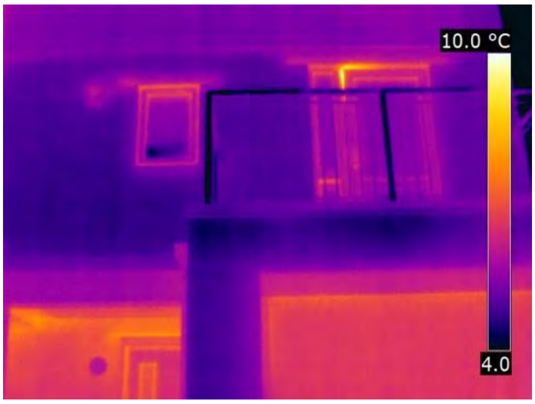


Image 8: Property 3A Front 1st Floor: Observations: Leakage at top left hand corner of door. Elevated temperature above window and door

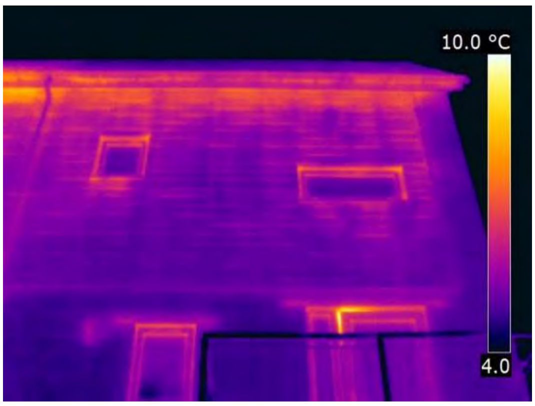


Image 9: Property 3A Front 2nd Floor. Observations: Elevated temperature at top of cladding. Note: cladding is ventilated

Figure 3-8: Property 5B thermography survey

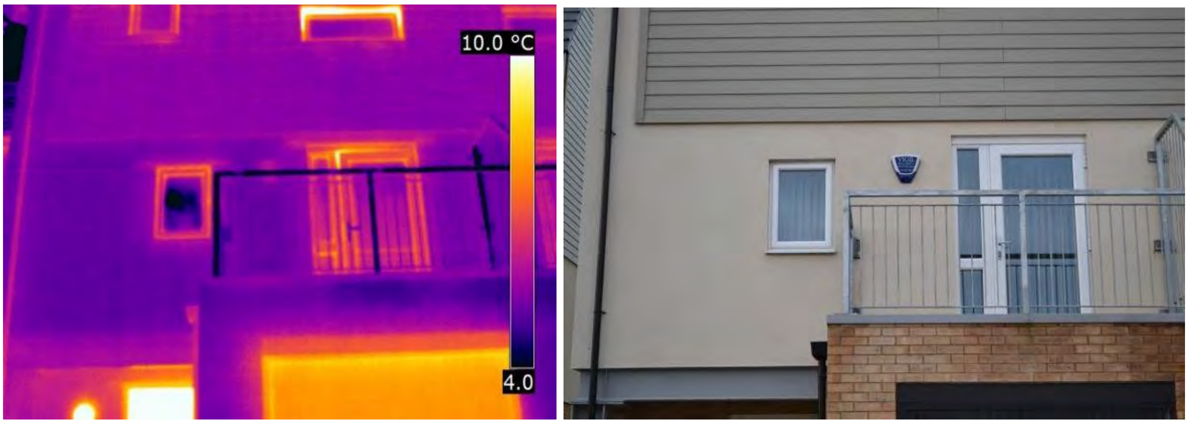


Image 27: Property 5B Front 1st Floor. Observations: Potential leakage at top left hand door corner.

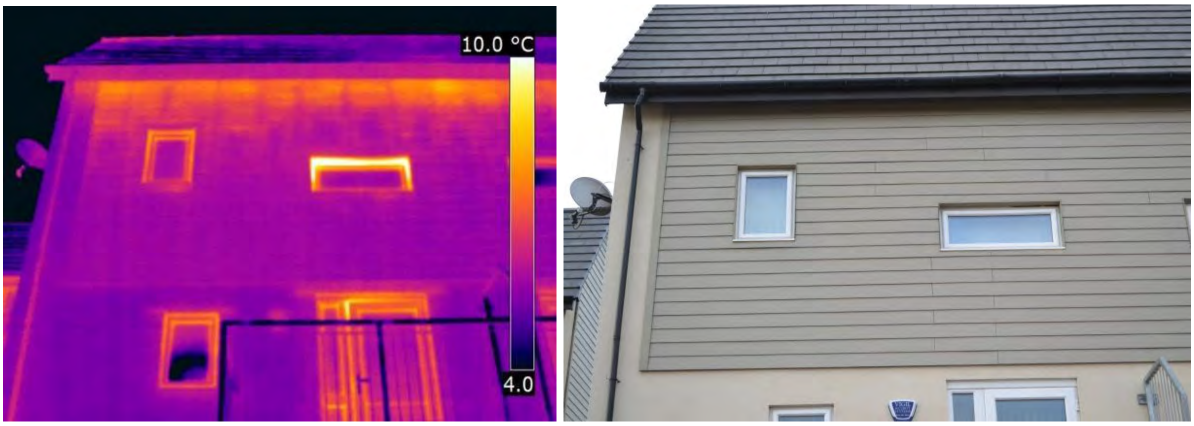


Image 28: Property 5B Front 2nd Floor. Observations: Localised heating at right hand window.

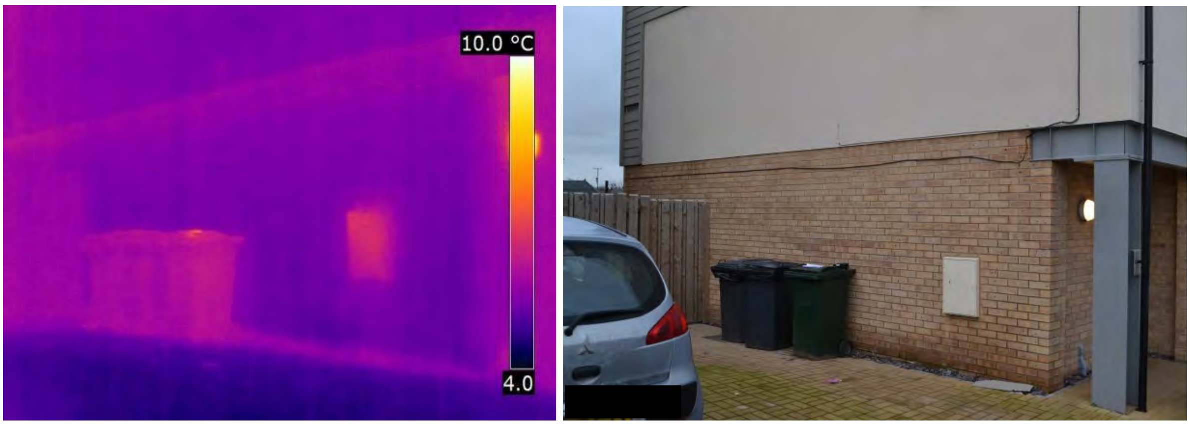


Image 38: Property 5B Side Ground Floor. Observations: Elevated temperature at meter box no other thermal anomalies observed

3.6 Conclusions and key findings for this section

MVHR: Issues were noted with the installation of the MVHR units in the loft spaces of the two properties tested. Excess lengths of flexible ducting were reported as a possible condensation trap; it is possible that a more detailed design approach could have minimised or eliminated this issue and yielded improved performance. It is recommended that the excess ducting is removed as soon as possible to avoid further complications, such as damp or mould. In future, TGP should ensure that their snagging team are trained properly to understand snagging issues in the context of MVHR commissioning, as this should not have been overlooked during the original commissioning process.

Key conclusions from the testing were as follows:

- Both properties presented significant variations from the target ventilation rates required under the building regulations. However, mandatory on-site flow rate testing was only introduced in Building Regulations Part F 2010.
- The general trend was for insufficient ventilation at the constant ventilation rate for the MVHR units – this was particularly evident in the air supply ventilation in both properties, and in the partial assessment of extract at Property 5A. This is a major concern for the property – in the event that air tightness targets are met & maintained, this could lead to mould formation, health issues and poor air quality.
- On closer inspection, the supply & extract rates to individual rooms showed a wide variation from substantial over-ventilation to severe under-ventilation. It should be noted that under-ventilation can lead to mould formation, so a re-commissioning should be undertaken by TGP.
- The cause of the deviation from design targets is likely to be due to a combination of distribution and terminal issues (i.e. poor commissioning, tenant interference with unlocked terminals, excess resistance in certain air pathways), and a central issue (i.e. main unit fan underperformance, or excess ductwork in loft space not accounted for in the design).
- Terminal vents supplying air to the rooms in the property had not been locked off – presenting a tampering risk.

Air tightness: When tested at the start of the project period, both Code 3 and Code 5 properties presented poorer air tightness values than the design target. As neither of these properties was tested at the time of commissioning, it is not possible to confirm whether there has been significant degradation as they weren't tested previously in the first year of occupation. Tenants in the Code 5 property reported poor sealing and drafts around the patio door at the rear of the ground floor, which is one factor that will have affected the air tests. Smoke testing was conducted at Property 5A, and the results show that there are a range of areas where significant air permeation and draughts occur (as shown in Figure 3-1, Figure 3-2, and Figure 3-3). Very little degradation in performance has occurred between the initial testing and the final testing, so it is advised that remedial action is taken & any degradation is noted to have occurred in the first year of occupation.

It is noted that both properties are currently experiencing relatively high air change rates through fabric air permeability, even before the MVHR systems are accounted for (in the range 6-10 air changes per hour). On a whole-house basis, ventilation rates are currently likely to be more than sufficient to ensure indoor air quality across the whole property without the need for further supply air provided by the MVHR units (though relatively sealed rooms, such as the bathroom, are likely to have insufficient local ventilation rates). This raises the question as to whether the presence of MVHR as a central system is currently a benefit in these properties, compared to the specification of intermittent extract fans for essential ventilation to WC's and kitchen (or localised units with heat recovery incorporated). Remediation of air tightness issues would require MVHR to be re-commissioned as a priority action; and action to ensure extract rates in wet rooms are adequate is considered essential.

The key remedial actions suggested for Property 5A are as follows:

- The skirting board should be re-installed, ensuring the skirting sits flush with the floor level, not the lino flooring finishing level.
- Investigate an improvement in the loft hatch insulation
- Investigate insulation and air tightness measures for the service hatch in WC.
- Consider remedial work to sealing at floor/ceiling, floor/wall, and window units. Also consider scheduling this in routine maintenance of new build properties in the 1-3 year time period.

  TGP should consider implementation of these measures across the similar properties on the development)

U-value study: The design U-value for the walls was 0.14 W/m^2.K (Code 5) and 0.19-0.21W/m^2.K (Code 3, depending on external finish), which means that Property 5A performed a little better than expected, whereas Property 3A performed equal to or a little better than expected. The results were considered excellent by the testing engineer.

Thermographic study: The results of the thermographic surveys for Property 3B, Property 3C, Property 3A, Property 5B, and Property 5A are broadly positive. However, three issues are similar across a number of the properties. These are summarised below:

- The air leakage areas highlighted from windows and doors should receive remedial action. TGP should send a contractor to site to readjust the setting of windows and doors, and check the sills for depressions. Air leakage around openings causes draughts and reduces comfort levels for tenants. This may influence behavioural choices on the level of heating, due to the sensation of reduced internal temperatures in the properties.
- Lovell has confirmed that the meter boxes do not penetrate the insulation layer in either property type. Although the observed heat loss is not a significant issue, it may be the case that as the cables pass into the wall cavity/envelope of the properties, some air leakage is present into the meter box. However, it is also possible that the electricity meters themselves are generating a little heat (as two additional devices were installed for the logging equipment) which is sufficient to register on the thermal cameras. If it were the former, the impact on building energy consumption is expected to be minimal, but this leakage path should be considered in future if designing the property to achieve air tightness at the building envelope.
- The cause of the thermal anomalies seen in the façades of the properties is uncertain. It may be possible to remove the façades to investigate. However, this may not prove conclusive, and would be rather invasive. The anomalies could be caused by a build-up of heat conducting through the wall and rising behind the ventilation area of the cladding

4 Key findings from the design and delivery team walkthrough

4.1 Introduction

Property walk-throughs and semi-structured interviews with the design team were carried out on Weds 13th June 2012 for the Code 3 and Code 5 properties. The findings of these investigations are presented below; the format proposed in TSB's guidance documents has been adopted.

4.2 Code 5 Properties

- The heat pump/SHW solution for heating and hot water was observed to be complex, involving six separate controllers and complex plumbing arrangements that could only be explained by the plumber who installed the unit (one for the heat pump, two zone thermostats, and three for the UFH which were not deemed to be particularly intuitive).

- The steel framed bay was again identified as a challenging element in construction – there is a slight mismatch in floor levels in the bay and main building to allow for contraction of the wood frame which should gradually subside, but is noticeable.

- MVHR controls were also considered to be poor in terms of usability, with four buttons marked 1, 2, 3, 4 – but no indication of what each setting means or LED indicator to indicate which mode is currently active.

- There is a concern regarding future maintenance of the heat pump, MVHR, and renewables systems. It was not clear that a suitable maintenance regime was in place for these systems, or sufficient information on site for an engineer to understand them. This was borne out when an engineer was called out to inspect the SHW system and reported it repaired – but the system remained non-operational. A simple maintenance schedule & system description should be requested by TGP as part of the handover package to combat this.

- The North elevation of the property was noted to offer poor daylighting, especially in the upstairs bedroom; conversely the south elevation is very well day-lit and pleasant. This is a feature of the passive solar design but does affect the feel of the rooms on the Northern elevation.

- The selection of heating technology was driven by SAP requirements and methodology. It is possible that a simpler solution was available

- (either a simpler heat pump arrangement or gas boiler) – but that the simpler solution 'failed' to be selected because of specifications in the methodology of SAP 2005. The updated SAP 2009 methodology would allow a simpler solution to be compliant, such as a combined gas boiler and PV system.
- A full review of all the controls, their current settings and instructions for tenants would be useful.

4.3 Code 3 Properties

- These properties have a much more straightforward servicing arrangement. The heating and hot water is controlled by a single controller and two room thermostats. However, the MVHR suffers the same poor user control as the Code 5 units.
- While the rear steel bays on these properties are connected to a traditional construction and therefore should not be subject to the same degree of movement as in the Code 5 units, similar construction issues (cranage required, junction detailing etc.) were encountered during the construction stage.

4.4 Conclusions and key recommendations for this section

There are a couple of common items across the two property types identified during the design walkthroughs which are likely to directly affect the performance of the properties, and also common issues which have come up as a maintenance issue during the defects period.

- Rear steel bays – complex to design, detail and construct, especially on the wood framed Code 5 properties. These also have a large amount of glazing; although solar shading is in place it will be interesting to see how this impacts on the internal temperatures and how the air tightness of the property changes over time.
- Heating zoning and controls – both properties have opted to use the property in a different manner to the intended layout, resulting in the actual use of rooms on bedroom and living area heating circuits being mixed up, hence bedroom heating timers cannot be set differently to the living areas – this is likely to lead to tenants heating the whole property to the same schedule and target temperature. The original intended layout was specifically designed so that the properties would achieve accreditation under the Lifetime Homes scheme. This accreditation results in an additional 4 credits under the Code for Sustainable Homes, allowing the scheme to achieve a Code for Sustainable Homes Level 5, as required by TGP. This result

highlights that, for some properties, there is a conflict between regulatory (Code and Lifetime Homes requirements), and real-life preferences. A review of the requirements of Lifetime Homes should include this consideration. For future developments, if the heating sub-circuits were further divided on a room-by-room basis, this could help avoid the unexpected mixing of the heating sub-circuits experience here.

- Services strategy in both cases was led by calculations to identify least cost options using SAP 2005 and changes in SAP 2009 would almost certainly lead to a different solution, especially for the Code 5 properties. This is illustrative of a case where regulation has favoured what may not be the best long term low energy solution in operational terms (e.g. the very complex heat pump/SHW/PV solution on the Code 5 property, selected primarily as a result of the relatively low carbon emissions factor for electricity in this version of SAP).
- Handover issues were noted in both homes – this is covered in more detail in the subsequent tenant interviews and walkthrough section of this report.
- MVHR systems were not correctly allowed for in the properties future maintenance plan. We would suggest that annual maintenance is aligned with the mandatory annual boiler safety check or similar. When constructing new properties a maintenance schedule should be included as part of the tender package, whereby the designer specifies maintenance intervals for all fixed services.

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

5.1 Introduction

The occupant evaluation process comprised:

- A BUS survey for each of the properties (Property 3B, Property 3C, Property 3A, Property 5B, and Property 5A)
- Interviewing the tenants of Property 3A, Property 5B, and Property 5A
- A walkthrough with the tenants of Property 3A and Property 5A

5.2 BUS survey findings

The BUS survey was initially issued to the four study dwellings, plus one additional Code 3 property which had the same layout as the two study dwellings. Of these properties, only three responses could be obtained (both Code 5 properties and one Code 3) so follow-up calls were required to boost uptake to five properties.

Within the BUS methodology, there are 4 summary variables. This project achieved the highest ranking in the domestic BUS surveys carried out, at the time of analysis, for three of these variables, which is a very positive reflection on the project's outcomes. The variables are as follows:

- BUS Summary Index
- BUS Satisfaction Index
- BUS Comfort Index

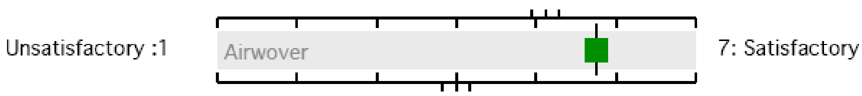
Underpinning these summary variables, there are 10 overall variables. This project has received the highest tenant satisfaction score for 6 of these variables. The variables are as follows:

- Air in summer: overall
- Air in winter overall
- Comfort: overall
- Needs

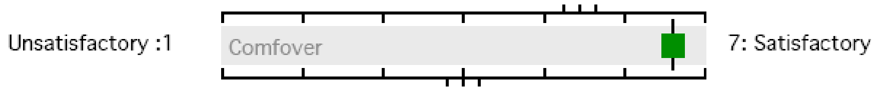
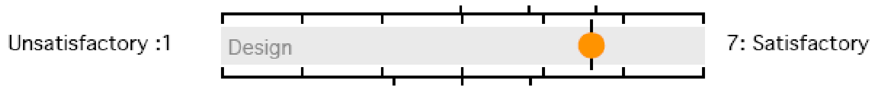
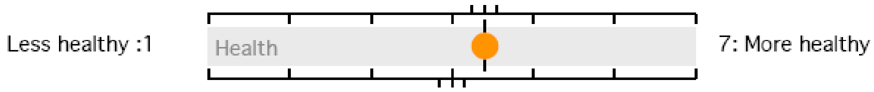
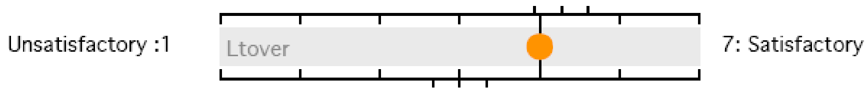
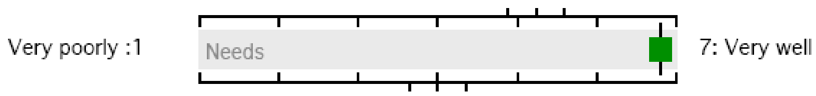
- Noise: overall
- Temperature in winter: overall

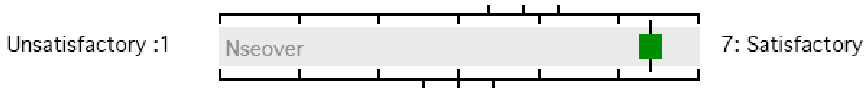
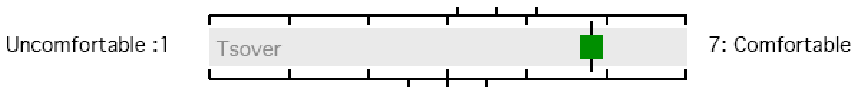
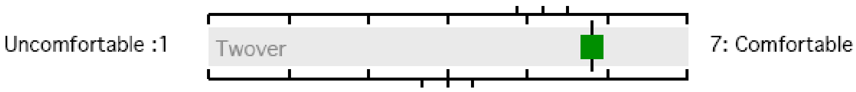
These are discussed in Table 5-1, and a further discussion of all of the evaluation variables is included in section 13.3. [4] An explanation of how to read the slider graphs in Table 5-1 is included in section 13.3.

Table 5-1: BUS survey results summary sliders

BUS survey category	BUS survey analysis
Air in summer: overall	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result in comfort terms. • It is however noted that permeability falling short of the design target will result in increased fresh air rates – good for freshness but contributing to increased winter heat load. • The reduced MVHR flow rates have resulted in tenants feeling the air is a little still. • The tenants have felt that the air is dry in the summer; this may be caused by the Code 5 properties both being mechanically ventilated. Current industry feeling is that MVHR systems cause dry air. Retrofitting a humidity device could help to combat this issue.
Air in winter overall	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project, but note comments above regarding air tightness and MVHR flow rates.

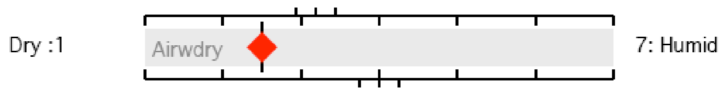
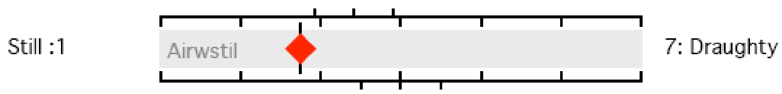
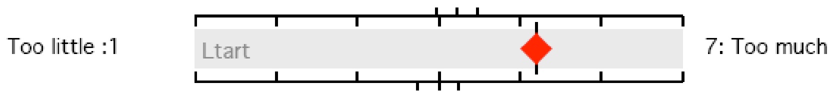
[4] Full results may be found online, at: http://portal.busmethodology.org.uk/Upload/Analysis/ffyv5cmc.s4j/index.html

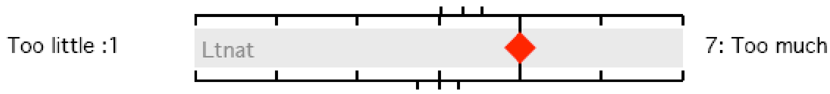
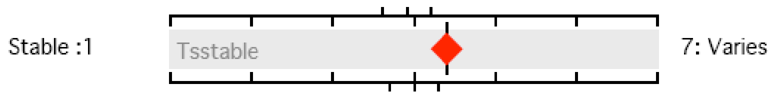
Comfort: overall	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project, and reflects both the spacious design and the ability of the building services to deliver comfort conditions, despite confusion over controls (especially in the Code 5 units).
Design	 Discussion: The results are at the upper end of the standard range reflecting the attractive architectural design and spacious nature of the properties.
Health (perceived)	 No significant comments on this value.
Lighting: overall	 Discussion: The results are at the lower end of the standard range • The tenants felt there was too much light from artificial light (dimming lights, or the fitting of lower wattage lamps, would offer a solution to this problem). • There was also perceived to be too much natural light. The tenants may be referencing excessive glare, which can be a common issue with large windows. If this is the case, the installation of glare reduction coatings to the windows would help.
Needs	 Discussion: The results show the highest levels of satisfaction from the BUS results database. Due to the storage space and services design, the tenants' needs are met very well.

Noise: overall	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. Custom design was undertaken to reduce noise transference between adjacent properties and these results reflect this attention to detail. The properties are also located at the edge of the estate.
Temperature in summer: overall	 Discussion: The results show the second highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project, and indicates that the MVHR, openable windows and solar shading are generally functioning effectively in reducing solar gain and purging excess heat via air flow; although excess temperature variation in summer was identified by respondents as an area of concern.
Temperature in winter: overall	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project, and indicates that the heating design is very effective in terms of meeting heat losses, despite the confusion the Code 5 tenants had regarding heating controls. However, the monitored energy data indicates that comfortable temperatures are being delivered at a high energy use and cost to the tenants in three of the four properties. Note the efficiency of the heating systems is addressed in Section 7 of the report.

There are a number of important points that can be learned from a deeper investigation of the BUS survey results as there are some variables that perform poorly in comparison to the scheme-wide results. The slider bars for each variable are included in section 13.3. However, to highlight the negative results from the BUS survey findings, the results that fall within the lower quintile of the BUS data set have been included in Table 5-2, below.

Table 5-2: BUS survey – negative results sliders

BUS survey category	**BUS survey analysis**
Air in summer: dry/humid	 Discussion: The results fall within the lower quintile of the BUS data set, showing that the properties are too dry during the summer. This may be caused by the Code 5 properties both being mechanically ventilated. Industry evidence shows that MVHR systems can cause dry air. Retrofitting a humidity device could help to combat this issue but this increases energy consumption and is one step closer to domestic air conditioning.
Air in winter: dry/humid	 Discussion: The project received the lowest results from the BUS data set, showing that the properties are too dry during the winter. The Code 5 properties are both heated to a relatively high temperature all day, all year round which could lead to dry air in these properties. Internal winter temperatures in the Code 3 property being monitored are not excessive, hence this may be a less significant factor. The MVHR may also be contributing to the dry air feel – this is a common issue.
Air in winter: still/draughty	 Discussion: The results fall within the lower quintile of the BUS data set, showing that the air within the properties is too still during the winter. Closed windows in winter, and the shortfall in MVHR air flow rates could explain this issue.
Lighting: artificial light	 Discussion: The project received the lowest results from the BUS data set, indicating that there is too much light from artificial sources. Dimming lights would offer a solution to this problem.

Lighting: natural light	 Discussion: The project received the lowest results from the BUS data set. There was also perceived to be too much natural light. The tenants may be referencing excessive glare, which can be a common issue with large windows. If this is the case, the installation of glare reduction coatings to certain windows, or a reduction in window size would help.
Temperature in summer: stable/varies	 Discussion: The project received the lowest results from the BUS data set, showing that the internal temperature varies too much in the summer. This is likely to be due to the large area of south facing windows causing temperature spikes during certain periods when gains are high. It is recommended that shading measures are introduced, and incorporated at the design stage for future developments.

In summary, issues behind the lowest scoring topics in the BUS survey results are all likely to be as a result of issues that are experienced commonly:

- MVHR drying the air to uncomfortable levels
- Glare from the large south-facing windows

The large areas of south-facing windows were specifically designed to maximise solar gain and make the most of the great south-facing views from the edge of the estate. However, it seems that the correct balance has not been achieved for these tenants. This may be caused by the contrast created by the low lighting levels in the north side of the property, and the brightness of the south-facing side. Indeed, lighting was the largest issue highlighted by the BUS surveys, as the natural lighting variable, and the artificial lighting variable both received the lowest scores when compared to the scheme-wide BUS survey results. Anecdotal feedback from the tenants suggested that the light fittings enforce bulbs to be installed which were too bright. Further to this, the bulbs required are energy efficient, and are seen as being a large capital expense (regardless of lower lifetime running costs). This issue may be being reflected subconsciously in these results. A more clear explanation to the tenants that the type of light bulbs required will be cheaper to run in the long-run would help to avoid this issue. However, low wattage versions should be available to reduce the light levels in the building.

Comments from tenant interviews suggest that tenant's disappointment with "gloomy" rooms on the northern façade may be the cause of this negativity, as the bright spaces to the southern elevations were generally well received. The large variation between the natural light levels on each side of the property accentuates the feeling of gloominess when moving from the southern side of the property to the northern one and glare when moving in the opposite direction.

5.3 Occupant walk-throughs and interviews

Two property walk-throughs and three semi-structured interviews were carried out on 13 June 2012 for both the Code 3 and Code 5 properties. Interviews were carried out in both Code 5 properties but only one Code 3 property due to time constraints; one walkthrough was carried out on each one. The findings of these investigations are summarised below; the section headings provided in TSB's guidance documents has been adopted.

5.3.1 Code 5 properties (Interviews in Property 5B and Property 5A and walkthrough of Property 5A)

The interviews in the Code 5 properties were particularly informative, as the tenant in one property was both technically and energy aware but the occupants of the second were much less informed in this area. A picture could therefore be generated of the range of responses that could be expected to the technologies installed.

- Tenants in both properties report broadly similar energy bills in the range of £1,000-£1,400 per annum. These are high considering the intended energy efficiency of the properties. (Note: Year 1 monitoring results suggest even higher bills in Property 5B of around £3,000; this is under further investigation)

- Lack of tenant friendly information at handover is an obvious issue. One tenant did a lot of their own research to understand the systems including downloading instructions for some items from the internet. The other tenant had a relatively poor understanding of their controls, in particular heating controls. Face-to-face demonstrations of all heating, hot water, ventilation controls would be welcomed as well as fault checks on PV system, solar hot water and heat pump, as well as a layman's instruction guide to all controls for easy reference. TGP requested demonstrations, and these were offered by Lovell, but provisionally agreed dates fell through on several occasions. During the course of the study a demonstration was provided when the tenants in Property 5A changed (early in year 2). However this was essentially an ad-hoc process and the technical representative who attended (from the plumbing contractor who installed the heat pump) was not carrying copies of the instructions for the controls. A clear specification for this process is required and the developer must press this as a high priority action in order to ensure proper understanding for tenants.

- The complexity of the heating/hot water system has already resulted in some confusion when the tenants have had to request maintenance to be carried out. One tenant has mastered most of the control systems but hasn't adjusted the UFH controls as "it's warm on the ground floor" and they were advised to leave them be. The other tenants had their controls set for them by the plumber and left them alone. This significantly limits the ability of tenants to take action to reduce energy consumption given that hot water and heating are a major component of energy demand in the properties. The less energy aware tenants were unable to achieve satisfactory operation with the information provided and would be unlikely to notice if PV, solar hot water or RWH systems failed. This is a critical issue. Checks of these systems should be included in annual maintenance schedules when the MVHR filters are changed.

- Due to the three-storey nature of the property, less able tenants may struggle to answer the door within a reasonable time period, before the visitors have left. Consideration should be made for the inclusion of an intercom or other measures if the property is likely to be occupied by the less able.

- Poor daylight in the top floor bedroom was noted by both sets of tenants

- MVHR noise was pointed out in one property and it was very noticeable – perhaps sufficient to disturb sleep. This could be due to poor commissioning. There are a number of potential solutions to this issue:

    - The system could be re-commissioned to try to re-balance the system

    - An attenuator could be included or duct length increased (at a cost to efficiency).

In the other property the tenant was unaware of the purpose of the MVHR and often opened windows for ventilation – this could have been avoided with proper handover advice.

- Comments from one tenant indicated that the lighting in the downstairs hallway cannot be switched from the first floor – so they leave a lamp on in the hall for when they need to go downstairs at night.

5.3.2 Code 3 property 3A (walkthrough and interview)

- There was a lack of useable information/demonstrations on operation of the property at handover – as with the Code 5 properties. No maintenance schedule proposed for the MVHR system. It is recommended that detailed handover sessions are conducted with the tenants, (which must be prioritised by & confirmed as having occurred by TGP) and user-friendly guides are issued, so that the tenants may refer back to them in future.

- The tenant was again unaware of the function of, or controls available for the ventilation system resulting in excessive use of windows for ventilation (making 2 of 3 properties with tenants not understanding MVHR). Also the tenant only became aware of the RWH system being present when maintenance was called to respond to non-flushing toilets.

- Again the tenant reported high bills which will be investigated further during the monitoring phase of the project. The property has high occupancy throughout the day and likely high hot water consumption and appliance electricity use. It has been noted on more than one visit that appliances such as TV’s have been left on with no one using them, plus windows left open during the heating season – so it is possible that “good housekeeping” measures may offer significant savings.

5.4 Common issues between both property types (Code 3 and Code 5)

- All three properties were using the top rear room (intended to be the living room) as a bedroom, and the master bedroom as the living room. This mixes up the intended bedroom/living area split on the heating circuits and prevents tenants from controlling these areas independently. Generally, it was felt that the room originally designed to be the lounge would have been too small to be used for this purpose. For a family home, tenants stated that it is more practical to have the lounge and kitchen together on the middle floor and bedrooms grouped together on the same floor (mimicking the “typical” setup seen in most existing 2 storey houses). Design decisions had been made to comply with Lifetime Homes in the code 5 properties;

however, as shown here, Lifetime Homes may require layouts that are inappropriate for more able bodied users of a property.

- Lack of tenant friendly handover information and demonstrations. It is essential that detailed handover sessions are prioritised by TGP and conducted with the tenants. User-friendly guides are required, so that the tenants may refer back to them in future.
- More than one property has reported issues with toilets flushing. This appears to be linked to the RWH systems. The tenants had no awareness of these systems on moving in and only became aware of their presence when problems occurred and engineers were sent out. Investigations indicated that only one of the downpipes feeds the RWH (the other feeds the water butt) so it may be that the mains top up function is unreliable and the amount of rain water collected is insufficient to meet the need throughout the year. It is recommended that an engineer is sent to site to investigate this issue further, and correct it if possible. TGP should undertake the recommendations from the site visit.

5.5 Conclusions and key findings for this section

The results from the BUS survey differed from those collected during the interviews, and walkthroughs of the properties. GNC suspects that this may be due to the tenants not engaging fully with the survey due to 'survey fatigue'. The BUS survey responses were generally more positive than the results from the interviews and walkthroughs. This is may be due, in part, to the ability to tease-out specific items when discussing issues in person. Furthermore, general questions are more likely to illicit a positive response, whereas specific questions typically receive more negative responses.

In general, the tenants are happy with the quality and look of their homes. In terms of the technologies though, there is an indication that there has been a disconnection between the design of the properties, and the way that they are used in practice – especially in the Code 5 units. In terms of the use of space, it was felt that the room originally designed to be the lounge would have been too small to be used for this purpose. For a family home with able bodied occupants, tenants stated that it is more practical to have the lounge and kitchen together on the middle floor and all the bedrooms on the same floor – opposing the lifetime homes requirements requiring the master bedroom to be on the first floor in the code 5 properties. In term of energy efficiency, the technologies that are intended to reduce energy consumption are, in general, not used effectively because of their complex design, and the lack of sufficient training and engagement with the tenants. This has resulted in higher energy consumption and energy bills than expected in the majority of cases, along with general confusion (see Section 6 for further detail on monitored performance).

From an ideal perspective, in the Code 5 units a simple central “system health” panel with warning lights linked to each of the technologies would make fault identification much easier for tenants and assist with maintenance response. The tenants are unlikely to notice a failure of the PV or SWH systems due to their relatively inaccessible location, so unless main heating/hot water/electricity services are disrupted these faults could go unnoticed for extended periods.

6 Monitoring methods and findings

6.1 Introduction

The monitoring plan includes two properties which are monitored in a very high degree of detail (one Code 3 and one Code 5 – Property 3A and Property 5A, respectively), and two which are monitored for utilities only (again one Code 3 and one Code 5 – Property 3B and Property 5A, respectively). This allowed us to carry out detailed investigation of property performance on each house type while also having an identical comparator for whole building energy use. The monitoring kit installed in each property is summarised in the Appendix, section 13.3).

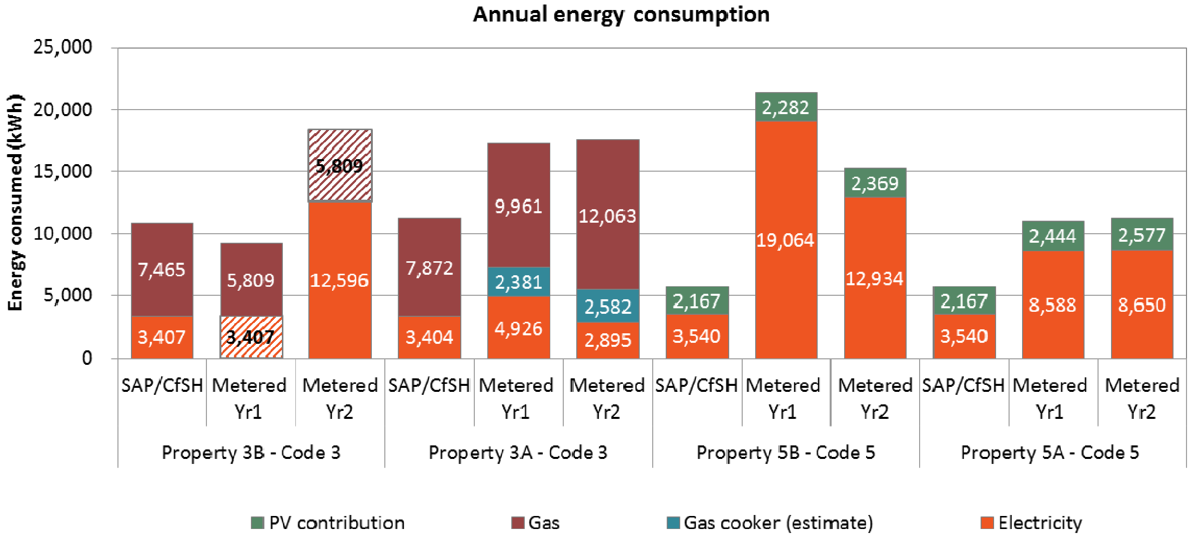
6.2 Energy performance

The overall building energy consumption is shown in Table 7-1 andFigure 6-1: Annual energy consumption - comparison of SAP/CSH prediction against monitored data.

Table 6-1: Annual energy consumption - comparison of SAP/CSH prediction against monitored data (kWh)

	Property 3B - Code 3			Property 3A - Code 3			Property 5B - Code 5			Property 5A - Code 5		
	SAP/CSH	Metered yr1	Metered yr2	SAP/CSH	Metered yr1	Metered yr2	SAP/CSH	Metered yr1	Metered yr2	SAP/CSH	Metered yr1	Metered yr2
Electricity	3,407	3,407	12,596	3,404	4,926	2,895	3,540	19,756	14,168	3,540	9,018	10,062
Gas	7,465	5,809	5,809	7,872	9,961	12,063	n/a	n/a	n/a	n/a	n/a	n/a
PV total generation	n/a	n/a	n/a	n/a	n/a	n/a	2,167	2,282	2,369	2,167	2,444	2,577
PV export	n/a	n/a	n/a	n/a	n/a	n/a	n/a	346	617	n/a	215	706

Figure 6-1: Annual energy consumption - comparison of SAP/CSH prediction against monitored data



Note: for simplicity, electricity consumption for the Code 5 properties has been presented in a manner consistent with SAP carbon emissions[5]

From these, the following initial conclusions have been drawn.

Property 3B

In year 1, this property performed better than expected by SAP predictions in terms of gas consumption. This calculation includes gas consumption for cooking, as calculated within the Code for Sustainable Homes (CSH), which may exaggerate the good performance of this property. The good performance of the gas consumption of the property could be due to tenant behaviour – such as under-heating or minimal gas use for cooking. However, in year 2, no gas consumption data was available due to metering issues. In year 2, the newly-installed electricity monitors showed exceptionally high electricity consumption for this property, when compared to predicted SAP consumption. Unfortunately, this property has received minimal investigation besides the energy data monitoring in the BPE project (acting as primarily as a comparator for property 3A), and issues were experienced with tenant engagement. As such, there is little available data to cross reference against to determine

[5] From an energy demand perspective, SAP is essentially blind to whether renewable electricity is used on site. When calculating energy costs, SAP assumes 50% of PV energy generated is used on site; for carbon, credit for carbon reduction is assigned to all energy generated from the PV, and deducted from the total carbon associated with energy demand. We have presented the energy consumption in the same way as the carbon emissions – i.e. the sum of the electricity consumption and PV generation is the building's electricity demand; in reality the tenant is actually billed for slightly more electricity than that presented here.

whether this electricity consumption is an accurate representation of consumption. A review of the daily pattern of electricity use showed no immediate evidence to explain usage at this high level although regular peaks in consumption of around 3-4kW throughout the day are unusually high for a gas heated property. TGP are following up with the tenant to attempt to verify the energy use and assist the tenant in identifying energy efficiency solutions if the high consumption is verified.

Property 3A

In year 1, this property demonstrated significantly poorer performance than design predictions, in both gas and electricity consumption. Closer examination of the monitoring results and occupancy leads to the following interpretation:

- High use of the immersion heater for hot water generation (1,470kWh) in the first part of the year was a major factor in the electricity use. The remaining electricity use was then in line with SAP predictions, despite the property’s high occupancy of 7 people compared to SAP assumptions of only 2.8. The tenant reported that they are active in switching items off, and had key meters installed in order to keep closer controls on their energy spend, so this ties in with anecdotal evidence. During year 2, the electricity consumption was 41% less than year 1. This was mostly due to the correction of the controls set up, reducing the use of the immersion heater – again highlighting the critical importance of commissioning and tenant education.

- In year 1, the hot water use was significantly higher than predicted by SAP – by around 40%. Given the high occupancy, this is unsurprising.

- In year 1, heating consumption was higher than SAP predictions by around 40%. This is surprising given the high occupancy & corresponding heat gains, but correlates with anecdotal evidence. The tenant was unaware of the presence of the MVHR system or its boost function and opened windows for kitchen ventilation. 6 The measured air permeability of the property was also poorer than the target by over 50% at the start of the monitoring period. Tenants were also in the property at all times, so the SAP assumed heating pattern would be overly conservative. Measured performance of the boiler also suggests that it was underperforming when compared to SAP (76% vs.

[6] This is a classic problem, and highlights the ease of which the design intentions of MVHR can be undermined by inadequate tenant knowledge. Further tenant engagement, user-friendly guidance documents, and handover meetings are recommended to overcome this.

91% expected) which would increase the gas consumed for a given amount of heat delivered. In year 2, (non-cooking) gas consumption further increased by 21%.

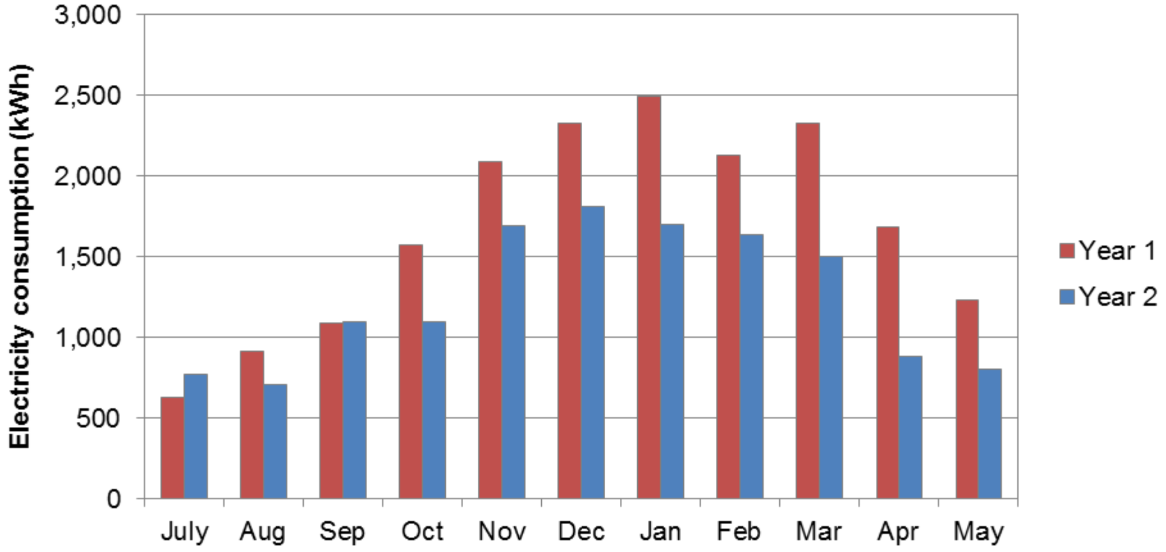
Property 5B

In year 1, this property showed energy consumption that was dramatically higher than predicted by SAP predicted. The tenants were contacted and the energy consumption was verified against their energy bills. The high consumption resulted in energy bills of over £2,500 a year in year 1, which is exceptionally poor for a Code 5 property.

Detailed monitoring equipment was not installed so it is difficult to confirm the key reasons for this remotely; from the monthly electricity use profile we estimate that heating contributed 9,000kWh per year or more, but this still leaves a very high residual energy use. Assuming that the energy data was correct, a fault with the heat pump or controls was suspected such that immersion top up is being used for heating and hot water. Investigations into this matter continued over the second year of the project, requiring several visits; it was necessary to call in an engineer from NIBE to diagnose faults in January 2014, who reported the heat pump was repaired during the site visit. In June 2014, another engineer was sent to site, and found that the internal thermostat temperature for the hot water vessel was set to 80°C, and this was corrected this to 65°C (note that temperatures of 65°C are only required weekly to prevent legionella and further reductions may be possible). Credit is due to the persistence of TGP staff with combating the issue of high energy bills at this property, despite conflicting reports from engineers. TGP are also intending to extend the monitoring of this property in order to verify that energy use drops to a level concurrent with the other Code 5 unit.

Further analysis of the electricity demand of Property 5B shows that there is evidence to suggest that the intervention during September 2013 was at least partially successful. Figure 6-2 compares month-on-month data for electricity consumption at Property 5B from year 1 and year 2 of the study. Recent months have seen a consistent reduction in energy consumption of >30%, suggesting that the heat pump is now functioning more efficiently. The reductions in electricity consumption since the NIBE engineer site visit in January 2014 have been larger than the reductions in the period October 2013 to December 2014, indicating that the second visit gave further benefit. Due to the reduced monitoring arrangement in Property 5B (when compared to Property 5A) means a full explanation of the underperforming system is not possible. However, electricity use got closer to that of Property 5A, and by the June to July 2014, the energy consumption of Property 5B and Property 5A was very similar, providing evidence that the heat pump at Property 5B is now operating in a manner similar to expected. However, both properties still used a very high quantity of electricity given the high specification of the properties.

Figure 6-2: Comparison of the electricity demand for Property 5B, for year 1 and year 2 of monitoring



A scheduled service on 16th September 2013 was attended by Verco and Daniel Kenning (TSB MO). The service was carried out by GNC's maintenance team (a plumber & an electrician) and the original plumber (Aqua, a sub-contractor of Lovell) who installed the unit. This failed to definitively identify the issue but confirmed the following:

- The UFH was inoperable due to a solenoid failure
- The compressor unit appeared to be running little if at all, and the unit was believed to be operating mainly, or entirely, on immersion.

The consumption for year 2 was 32% lower than year 1, while the other Code 5 property recorded very similar consumption year on year, so it appears that the site visits had some positive impact. However, the property still has an electricity consumption total of over 3 times higher than SAP predictions and approximately 50% higher than the other Code 5 property, which is highly unsatisfactory given the energy efficient design.

When the maintenance team visited in September 2013 the solar water heating system was not operating and needed refilling with glycol solution – air in the system is believed to have tripped the pump. (Note: this proved to be the case in both Code 5 properties in September 2013). SWH systems need regular maintenance, and glycol top-up is required annually. Incorporating SWH into the regular maintenance schedule is recommended.

Property 5A

This property has some outstanding issues with the metering configuration; however, the property is not performing as expected as the property is using approximately double the electricity consumption predicted by SAP. This underperformance has been near identical for the two years monitored, despite a change of tenants for the second year.

- It was noted during the walkthroughs that the tenants had set the thermostats to 21 degrees, but they commented on the property being very warm, especially on the upper floors. Our own monitoring equipment (only present on floors 1 and 2) indicated that the internal temperature was higher (25 degrees). Possible contributors to this issue are:
    - Heat from the UFH system (which has a slow response time) on the ground floor rising through the house and combining with internal gains to overheat the upper floors.
    - Low thermal mass associated with the wood frame construction reducing the potential for night purging of excessive temperatures
- Heating energy delivered was very high (around five times the SAP heat demand). The tenant keeps the property very warm (circa 25 degrees) at all times because one tenant had health issues affecting mobility and is in most of the time; another tenant also works from home. This high internal temperature coupled with fabric issues (air permeability of almost double the design target) are a significant contributor. However, a theoretical analysis of the air tightness test result and elevated temperature still leaves at least 50% of the delivered heating unaccounted for. Tenants opening windows to relieve summer overheating on the top floor may be a factor (this was mentioned in the tenant interviews) as the heating is left on all year round.
- Sub metering data suggests that the heat pump achieved a COP of 3.27 over year 1, so this is not believed to be the issue. Heat transfer between the heating buffer jacket into the hot water system may be a key factor, as the hot water tank is enclosed in the heating buffer vessel. This could also account for the apparent low heat consumption of the hot water system (circa 2,000kWh for year 1, which is significantly below expectations, noting that the solar hot water system has not been operational).

- Losses from the heating/hot water buffer vessel are not properly accounted for in the SAP calculations and could contribute significantly to system energy use during the summer months.

- The remaining electricity consumption (lighting, pumps, fans and small power) was also very high, at over 7,000kWh per annum. It is noted that the tenants were in the house all the time, and a significant amount of audio visual (AV) equipment was used for entertainment purposes, as well as one tenant working from home regularly. The tenants have an electric cooker which could not be independently metered – this may be a significant contributor, as well as pumping energy for the heating & hot water system which operates for a high number of hours per annum.

At the end of year 1, the original tenants moved out, and new tenants moved in. Anecdotal evidence suggests that the new tenants did not significantly change the heating controls, which supports the negligible difference between year 1 and year 2 consumption for this property.

An in depth analysis of building energy consumption is detailed in Appendix section 13.3. A full metering breakdown analysis is presented for Property 3A and Property 5A. The performance of individual systems is analysed, and reasons behind unexpected energy consumption data are discussed. A range of issues with the quality of the monitored data have been raised and addressed in Appendix section 13.3.

The results of the energy consumption have a direct impact on the carbon emissions performance of the properties, as shown in

Table 6-2 and Figure 6-3. When considering the metered electricity data, we have accounted for the exported electricity and “extra credit” gained under SAP as an additional item. SAP credits electricity generated by PV with a higher carbon factor than energy from the grid, hence in order to make a fair comparison the same benefit must be applied to the analysis.

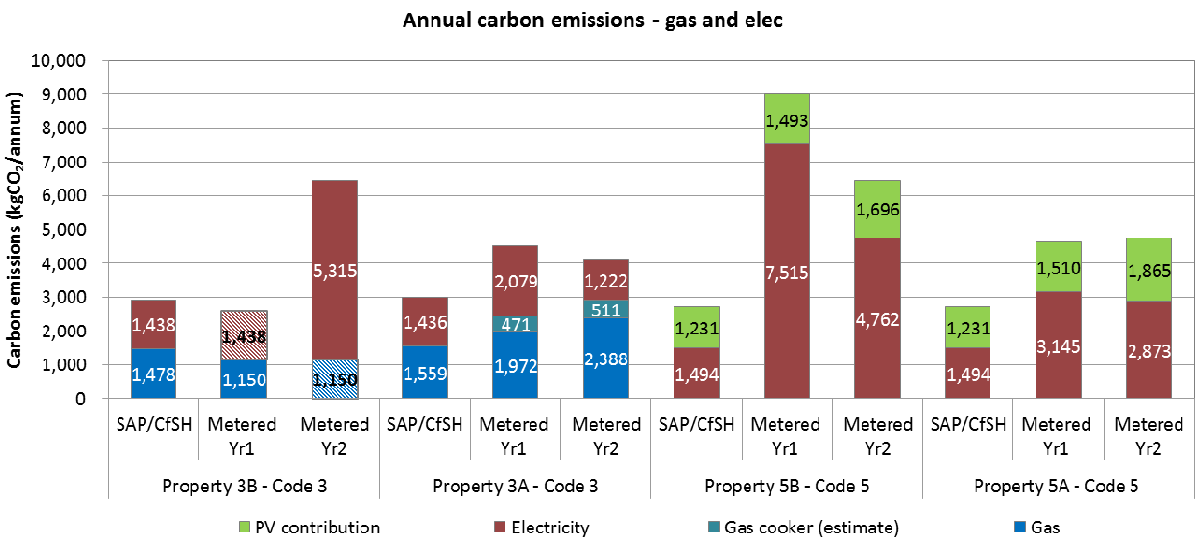
6.3 Carbon performance

The general trend in carbon emissions performance mirrors that of the energy performance; only Property 3B appears to be performing well when compared against SAP predictions, furthermore a reduction was seen between year 1 and year 2, once the use of electric immersion for water heating was minimised. However, it is noted that the impact of the PV systems on the performance of the Code 5 properties is significant; as assessed under SAP 2005, the Code 5 property 5A has 20% lower carbon emissions than the Code 3 property 3A (3,358 kg CO_2/annum vs. 4,051 kgCO_2/annum).

Table 6-2: Annual carbon emissions - comparison of SAP/CSH prediction against monitored data (SAP 2005 carbon factors: 0.422 kgCO_2/kWh electricity, 0.194 kgCO_2/kWh gas, and 0.568 kgCO_2/kWh electricity displaced from grid)

	Property 3B - Code 3			Property 3A - Code 3			Property 5B - Code 5			Property 5A - Code 5		
	SAP/CSH	Metered yr1	Metered yr2	SAP/CSH	Metered yr1	Metered yr2	SAP/CSH	Metered yr1	Metered yr2	SAP/CSH	Metered yr1	Metered yr2
Electricity	1,438	1,438	5,315	1,436	2,079	1,222	1,494	7,858	5,108	1,494	3,502	3,249
Gas	1,478	1,150	1,150	1,559	1,972	2,388	n/a	n/a	n/a	n/a	n/a	n/a
PV total generation	n/a	n/a	n/a	n/a	n/a	n/a	1,231	1,296	1,346	1,231	1,388	1,464

Figure 6-3: Annual carbon emissions - comparison of SAP/CSH prediction against monitored data (SAP 2005 carbon factors: 0.422 kgCO_2/kWh electricity, 0.194 kgCO_2/kWh gas, and 0.568 kgCO_2/kWh electricity displaced from grid)



6.4 Energy cost modelling

The general trend in carbon emissions performance mirrors that of the energy performance; only Property 3B appears to be performing well when compared against SAP predictions.

Figure 6-4: Annual energy bill - comparison of SAP/CSH prediction against monitored data

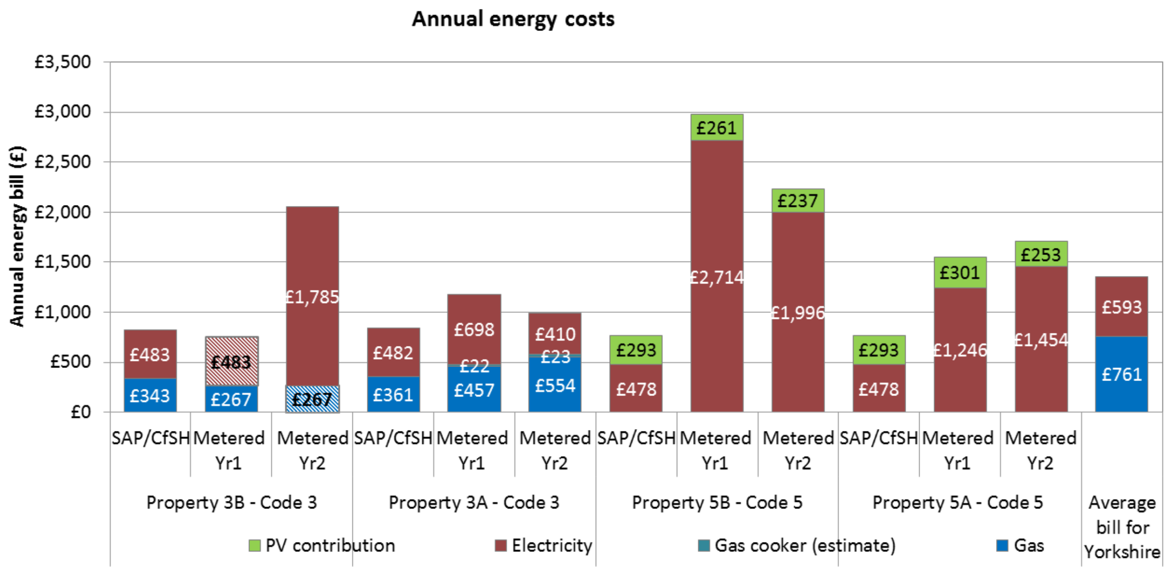
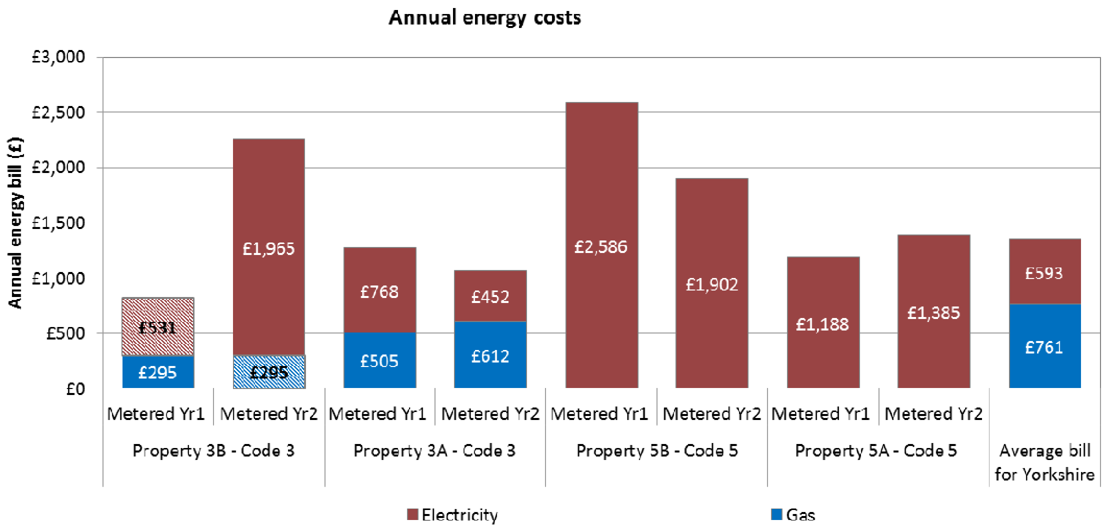


Figure 6-5 compares the energy bills of the properties with the UK average bills, using the most recent data from DECC Quarterly Energy Prices June 2014. Average energy consumption and prices shown are for the Yorkshire and Humber region, using pre-payment costs for Property 3B and Property 3A, and direct debit costs forProperty 5B and Property 5A. Thus giving an accurate view of the likely bills for these properties.

The tenants of Property 5A were given an energy bill rebate by TGP, of £100, which was accepted, to help with the additional costs associated with the fault with the solar hot water system.

Property 3A and Property 5B see a good reduction in energy bills from year 1 to year 2, due to the site-visits and remedial action taken. However, Property 5B still has an energy bill much higher than the Yorkshire average. Property 5A has seen a small rise in energy bills from year 1 to year 2, which are broadly in line with the average for Yorkshire. However, for buildings of this high specification, consumption is still significantly higher than expected in both properties.

Figure 6-5: Annual energy bill - comparison of UK average against monitored data



6.5 Conclusions and key findings for this section

Key observations from the energy monitoring are as follows:

1. Broadly, the Code 5 properties used less absolute energy than the Code 3 properties in year 2 (primarily due to the presence of heat pumps, and the PV contribution). In year 1, when the heat pump in property 5B was not functioning properly, the energy consumption in this property was higher than that of property 3B.
2. One Code 5 property (5A) also demonstrated lower carbon emissions than the property 3A in both years of the study, suggesting that the concept behind the code 5 homes is not entirely flawed. However, the energy bills are typically higher for the Code 5 properties than for the Code 3 properties, which is an important issue in the context of social tenants. If a simpler heat pump system could be identified, the code 5 solution might well deliver some of the improved performance originally intended.
3. The Code 5 properties both perform very poorly when compared with design expectations. Carbon emissions are more than double the target in both cases, with one property exhibiting startlingly high energy consumption. This is driven by a number of issues:
    a. Complex controls & heat pump system design resulting in "default to on" guidance given to tenants for heating & hot water.

b. Tenant behaviour and understanding of controls – exacerbated by controls design issues.

c. Faults with the heat pump system in property 5B, and solar hot water systems in both code 5 properties.

This is considered a disappointing result given the £25,000 cost premium and additional operational and maintenance complexity these properties feature relative to the Code 3 units.

a. In Property 5A, the tenant is in all the time, and internal temperature sensors indicate a steady internal temperature of 25°C. The result is carbon emissions and an energy bill greater than either of the Code 3 properties.

b. Property 5B had approximately double the energy bill of Property 5A, although it reduced in year 2. The result is extremely high carbon emissions and corresponding energy bill, of over £2,500 in year 1 and approximately £2,000 in year 2.

4. The Code 3 properties, in general, have a poor performance when compared to design expectations, with one property exhibiting energy and carbon performance approximately 50% higher than SAP predicts.

    a. Property 3A is circa 50% poorer performing than SAP predicts. Property 3A has a higher than predicted occupancy, as well as some construction and technical performance issues, such as an under-performing boiler and poor air permeability (as shown in the air permeability testing and the thermography), which are seen to be key factors in the variance from design performance. The hot water demand is high, and the immersion heater was heavily used in the first half of year 1.

    b. Property 3B had gas consumption data for year 1 (which showed to be below 22% below SAP prediction), and electricity consumption for year 2 (which is 3 to 4 times greater than SAP prediction). Unfortunately, gas and electricity data for the same year is not available, due to metering and access issues.

5. In terms of heating systems, the gas boiler installed at Property 3A is performing less efficiently than expected, while the heat pump installed at Property 5A appears to be operating close to the manufacturers stated efficiency. While the metering on the boiler is considered more robust than that on the heat pump, these results indicate

that on direct comparison the heat pump is a lower carbon technology per unit of heat delivered.

6. PV systems on both Code 5 properties performed well, during both years, and are considered an effective and tenant friendly solution to reducing carbon emissions and energy costs – provided they are checked for faults with sufficient regularity as they are out of sight.
7. Significant issues with the accuracy of current-transformer (CT) type electrical sub-meters have been noted. The units operate inconsistently when measuring circuits with small loads, resulting in an incomplete picture of the breakdown of electrical energy consumption in the properties. Hard wired meters are therefore recommended in projects of this nature, despite the increased physical size and disruption.
8. The PV systems of both Code 5 properties are generating more than the predicted electricity predicted by SAP.
9. Credit is due to the persistence of TGP staff with combating the issue of high energy bills at Property 5B, despite conflicting reports from engineers, as the actions have successfully reduced the energy bills of this property.

Difficulties encountered with the monitoring equipment in the properties have been a significant limitation in providing insightful in-depth analysis. However, on-site measurements, estimates and modelling have all been used to attempt to explain un-metered consumption and account for missing data.

The issues with the sub-metering do not, however, affect the overall conclusions regarding whole-house energy demand.

7 Other technical issues

7.1 Introduction

Technical issues from the study broadly fit into the following aspects of the project: design & construction, commissioning, controls, monitoring issues, and tenant engagement. All sections of this report include specific issues; however, the issues are drawn together in this section.

7.2 Design and construction

Design and construction issues have been fully covered within the design and construction audit, in section 0. In general, economic conditions had a very large impact on this development.

Meeting the Code 5 energy performance requirements in theory (the SAP calculations) was relatively straightforward however in practice design and installation of the heat pump/solar hot water system was complex and a challenge for the design team – this also adds significant complexity to the controls and commissioning and is a potential maintenance issue further down the line.

In terms of construction, the suspended steel bays to the rear of the properties were particularly difficult to detail and construct. This extended the build time significantly and added substantial design complexity

7.3 Commissioning:

This study did not cover the commissioning phase so issues pertaining to original commissioning cannot be confirmed. No major issues were reported by the design team apart from leaks in the UFH circuits in the Code 5 units. However, other elements of the study have indicated some possible commissioning issues including:

- Deviations in MVHR flow rates from design values (the absence of commissioning reports prevented any confirmation that rates were correct at time of commissioning – it's possible that flow rates were not tested as this wasn't specifically required).
- High temperature setting on hot water system in one code 5 property

It should be noted, that tenants may have adjusted some of these settings themselves (although the tenant in one property was not aware of the presence of the MVHR so this is unlikely in that case).

The solar hot water system at Property 5A was not correctly re-commissioned after the heat metering was installed, and did not function in the first year of the study. Rectifying the fault was not straightforward. The first engineer called out incorrectly reported the unit as fixed and the problem had to be escalated to a higher level. The error warning technique for these systems should be improved (perhaps with an audible alarm) so that it is clear to tenants when they are not receiving the benefit of the SHW system. A further list of technical issues is included in Appendix section 12.2.2.

7.4 Controls

It is clear from the energy bills, monitored data, and the interviews, that the design of the system controls for the heating and ventilation technologies, their commissioning and the communication of how to use these, have all made it very difficult for tenants to understand how to use the systems effectively and correctly.

- A lack of tenant friendly written information on the technologies installed, and the lack of a handover demonstration is viewed as the primary issue
- Excessive complexity in the controls for the heat pump and underfloor heating systems makes it unlikely that even a technically aware tenant would fully master the controls. A simpler, centralised time/zone controller with basic local thermostats for individual rooms could be a more usable solution, rather than having three separate time/temperature controllers on the UFH (family room, bathroom, and hallway).

7.5 Swapped use of top floor rear bedroom and living room

The interviews have highlighted that in both Code 5 properties (Property 5B and Property 5A), and in one of the Code 3 properties (Property 3A), the tenants had opted to use the top floor rear room, intended to be the living room, as the master bedroom. Generally, tenants felt that the room originally designed to be the lounge would have been too small to be used for this purpose. For a family home, tenants stated that it is more practical to have the lounge and kitchen together on the middle floor and all the bedrooms on the same floor. This architectural issue highlights that even with good intentions at the design stage; the tenants may use the property differently. The result is that the heating circuits (which were split between bedrooms and living space) are now mixed up and the room thermostat in what is now used as the living room, controls temperatures in some of the bedrooms – limiting tenant's ability to split the control of heating in these areas. This highlights the disconnection between the design intent and the way in which the properties are used in practice.

Interestingly, this original layout was designed and driven by the requirements and regulations within Lifetime Homes.

7.6 Monitoring issues

The quality of the energy monitoring and sub-metering have created some significant hurdles for the project. A full discussion is presented alongside the monitoring analysis in in Appendix section 13.3. Specific monitoring issues are listed within Section 14.5.1.

7.7 Tenant engagement

Further to the 'survey fatigue' discussed in Section 5.4, one tenant has not responded on a number of occasions when engineers called to install internal meters, despite expressing an initial interest in participating in the project. Towards the close of the project, a second tenant repeatedly failed to provide access for a final air test. During the design review it was noted by the contractor that similar issues had also occurred previously when one of the tenants had reported faults.

It is possible that further review with the housing and contractor team prior to property selection could have highlighted this risk for one of the study properties. This would be worth considering at the scoping stage in future projects.

8 Wider Lessons and key messages

8.1 Introduction

Wider lessons and key messages from the study broadly fit into the following aspects of the project: procurement, design, operation/maintenance, and energy performance. These are detailed in the following sections.

8.2 Procurement

- The partnership approach used during design and procurement of the project was viewed very positively by the design team and this helped to achieve the Code 5 targets.

8.3 Design

- Design of the properties was approached from a fabric first principle (i.e. insulate the property well) and then “least cost” basis then the heating, ventilation and renewable technologies were selected based on the cheapest way to achieve the Code targets for energy use. This led to a very complex heat pump/solar hot water/solar PV/mechanical ventilation configuration on the Code 5 homes with complicated controls that are hard for tenants to understand.

- Complex envelope design has led to lower levels of airtightness than anticipated. Improve design of joints etc.

- The architect designed the properties for maximum solar gain on the south side making the properties very bright on this side and with good views. The good views were very well received by all. However, issues with glare/excessive natural light were highlighted on the south side, and the smaller windows on the North elevation (intended to reduce heat loss) led to some spaces feeling “gloomy” or “dark”.

- Generally, it was felt that the room originally designed to be the lounge would have been too small to be used for this purpose. For a family home, tenants stated that it is more practical to have the lounge and kitchen together on the middle floor and all the bedrooms on the same floor. Thus, the properties are used in a different lay-out than designed.

- The heat pump systems are very complex and raise concerns for future maintenance. Although there are maintenance staff trained in the system it is plausible that fault diagnosis may be challenging on these systems as they will have had little direct experience.

- Design of the controls for the MVHR systems and the heating and hot water systems in the code 5 properties did not take usability into account, which is one of the two root causes of subsequent difficulties experienced by the tenants in their being able to take actions to reduce energy consumption. The complexity of the system would make it very difficult to create a genuinely user friendly guide to the controls. (The other route cause was the fact that TGP did not ensure delivery of face to face training).

8.4 Operation/maintenance

- Formal handover demonstrations did not occur to show tenants how to use the technologies in their properties, despite being offered on several occasions. A simple, layman's guide to heating, hot water, and ventilation controls and simple checks on renewable technologies would be beneficial as well as a face to face demonstration. The importance of attending such training and handover should be highlighted to tenants & driven forwards by TGP.
    - The combination of technologies in the Code 5 homes is hard for tenants to understand. The tenant in one house (Property 5A) was able to decipher most of the controls through their own efforts; in the other property the tenants had to call out maintenance staff to set their heating controls.
    - Controls in the Code 3 houses were better understood as the heating is controlled from a single "typical" timer/thermostat unit.
    - MVHR controls are particularly un-intuitive and some residents were unaware the system was in place
    - Issues with controls and handover could be resolved up-stream of in-use performance, through adequate specification and thoughtful design, focussing on simplicity
- No scheduled maintenance was in place to replace the filters on the MVHR systems, which should be carried out annually.
- Due to the "hidden" nature of the PV, solar hot water and ventilation systems, these systems could easily fail without the tenants noticing – indeed one solar hot water system did fail following meter installation and this was picked up by the consultant

team – the tenant didn't know. A better warning system would be beneficial (perhaps a simple "health check" monitor for the house) to alert tenants to failures and help them to report these correctly to maintenance.

8.5 Energy performance

- One of the Code 3 properties is being monitored to a high level of detail. This property is using significantly more heating than anticipated. The property exhibits energy and carbon performance approximately 50% higher than SAP predictions. This property has a higher than predicted occupancy, as well as some design issues, such as an under-performing boiler and poor air permeability (the initial air testing of the property showed it to be 56% less air-tight than design specifications), which are key factors in the variance from design performance.
- The other Code 3 property is estimated to be performing poorly; however, electricity and gas consumption data was not available during the same year, due to metering and access issues.
- The Code 5 properties are using dramatically more electricity than anticipated. This is a cause of considerable concern and will be costing the tenants a significant premium in energy bills.
    - At Property 5A detailed metering is in place and the property is using double the predicted electricity consumption. The tenants kept the house very warm and were in all the time, which partly explains the high energy use by the heat pump. The building U-value is in line with the design-stage target, whereas the smoke testing and final air permeability testing have shown that the property is 83% less air tight than design specifications. SAP modelling indicated that this would increase heating energy consumption by circa 20%, compared to circa 40% increase for the observed high temperature of circa 25 degrees (4 degrees higher than SAP's assumed living room temperature).
    - At Property 5B only basic metering is in place. This property is using around four times as much electricity as predicted at designs stage. This is a cause for concern. Remedial action has been taken in terms of correcting heat pump controls, which has had a positive impact. However, the property still continues to perform poorly.

- The boiler at Property 3A appears to be around 75% efficient – this is significantly below the design expectation (around 90%). Within this analysis, it has not been possible to verify the reason for this; a boiler service yielded no obvious concerns.
- The heat pump at Property 5A appears to be performing well as an individual heat generating unit, with a COP of 3.27 which is in line with manufacturer's data and better than SAP defaults.
- The PV systems at Property 5B and Property 5A are performing in line or better than expectations overall.
- The solar hot water system at Property 5A suffered a fault after, or as a result of, the metering installation and its performance cannot be assessed at this time.
- Further investigation is warranted for Property 3B, to determine whether the high monitored consumption is an accurate reflection of the actual energy use, or whether it is a meter calibration issue.
- Credit is due to the persistence of TGP staff with combating the issue of high energy bills at Property 5B, despite conflicting reports from engineers, as the actions have successfully reduced the energy bills of this property.

8.6 Recommendations

The recommendations identified through the various strands of this study have been summarised in the table below. The recommendations are aimed at specified stakeholders, and given a priority level. Where appropriate, remedial actions have been identified which should be pursued in order to improve the performance and occupant comfort in the properties.

The list is split into the following categories:

- Design considerations
- Simplicity, usability and tenant engagement
- In use performance

<table>
<tr><th colspan="6">Design considerations</th></tr>
<tr><th>Recommendation</th><th>Supporting evidence [element of study]</th><th>Stage of development</th><th>Stakeholders</th><th>Priority</th><th>Remedial action required?</th></tr>
<tr><td>Design for flexibility - further design consideration should be given to the use of space in a property, once it is in occupation.

For some properties, there is a discrepancy between the Lifetime Homes requirements, and real-life preferences. A review of the requirements of Lifetime Homes should include this consideration. This is an example of regulation/codes constraining design & causing undesired effects.</td><td>• Room use was different from design, in all properties [walkthroughs, occupant surveys]
• The living room might be best placed where the kitchen is currently located (to benefit from views) with the kitchen on the north side [walkthroughs, occupant surveys]
• Balcony to rear of property would be more useful than front as could see the view [walkthroughs, occupant surveys]
• Kitchen/diner was felt to be too small relative to the rest of the house [walkthroughs, occupant surveys]
• There isn’t space for a fridge, washing machine and tumble dryer in the kitchen – although an electrical spur is included for both washer and dryer [walkthroughs, occupant surveys]
• Locating kitchen diner on ground floor might be a consideration for tenants with low mobility [walkthroughs, occupant surveys]</td><td>Concept / Design</td><td>Design team / BPE wider lessons</td><td>High for future schemes / Low for existing schemes</td><td>n/a</td></tr>
</table>

Design considerations					
Recommendation	**Supporting evidence [element of study]**	**Stage of development**	**Stakeholder**	**Priority**	**Remedial action required?**
More careful design required to minimise heat loss without compromising the 'feel' or risking issues of solar glare, for example, incorporating shading measures into future developments.	• Smaller windows on the North elevation make some spaces feel "gloomy" or "dark" [walkthroughs, occupant surveys] • Window on GF staircase would be welcome [walkthroughs, occupant surveys] • The internal temperature varies too much in the summer, due to the large area of south facing windows [walkthroughs, occupant surveys] • Glare issues with large windows shown by BUS	Design	Design team	High (current and future schemes)	It is recommended that shading measures are reviewed in further detail – consider using a more sophisticated method than the SAP overheating test which these properties passed. – perhaps a simple dynamic model?
Consideration should be made for the inclusion of an intercom or other measures if the property is likely to be occupied by the less able.	Due to the three-storey nature of the property, less able tenants may struggle to answer the door within a reasonable time period, before the visitors have left. [walkthroughs, occupant surveys]	Design / Procurement	Design team/ Developer	Low	Alarm control panel upstairs would be welcome (there is only one by the door) plus an intercom/door entry system for when doorbell rings when tenants are on the top floor
MVHR controls are battery operated which is an important limitation to the usability of the system. It is recommended that the developer seeks better clarification for future developments.	One tenant noted that MVHR controls are battery operated and was unsure who would replace batteries if they ran out; with no LEDs on the control and minimal difference in noise level on boost it would be hard to tell if the battery ran out. [walkthroughs, occupant surveys]	Design	Developer	Medium	n/a

Design considerations					
Recommendation	**Supporting evidence [element of study]**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
Strong partnerships for future developments should be encouraged, and perhaps included in tender scoring	Partnership approach used during design and procurement of the project was viewed very positively by the design team [design review, construction review, delivery model]	Procurement	Design team / Developer	Medium	n/a
Window cleaner access - windows have been designed to be cleaned from the inside; but the brise-soleil restricts access for window cleaners working from the outside.	Tenants reported that it is difficult for window cleaners to get to the top of the rear bays [walkthroughs]	Design	Design team	Low	Inform tenants that windows can be cleaned from inside.
Sufficient provision of amenities should be considered during the design stage	• One of the tenants thought the storage spaces lacked sufficient shelves, so has installed their own [walkthroughs] • There was no TV aerial installed and tenant had to pay for the bins [walkthroughs, occupant surveys]. TGP has since reimbursed the tenant for these. • Ventilation (extract) in lobby suggested to clear shoe odour [walkthroughs, occupant surveys]	Design	Design team	Low	n/a

Design considerations					
Recommendation	**Supporting evidence [element of study]**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
Consider system designs that allow flexibility for heating design – e.g. a central system that allows room-by-room controls or consider modern wireless systems that were not proven at the time of the design phase of this development. Ideally the tenant could define which rooms are bedrooms & which are living space. This could help avoid the unexpected mixing of the heating sub-circuits experienced here, with the change in room use.	Heating zoning and controls – both properties have opted to use the property in a different manner to the intended layout, resulting in the actual use of rooms on bedroom and living area heating circuits being mixed up, leading to tenants heating the whole property to the same schedule and target temperature. [walkthroughs, occupant surveys, monitoring]	Design / commissioning / in-use	Design team	High	n/a in this case

Design considerations					
Recommendation	**Supporting evidence [element of study]**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
Developer should demand robust solutions for air tightness in tender documents (e.g. mechanically fixed solutions) The design team should consider more mechanically robust solutions in future (overlapping junctions, alternatives for bay/property interfaces and fenestration) and feed experiences into design teams in future, as silicone sealant is not sufficient to achieve lasting air tightness. Consider post occupancy testing for other traditional build properties to determine if these issues are specific to the unusual architectural design of this scheme	• Detailing the floor junction between floors was a particular challenge due to the differential movement [construction] • Rear steel bays were difficult to detail and construct [construction] • Cladding the vertical steelwork in a watertight manner was difficult [construction] • High heating consumption and bills in both Code 3 and Code 5 properties [monitoring, walkthroughs] • Observed drafts, sealant cracks and degradation [walkthroughs] • Air tests – significant underperformance [fabric testing] • Thermography - air leakage areas highlighted around doors and windows; thermal anomalies at the meter boxes may indicate minor air leakage here [fabric testing]	Procurement / Construction / Commissioning	Developer / Design team / Contractor / BPE wider lessons	High	TGP should send a contractor to site to re-adjust the setting of windows and doors, and check the sills for depressions, along with other air leakage areas highlighted. Air leakage around openings causes draughts and reduces comfort levels for tenants. This may influence behavioural choices on the level of heating, due to the sensation of reduced internal temperatures in the properties.

Design considerations					
Recommendation	**Supporting evidence [element of study]**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
A full wiring diagram of the property would be immensely useful in identifying which items are connected to which circuits	Lack of clarity over identifying which items are connected to which circuits. This is particularly relevant for smaller, constant use items like UFH controls, thermostats, etc. which may use small but significant amounts of power [monitoring]	Design	Design team	Low	n/a

Simplicity, usability and tenant engagement					
Recommendation	**Supporting evidence**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
Usability and controls must be considered at an early stage. Multiple technologies add complexity and maintenance liabilities, whereas simple designs are likely to be more effective in operation. Passive solutions that avoid complex controls are likely to be more effective, provided adequate fault identification & checks are in place. For example, the Building Controls Industry Association guide '*Controls for End Users: a guide for good design and implementation*' by B. Bordass, A. Leaman, and R. Bunn, should be used during design, specification, and implementation, which gives the 6 key factors for reviewing controls as being: • Clarity of purpose • Intuitive switching • Usefulness of labelling and annotation • Ease of use • Indication of system response/ feedback • Degree of fine control	• Installation of the heat pump/solar hot water system was a challenge [design team interviews] • Significant complexity of system controls and commissioning [walkthroughs, commissioning] • Maintenance issues are becoming apparent with all systems [walkthroughs, fabric testing, monitoring] • Tenants can't switch on ground floor hall light from first floor (ground floor hall very dark) [walkthroughs, fabric testing, monitoring]	Design / Procurement / Commissioning	Design team	High	• A full review of all the controls, their current settings and instructions, for tenants of the Code Level 5 properties, would be useful.

Simplicity, usability and tenant engagement					
Recommendation	**Supporting evidence**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
The housing developer should prioritise better guidance, handover, and engagement. A more user friendly guide for systems and controls is required, and a simple copy of the maintenance schedule for the tenant might also be beneficial. A face to face demonstration of *all* controls to the tenants, including where errors would be shown on user interfaces, to assist them when reporting issues.	• Lack of tenant-friendly information, and lack of a handover demonstration [occupant surveys] • Poor energy performance [walkthroughs, fabric testing, monitoring] • Training and guidance was offered several times by the main contractor, but was delayed due to scheduling issues, and did not get delivered.	Procurement / Commissioning / Handover	Developer	High	Property 3A tenant would appreciate face-to-face advice (as opposed to a lengthy handbook) due to language barriers. A simple copy of the maintenance schedule for the tenant & developer would be beneficial
A simpler heat pump system (in terms of equipment and controls) could be a low carbon heat source for tenants – air source heat pumps should not be written off as a potential solution in low carbon homes.	The heat pump at Property 5A is a lower carbon technology per unit of heat delivered than the gas boiler at Property 3A [monitoring]	Concept / Design	Design team	Medium	
Training for tenants and maintenance teams is essential to ensure correct response to reported faults – both in the office and “on the ground”	Problems reported in maintenance response on Code Level 5 properties – technologies were poorly understood by tenants and TGP’s customer service advisers. When issues with the heat pump and PV systems were reported there was uncertainty over who to send. [occupation, monitoring, occupant surveys]	Design / Handover / Occupation	Developer	Medium	**n/a**

Simplicity, usability and tenant engagement					
Recommendation	**Supporting evidence**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
A more clear explanation to the tenants that the type of light bulbs required will be cheaper to run in the long-run would help to avoid confusion.	Anecdotal feedback from some tenants suggested that the light fittings enforce bulbs to be installed were too bright. Further to this, the bulbs required are energy efficient, and are seen as being a large capital expense (regardless of lower lifetime running costs). [walkthroughs]	Design / Handover / Occupation	Developer	Low	**n/a**

In-use performance					
Recommendation	**Supporting evidence [element of study]**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
A maintenance schedule should be requested from the contractor as part of the handover pack – for all the main systems; detailing maintenance tasks, intervals, consumables and trades required and any specialist knowledge or training needed. On-going maintenance schedule should be incorporated into developments	There is a concern regarding future maintenance of the heat pump, MVHR, rainwater harvesting, and renewables systems. It was not clear that a suitable maintenance regime was in place for these systems, or sufficient information on site for an engineer to understand them. This was borne out when an engineer was called out to inspect the SHW system and reported it repaired – but the system remained non-operational. [monitoring, fabric testing] The gas boiler installed at Property 3A performed less efficiently than expected in year 1 (76% vs. 93%) - Regular boiler checks should be scheduled to maintain boiler efficiency [monitoring] The solar water heating system in Property 5B was not operating and needed refilling with glycol solution – air in the system is believed to have tripped the pump [monitoring] The Code 5 properties reported issues with toilets flushing. This appears to be linked to the RWH systems. Tenants had little awareness of system & the rainwater tank may only be fed by one downpipe. [monitoring, occupant surveys]	Commissioning / handover	Developer	High	• Develop a regular maintenance schedule. (TGP have progressed this). • Solar hot water system function should be assessed annually with a boiler inspection, including glycol top-up annually. • Investigate options to re-route more of the guttering to feed the rainwater harvesting system in order to improve performance.

In-use performance					
Recommendation	**Supporting evidence [element of study]**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
An engineer should be sent to Property 5B to investigate and resolve the suspected fault with the heat pump or controls. This was undertaken and has resulted in an increase in performance, but the property still performs poorly when compared to SAP.	Property 5B showed energy consumption that it was dramatically more than predicted by SAP. [monitoring]	Occupation	BPE wider lessons	High	Remedial action taken during year 2 through two site visits, and consumption reduced as a result.
The lead contractor and the developer must to ensure they have individuals with the specialist expertise required to ensure quality when snagging newer technologies such as MVHR. The housing developer should improve tender documentation to get higher quality works. The Institute for Sustainability has developed some standard tender documentation for contracts.	Issues with quality & reliability in delivery of "new" technologies for the design team such as MVHR, heat pumps, solar hot water systems – which were installed by sub-contractors [monitoring, fabric testing, occupant surveys, walkthroughs]	Contractor / Developer / Commissioning	Design team/ Contractor / Developer	Medium	n/a

In-use performance					
Recommendation	**Supporting evidence [element of study]**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
"Soft landings" - Developer should consider a soft landings approach to design & handover to encourage long-term thinking, and ensure follow-up checks are in place for property performance, especially where novel design approaches are proposed. Contractor could have a nominated 'Champion', with a responsibility to achieve on-going performance of the properties, including an air tightness champion whose role is to ensure air tightness standards are maintained during construction (e.g. where multiple contractors might be involved, such as seals around plumbed pipes) and in-use phases. A nominated tenant controls training champion could be beneficial (developer side). On-going support from the contractor after occupation (beyond defects period & with a broader scope of support), would be a useful offering.	Problems reported in maintenance response on Code Level 5 properties – technologies poorly understood and when reported, uncertainty over who to send. [monitoring, fabric testing, occupant surveys] Poor energy performance of Code 5 properties [monitoring] Failures of SWH & heat pump systems [monitoring] Degradation of air tightness (mastic sealant, window sealing etc.) [fabric testing, walkthroughs]	Design/Procurement / /Commissioning /Handover/In-use	Developer & design team	Medium	n/a

<table>
<tr><th colspan="6">In-use performance</th></tr>
<tr><th>Recommendation</th><th>Supporting evidence [element of study]</th><th>Stage of development</th><th>Stakeholders</th><th>Priority</th><th>Remedial action required?</th></tr>
<tr><td>MVHR recommendations:
The MVHR systems should be re-commissioned to re-balance air flow rates.
Tighter monitoring of the installation and commissioning process could minimise or eliminate MVHR issues and yield improved performance.
Review of the MVHR snagging process recommended (developer/contractor/sub-contractor) – individuals may not have appropriate knowledge or training to snag correctly
The housing developer should also ensure snagging is carried out by appropriate expert – technology champions?
New legislation is now in force to help with this, as detailed in the Domestic Ventilation Compliance Guide 2010.
Tenants must be trained in the correct use of MVHR</td><td>MVHR noise was noted in one property. Could be poor commissioning. [occupant surveys, walkthroughs]
Tenant at Property 3A reported a draft from MVHR [occupant surveys, walkthroughs]
Un-insulated ductwork noted in loft – mould & health risk [fabric testing]
MVHR unit in Property 5A is not mechanically fixed to the backboard [fabric testing]
MVHR terminals in Property 3A were left unlocked, risking tenant intervention [fabric testing]
Test report on flow rates received – significant variations between properties [systems testing]
Supply & extract rates to individual rooms showed a wide variation from substantial over-ventilation to severe under-ventilation. (See Figure 4 1 and Figure 4 2 in section 14.5.2 of the appendix for further detail) [system testing]</td><td>Design stage / commissioning / in-use</td><td>Design team/ Contractor / Developer</td><td>High</td><td>To reduce noise, it is recommended that an engineer is sent to site to investigate. An attenuator could be included.

Under-ventilation can lead to mould formation, re-commissioning should be implemented by TGP.

Excess ducting should be removed as soon as possible to avoid further complications, such as damp or mould</td></tr>
</table>

In-use performance					
Recommendation	**Supporting evidence**	**Stage of development**	**Stakeholders**	**Priority**	**Remedial action required?**
Options for better fault reporting on passive renewable energy systems should be investigated - a simple central "system health" panel with warning lights linked to each of the technologies would make fault identification much easier for tenants and assist with maintenance response	Problems reported in maintenance response on Code Level 5 properties – technologies were poorly understood by tenants and TGP's customer service team leading to uncertainty over whether there was a fault with one PV system & what type of engineer to send. [walkthroughs, occupant surveys] The tenants did not notice failure of the PV or SWH systems due to their relatively inaccessible location, so faults went unnoticed for extended periods. [monitoring, walkthroughs, occupant surveys]	Design stage / procurement/ BPE wider lessons	Design team / BPE wider lessons	Medium	n/a
It is recommended that only direct wired meters are used for monitoring circuits with low load, despite the increased physical size and disruption. There appears to be a gap in the market for compact, unobtrusive direct electricity & heat sub metering for domestic properties.	Significant issues with the accuracy of current-transformer (CT) type electrical sub-meters have been noted: • Inconsistent performance when measuring circuits with small loads [monitoring] • Incomplete picture of the breakdown of electrical energy consumption [monitoring]	Design stage / procurement/ BPE wider lessons	BPE wider lessons	Low	n/a

Appendix A - Introduction

9.1 Project team

The project team involved in this study comprises the following individuals. The lead individual/contributor from each organisation is presented in **bold** type:

- Victoria Moore – The Guinness Partnership (TGP) – Board level client representative
- **Shebina Ahmad** – Guinness Northern Counties (GNC) – client project lead involved throughout the development
- Richard McWilliams – Technology Strategy Board (TSB) monitoring officer
- **Fionn Stevenson** – TSB Evaluator
- **Greg Waring** – Consultant with Verco – Project manager
- Arnout Andrews/Duncan Price – Principal consultant & Director with Verco – expert input
- Chris Dunn/Max Goodman – Verco analysts – data analysis and reporting
- **Chris Charlton** – Lovell (House-builder) – Development co-ordinator for the development
- Andrew Elsworth – Lovell – Quantity Surveyor for the development
- Trevor McCartney – Lovell – Site manager for the development
- David Trigg – Lovell – Chief Quantity Surveyor for the development
- **Benjamin Costello** – Director of AA Design – Architect
- Pete Smith – AA Design – Architect
- **Adam Humphreys** – t-mac technologies – metering provider

9.2 Study buildings and the development as a whole

The four study buildings were constructed as part of the on-going development of the estate. This phase of the development concentrated on an existing residential street, and consisted of 24 new properties. The units are predominantly three storeys and a full breakdown of unit types is provided in Table 0-1 subsequently.

The development was intended to be a flagship scheme in terms of environment, energy and sustainability. Every property in the development was designed and constructed to exceed the buildings regulations standards at the time (2006 Building Regulations), with 22 of the properties achieving Code for sustainable homes level 3, whilst two of the properties attained Code level 5.

Our study buildings consist of the two Code 5 properties and two of the Code 3 properties, located on the southern edge of the development. Each building is a three storey construction and all have very similar floor plans. The Code 3 properties are 3 or 4 bed (option of a 4th bedroom or study), whilst the Code 5 properties are 3 bedroom with an additional family space instead of a 4th bedroom. Both the Code 5 properties are semi-detached (adjoined to each other) and we have chosen two end-terrace Code 3 properties from a row of three, to best replicate the semi-detached Code 5 properties.

Figure 8-1: Study properties. Property 5B and Property 5A are Code 5. Property 3B, Property 3C, and Property 3A are Code 3

A key feature of the architectural design for all the study properties was to exploit the south facing frontage to achieve excellent day-lighting, benefit from passive solar gain in the winter and maximise the potential for the use of solar renewable energy technologies. This resulted in an unusual cross section featuring a suspended bay construction to the upper two floors of the properties, which is described in more detail below.

In terms of material selection, all the study buildings were initially designed to use a wood framed construction, with a mixture of Hardie Plank cladding and exposed brickwork to the external faces of the properties. The Code 3 dwellings were subsequently switched to a traditional cavity wall construction for cost reasons, although the external cladding and finishes were maintained in keeping as far as possible in line with the planning submission.

The overall approach to achieving Code 5 included improved energy specifications – but it is really technology led. The Code 5 houses use air source heat pumps (ASHP) as the main heating and incorporate both solar photovoltaic (PV)and solar hot water (SHW) panels.

The site of the development was previously poor quality scrub land. The phase of the development containing the study properties is located on a slight slope running downhill from South to North. It is bordered by the existing properties within the estate, which run parallel to the North and East, with an active farming field to the South and West.

9.3 Monitoring

Our monitoring plan includes two properties which are monitored in a very high degree of detail (one Code 3 and one Code 5), and two which are monitored for utilities only (again one Code 3 and one Code 5). This allows us to carry out detailed investigation of property performance on each house type while also having an identical comparator for whole building energy use.

The monitoring kit to be installed in each property is summarised below:

9.3.1 Code 5 properties

Property 5B: Utilities monitoring plus one sub-meter for monitoring PV generation (see Table 8-1).

- Gas – pulse interface and logger. Electricity import/export plus local data concentrator (LDC) which reports back via a mobile phone SIM card to the monitoring company.
- Water data logger and water meter
- Solar PV generation (sub-meter)

Table 8-1: Property 5B meters

Meter	Equipment
Gas meter – gas incomer	U6 (2L Model) Metric Gas Meter

Water	Elster Kent V200 type with 22mm connections
Electricity – PV output	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – electricity incomer	Elster AS230
Electric export	Elster AS230

Property 5A: Detailed monitoring in compliance with TSB programme (see Table 8-2).

Utility metering:

- Gas - gas meter not required as tenant does not use gas. There is a gas supply to the building, but the tenant does not have any gas appliances or an account with any gas supplier hence the gas is cut off.
- Electricity import/export plus LDC
- Water data logger and water meter
- Irradiance sensor hard wired into loft and fitted to rear steelwork as close to roof level as possible – with COV logger

Environmental and detailed monitoring:

- Electricity and heat Sub-metering and environmental sensors
  - Temperature, humidity and CO_2
  - Heating and DHW heat output from heat pump
  - Overall heat pump heat output
  - Solar hot water heat output
  - Electrical sub-circuits metered where technically and financially feasible (lighting, small power, heat pump, heat pump booster, MVHR, heating controls, immersion heaters)
  - Some sub circuits could not be monitored due to lack of space in the consumer unit (solar pump, smoke alarms, door-bell, rainwater harvesting, electric cooker)

- Solar irradiance sensor
- Solar PV generation, import and export

- N.B. four heat meters have been allowed for this property – for total heat pump output, solar thermal output, hot water output and heating output.

Table 8-2: Property 5A meters

Meter	Equipment
Electricity – heat pump	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – ground floor sockets	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – heating controls	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – ground floor lighting and second floor lighting	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – ELK boiler	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – first/second floor sockets	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – PV output	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – immersion heater	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – first floor lighting	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Internal humidity (%) and internal temperature sensors (°C)	2 per property: Wireless Temp & RH Sensors:001-1217 plus 2 off batteries 500-50362
Carbon dioxide (CO_2 ppm), humidity (%), and temperature (°C) sensor	Wireless Temp/c02/RH: 001-1230 plus 1 off batteries 500-50362
Illumination (lux)	Unspecified
Temperature (°C)	Wireless External Temperature Sensor:001-1232
Heat meter – Heating output	22mm heat Meter: Kamstrup 22mm Heat Meter plus pulse module (not M-Bus) Plus WiST Pulse Counter 001-1239
Heat meter –Heat pump output	22mm heat Meter: Kamstrup 22mm Heat Meter plus

	pulse module (not M-Bus) Plus WiST Pulse Counter 001-1239
Heat meter – Domestic hot water output	22mm heat Meter: Kamstrup 22mm Heat Meter plus pulse module (not M-Bus) Plus WiST Pulse Counter 001-1239
Electricity – MVHR (heat recovery)	Single Phase Direct Connect Electricity Meter:500-51947
Heat meter – solar thermal output	22mm heat Meter: Kamstrup 22mm Heat Meter plus pulse module (not M-Bus) Plus WiST Pulse Counter 001-1239
Electricity – electricity incomer	Elster AS230
Water meter	Elster Kent V200 type with 22mm connections
Irradiance meter	Elster AS230
Electric export	Elster AS230

9.3.2 Code 3 properties

Property 3B: Utilities monitoring only (see Table 8-3)

Meters were installed later than originally planned, due to tenant failing to allow access to the property on multiple occasions.

- Gas pulse interface and logger
- Electricity import/export plus LDC
- Water data logger and water meter were planned, but could not be fitted due to tenant refusing access.

Table 8-3: Property 3B meters

Meter	Equipment
Gas meter – gas incomer	U6 (2L Model) Metric Gas Meter
Electricity	Unspecified

Property 3A: Detailed monitoring in full compliance with TSB programme (see Table 8-4).

Utilities metering:

- Gas pulse interface and logger

- Gas pulse interface for sub-gas meter provided by t-mac for metering of cooker gas consumption
- Electricity import/export plus LDC
- Water data logger and water meter

Environmental and detailed monitoring:

- Electricity gas and heat sub-metering and environmental sensors
    - Temperature, humidity and CO_2
    - Heating and DHW heat metering on heat output from boiler
    - Metering of all electrical sub-circuits (lighting, small power, MVHR, immersion heater, heating controls)
    - Some electrical sub circuits could not be metered due to space/cost constraints (electrical supply to gas cooker, smoke alarm, doorbell, rainwater harvesting)

Table 8-4: Property 3A meters

Meter	Equipment
Electricity – Bedroom 2 (landing and downstairs)	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – immersion heater	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – second floor lighting	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – first floor lighting	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – second floor sockets	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – kitchen sockets	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – heating controls	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-1216 & 001-1231 & 500-51759
Electricity – ground floor lighting	Esti Meter GPRS 8CT, SIM Card & Power Supply:001-

	1216 & 001-1231 & 500-51759
Internal humidity (%) and internal temperature sensors (°C)	2 per property: Wireless Temp & RH Sensors:001-1217 plus 2 off batteries 500-50362
Heat meter – Hot Water	22mm heat Meter: Kamstrup 22mm Heat Meter plus pulse module (not M-Bus) Plus WiST Pulse Counter 001-1239
Carbon dioxide (CO_2 ppm), humidity (%), and temperature (°C) sensor	Wireless Temp/c02/RH: 001-1230 plus 1 off batteries 500-50362
Temperature (°C)	Wireless External Temperature Sensor:001-1232
Electricity – MVHR (heat recovery)	Single Phase Direct Connect Electricity Meter:500-51947
Heat meter - Heating (meter replaced during monitoring period)	22mm heat Meter: Kamstrup 22mm Heat Meter plus pulse module (not M-Bus) Plus WiST Pulse Counter
Cooking gas	Unspecified
Water	Elster Kent V200 type with 22mm connections
Gas meter – gas incomer	U6 (2L Model) Metric Gas Meter
Electricity – electricity incomer	Unspecified
Electric export	Unspecified

9.4 Photographic Survey

A photographic survey was conducted to act as a visual library of the as-built properties and the technologies installed within them. The photographs cover all of the key aspects of the properties to give an idea of how the properties are set up, and provide a visual aide.

9.4.1 Code 5 properties

Image ref:	**1**	**Floor:**	**n/a**	**Room:**	**n/a**

Front of the two Code 5 properties (Property 5B on the left, Property 5A on the right) with one of the Code 3 properties (Property 3A) in shot in the background (left). Both Code 5 units are monitored in this study, with Property 5A monitored in detail. The front wall of all the properties in the study is North facing and features small windows, in contrast to the rear of the property.

Image ref:	2	Floor:	n/a	Room:	n/a

Rear of Property 5A (Code 5 property receiving detailed metering and analysis). The steel framed bay structure is clearly visible on the left hand side of the image, complete with solar shading above the large first and second floor windows. The rear “family” room on the ground floor is partly obscured by the shed; however it should be noted that the bay structures on the floors above offer some shade to the windows on the ground floor.

Detailing in fitting the steel framed bay onto the wood framed structure was a key challenge in the design process.

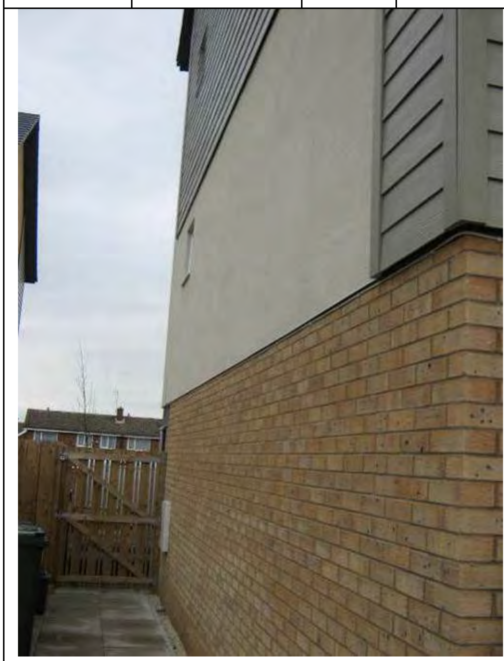
Image ref:	3	Floor:	n/a	Room:	n/a
					
External Air Source Heat Pump at Property 5A (Code 5). Located in the rear garden area.					

Image ref:	4	Floor:	Ground	Room:	By M&E cupboard under stairs
					
System control units at Property 5A (Code 5). Located by the M&E cupboard under the stairs. The top unit (NIBE) programs the heating system including heat pump. The bottom unit (ECO-VAT) controls the rainwater harvesting system.					

Image ref:	5	Floor:	Ground	Room:	

Rainwater harvesting system water butt (for external water use), Property 5A (Code 5) property. Located in rear garden.

Image ref:	6	Floor:	Ground	Room:	



The West facing side wall of the Property 5A (Code 5) property.

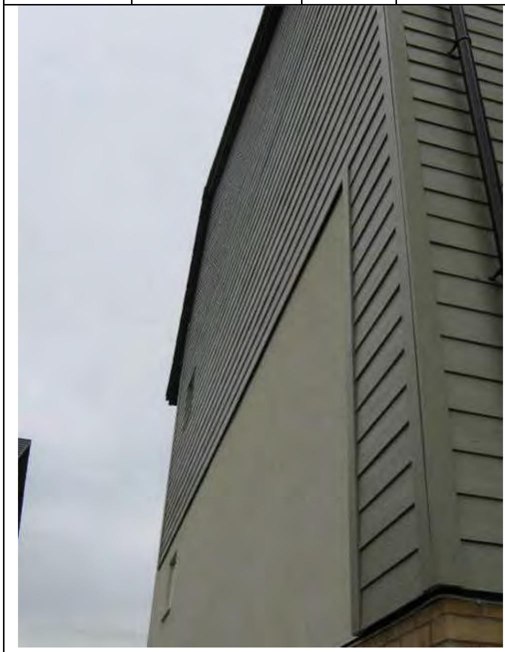
Image ref:	7	Floor:	Ground	Room:	
					
The West facing side wall of the Property 5A (Code 5) property. Note the mix of external finishes – Hardie Plank cladding, with render and brick clad at ground floor level.					

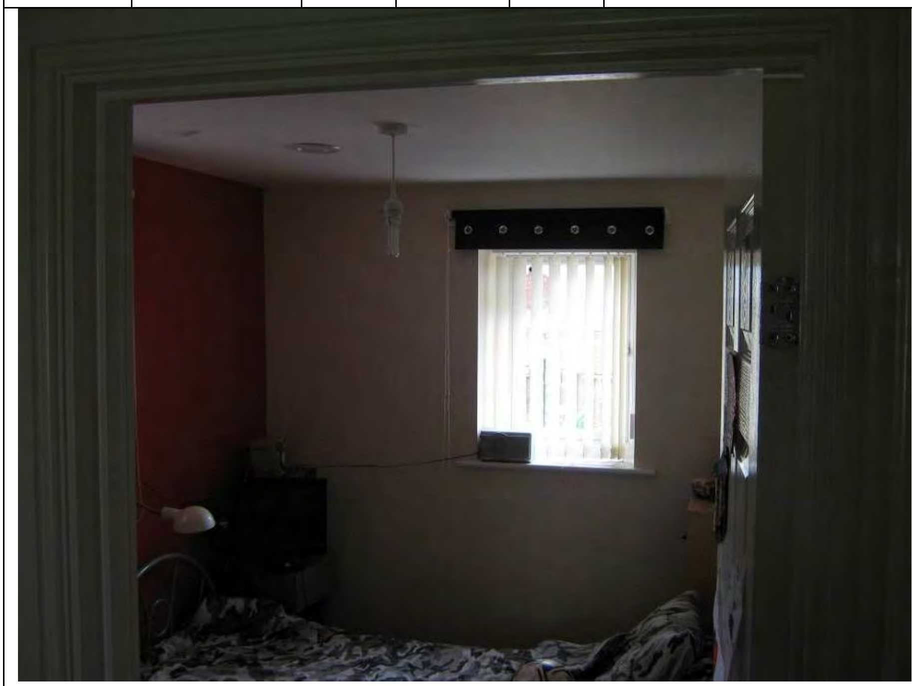
Image ref:	8	Floor:	Ground	Room:	
					
The rear (south facing) patio of the Property 5A (Code 5) property. This patio area and the bottom floor rear room of the property benefits from some natural light but are shaded from direct sunshine by the overhanging 1st floor kitchen above.					

Image ref:	9	Floor:	Ground	Room:	Family room/bedroom 4 (rear)
					
The main hot water tank connected to the air source heat pump in the Property 5A (Code 5) property.					

Image ref:	10	Floor:	1st	Room:	M&E cupboard
					
The 1st floor M&E cupboard in the Property 5A (Code 5) property.					
Image ref:	**11**	**Floor:**	**Ground**	**Room:**	**Entrance hall**

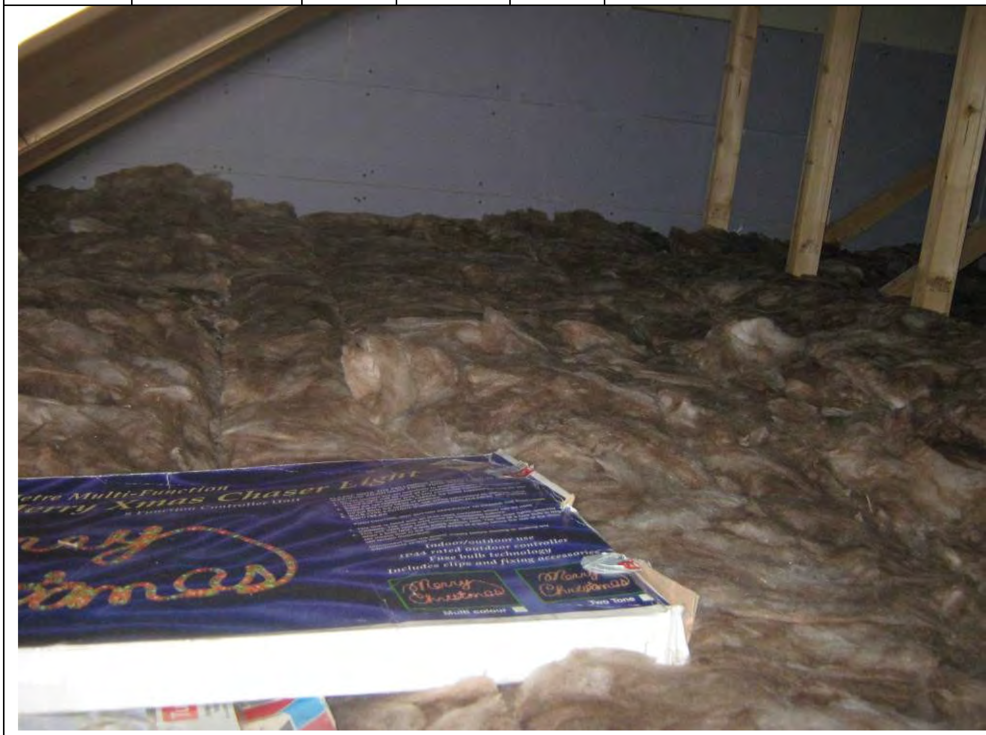
The Solar PV meter, PV inverter isolation switch, and fuse board in the Property 5A (Code 5) property.

Image ref:	12	Floor:	2nd	Room:	Bedroom



One of the top floor front (north) facing bedrooms in the Property 5A (Code 5) property. The front, north facing rooms in all the study properties feature small windows and are dark compared to the south facing rooms at the rear.

Image ref:	13	Floor:	Loft	Room:	Loft



Loft insulation in the Property 5A (Code 5) property.

Image ref:	14	Floor:	Loft	Room:	Loft

Loft insulation in the Property 5A (Code 5) property.

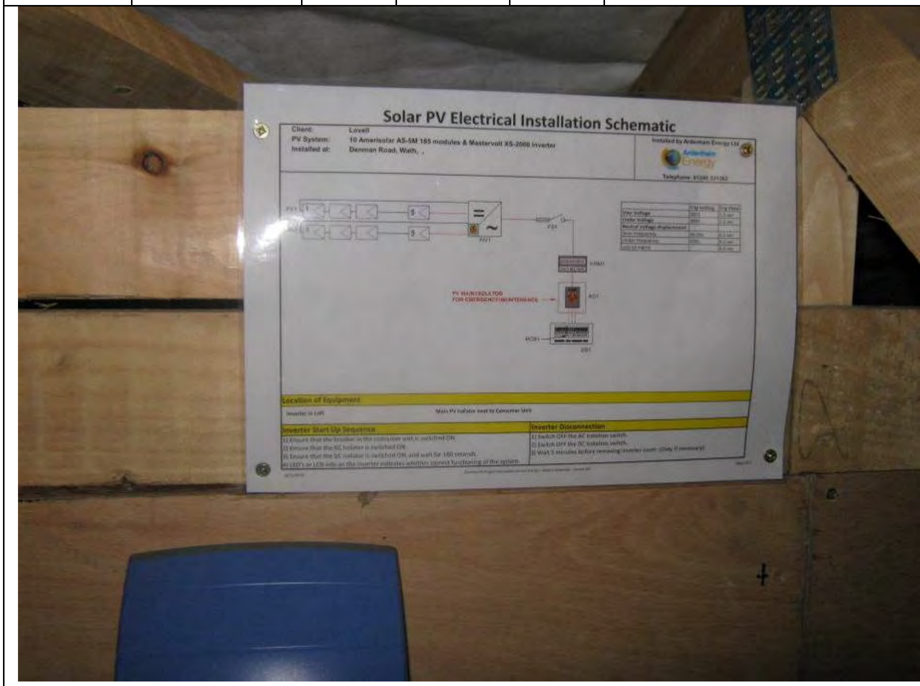
Image ref:	15	Floor:	Loft	Room:	Loft

PV inverters (2 of 3) in the Property 5A (Code 5) property.

Image ref:	16	Floor:	Loft	Room:	Loft

PV inverter (1 of 3) in the Property 5A (Code 5) property.

Image ref:	17	Floor:	Loft	Room:	Loft

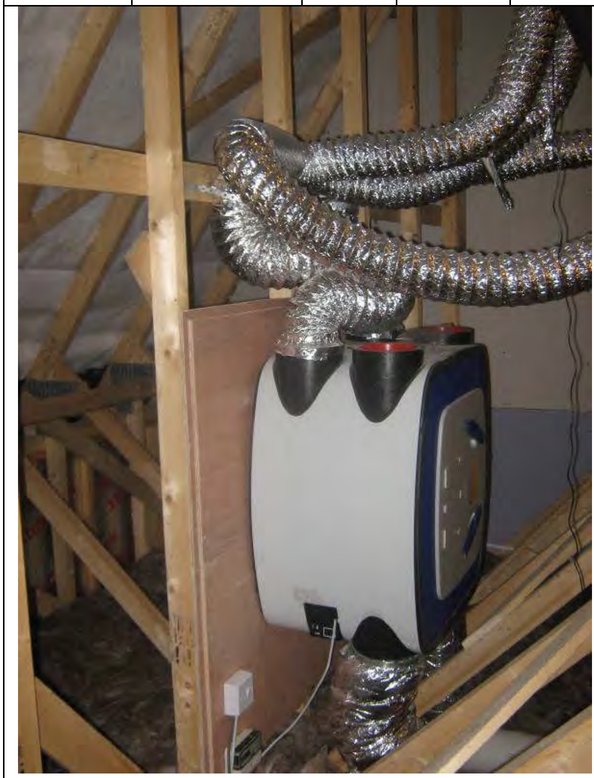


PV system diagram in the Property 5A (Code 5) property. The diagram is incorrect because the system actually has 14 PV panels making up 2.6kWp (rather than the 10 panels / 1.85kWpindicated on the diagram) and 3 inverters (rather than 1 as suggested on the diagram).

Image ref:	18	Floor:	Roof	Room:	n/a

14 x 185W PV panels on the roof of the Property 5A (Code 5) property.

Image ref:	19	Floor:	Loft	Room:	Loft



MVHR unit in the loft of the Property 5A (Code 5) property. Controls are located in the kitchen and bathrooms.

9.4.2 Code 3 properties

Image ref:	19	Floor:	n/a	Room:	n/a
					
Front of the row of three Code 3 properties (Property 3B, Property 3C, Property 3A), with one of the Code 5 properties (Property 5B) in shot in the foreground (right). Both end unit Code 3 properties are monitored in this study (Property 3B and Property 3A). The front wall of all the properties in the study is North facing and features small windows, in contrast to the rear of the property.					

Image ref:	20	Floor:	n/a	Room:	n/a
					

Rear of Property 3A.

Image ref:	21	Floor:	1st	Room:	M&E cupboard

Gas boiler in Property 3A.

Image ref:	22	Floor:	1st	Room:	Kitchen

Kitchen with gas cooker in Property 3A.

Image ref:	23	Floor:	2nd	Room:	Bedroom
					
Top floor lounge (used as a rear bedroom in practice) in Property 3A. The rear, south facing rooms of all the study properties feature large windows to benefit from the natural light and views over the adjacent field.					

Appendix B - About the building: design and construction audit, drawings and SAP calculation review

10.1 Introduction

Design of study buildings

Passive solar design resulted in an unusual cross section featuring a suspended bay construction to the upper two floors of the properties. The extended bay areas were protected from excessive solar gain in summer using a combination of an extended roof shading living space, suspended brise-soleil protecting the kitchen/diner, and the bay itself shading the ground floor study space. An asymmetric roof was specified to maximise space for solar PV and solar hot water panels.

Surrounding environment

The site is bordered by the existing properties within the estate, which run parallel to the North and East, with an active farming field to the South and West. Across the field to the South of the site is a relatively new farm development with long distance views of the site. The surrounding context of the site was described as "nondescript architectural quality" in the planning application. Surrounding developments are relatively young in age and mainly consist of two storey semi-detached family dwellings. There is no significant planting or trees in the surrounding area. The study buildings are therefore exposed to southerly winds across the open field.

Figure 8-2: Green field boundary at the site

Figure 8-3: Existing properties at the estate

10.2 Overview of the planning, design and construction process

The first phase of the development near Rotherham was spread across a substantial period of time. The scheme was initially conceived in 2006, prior to the onset of economic instability in 2009. The change in economic climate had a substantial impact on the timing of delivering the development, and had knock on impacts on design due to budget constraints. This section summarises the history of the development, separating the process into the planning phase (running up to planning consent), and the Design and construction phase (running from planning approval to commissioning).

The development was delivered through a partnering arrangement. This allowed the delivery partners to be selected through a framework agreement, eliminating the need for a formal tendering process. The use of this procurement route was highly praised by the architect, designer and TGP as fostering a positive and collaborative working relationship which helped significantly when designing properties to meet the high Code levels on the Code 5 dwellings. To its detraction, it was noted that this approach could be slower when decision making was required as decisions were expected to be more widely consulted upon.

10.2.1 Planning phase

The bulk of the scheme's development up to planning consent was carried out by the architect (AA Design Ltd, Sheffield) and GNC. The planning submission aimed to retain flexibility during the design phase and was therefore not overly prescriptive in technical detail where this could be avoided.

The outline planning application was submitted in February 2007 and full planning application submitted in November 2007.

The Code for Sustainable Homes (CSH) was introduced during the planning stage design process so initial targets were based on the Ecohomes standards and transferred to the CSH). Unfortunately, the planning stage work was carried out entirely by the architect, and due to staff turnover no-one was available for comment on the impact of this change. The design of the properties was approached from first principles rather than simply adapting existing standard designs to achieve a higher Code rating.

Figure 8-4: Early concept sketch of the site (top) and planning stage site layout drawing (bottom). The Code 5 "eco prototype" properties are located on the southern edge of the site, ringed in red above. The top sketch is not aligned to North and is an early plot layout prior to consideration of individual property designs, hence

the rotation of the axis of two Code 5 properties.

The first sketch was produced as a plot layout sketch before the internal layout of the properties was considered. Further examination of the space available indicated that five properties could be fitted into the space available hence the change from four to five plots in the highlighted area

A very early initial concept sketch and a section drawing from the planning application are included below. There are substantial changes from concept to planning stage, this is to be expected – the following is comment by the Development Co-ordinator regarding the changes:

> *"The top drawing was a very early concept drawing by the architects and Guinness Northern Counties. The design as drawn would not have achieved a Code 5 SAP rating as PV panels were required to do this. The bathrooms were moved to the centre of the building to enable windows to be placed in the bedrooms. Wind turbines do not work on small scale schemes and were therefore removed. The passive stacks were removed and replaced with a high efficiency MVHR system as the air permeability of the building was below 3 and the MVHR gave a big advantage in achieving the required SAP rating.*
>
> *After a lot of consideration and modelling in SAP it was decided that PV with a heat pump was the most cost effective way of achieving Code 5."*

It is noted that the overarching concept of passive solar design has been retained along with the asymmetrical roof profile, wood framed construction and solar water heating. High cost or riskier elements such as the high thermal façade, passive stack ventilation, wind turbine and green roof were not carried through to the planning stage design – it is noted that the concept sketch presented here was a very early example showcasing ideas of technologies that could be used in the final dwellings. In practice the decision of the services strategy which could be used to meet Code 5 was made in the design phase by Lovell's (later in the project) hence options like passive stack ventilation, wind turbines etc. were at their discretion. Green roofs were ultimately included on a pair of Code 3 bungalows elsewhere on the development where they could be accessed more readily in the event of any problems.

Figure 8-5: Early concept sketch of the eco-prototype dwellings

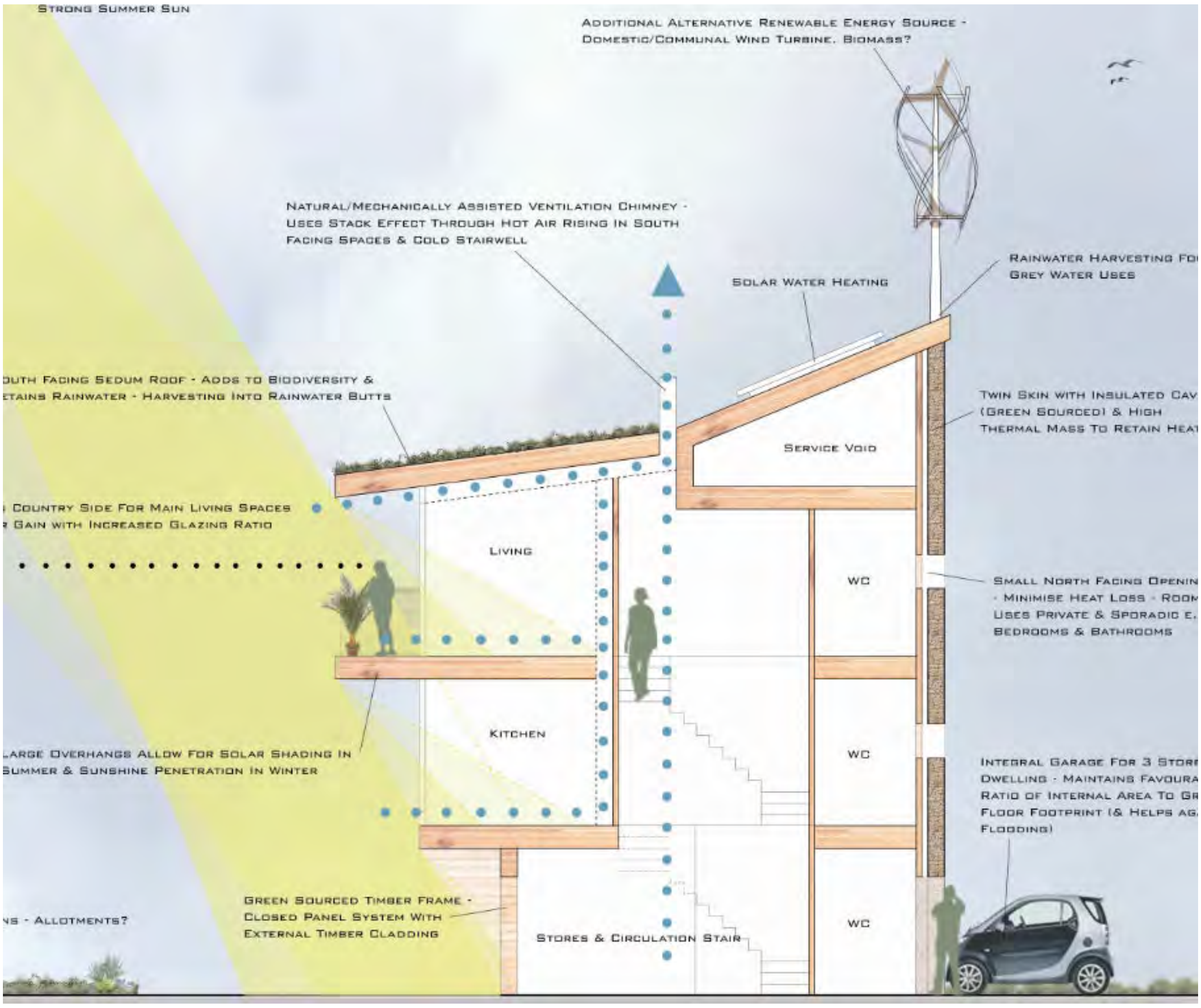


Figure 8-6: Planning stage section drawing highlighting the novel suspended bay to the rear of the property and passive solar design

An asymmetric roof was specified to maximise space for solar PV and solar hot water panels. There were no structural changes required to the planning stage designs to accommodate the MVHR systems; the ductwork passes through stud walls and ceiling voids and does not penetrate any structural features.

The wood framed solution was desirable for a number of reasons:

- It helped to achieve the required points for selection of renewable materials under CSH
- prefabricated panels offered an excellent U-value standard
- Wall thickness compared could be reduced to conventional cavity construction,

10.2.2 Design and construction phase

Planning approval was granted on 20th March 2008, allowing the project to move into the detailed design phase. At this stage Lovell were selected as the lead contractor under the partnership arrangement and took an active role in the design process along with select suppliers and subcontractors involved in the design process (e.g. ITHO (ventilation), NIBE (heat pumps) and Aqua Interiors (Mechanical design)).

The detailed design process was significantly lengthened by the unstable economic situation. Extensive value engineering was undertaken during the detailed design process in response to budget constraints; however the overarching goal of delivering a flagship sustainable scheme was retained and protected as far as possible. The passive solar design, rear bay structure, and external finish on the properties were already locked in through the planning process, so cost savings were generally made internally if possible. A summary of the impacts of the economic situation on the delivery of the scheme follows:

- Initial start date was November 2007 with expected completion April 2009.
- End of November 2007 GNC started to look at costing.
- 7th January 2008 announced as start date.
- Start on site moved to June 2008.
- April 2008 fee underwritten to get timber frames designed by Frame UK.
- 29th October 2008 value engineering meeting held.
- May 2009 set as the new start date after several value engineering exercises.
- Construction pre-start meeting announced for 8th April 2009.
- July 2009 another value exercise carried out.
- 7th Jan 2010 identified as new start date, due to on-going contract discussions.
- Actually started on site February 2010.

As far as the study dwellings are concerned, the most striking impact of the value engineering process during the detailed design phase was to reduce the number of Code 5 properties from 5 to 2. The cluster of 3 previously Code 5 properties was reduced to a Code 3 standard. However, the planners required that the layouts and external appearance of the properties had to be maintained – resulting in a very favourable set of study buildings for this building performance evaluation project.

The Code 3 dwellings were also switched to a traditional cavity wall construction for cost reasons – although the external cladding and finishes were maintained in keeping as far as possible in line with the planning submission.

In light of the planning restrictions there were few significant changes to the external architectural design of the properties during the design and construction phase.

A number of key features of the properties required extensive detailing during this stage of the process.

- Design and detailing of the steel rear bays was complex – especially on the Code 5 properties where the steel frame had to mate with the wood framed main building – therefore one structure would "settle" while the other would remain rigid. This differential movement added substantial complexity to the design process.

- The mechanical services strategies had to be determined and implemented. For the Code 3 properties this was not overly complex, however in order to achieve Code 5 a range of technological solutions was available and selection of the preferred strategy was based on techno-economic evaluation of a number of solutions in SAP to identify the least cost option. The properties were designed from the planning phase with generous space for M&E services on each of the three floors in the form of fitted cupboards directly above one another, to allow for easy routing of pipework. This eliminated the need for architectural changes in response to decisions affecting M&E strategy.

Build time for the properties was longer than a typical estate house due to the steel bays. Property 3A (Code 3 study building) started on site 5 July 2010, and Property 5A (Code 5 study building) started on site 26th July 2010. Practical completion was officially the same as the rest of the phase on 27th May 2011.

10.2.3 Construction/construction management processes

The project was delivered through a partnership arrangement which changed the dynamic of the project compared to a more traditional tendering process split between initial and detailed design and construction. It also ensured a high degree of continuity in team members throughout.

- Partnership agreement worked very well and encouraged a collaborative approach

- NHBC warranty and inspection process ensured high quality standards throughout and was very thorough.

- Lovell was the lead contractor and delivered the project through managed sub-contractors and own labour.

- Construction was co-ordinated on site by Lovell site manager – this worked well and targets were achieved e.g. air tightness first attempt demonstrates effective management.

10.2.4 Construction phase influences

- Novation of design team – through partnership arrangement
- Programme – the novel design of the timber framed properties and the hanging steelwork made the construction period longer (up to 28 weeks vs. 18 for a "standard" unit). If repeated they would probably still take longer than 18 weeks (maybe 24) due to the process needed.
- Economic influences had a major influence on the delivery of the development - the completion of detailed design and construction was substantially delayed as a result of extensive value engineering required to reduce costs in line with market forces.

10.3 Examination of design intent

10.3.1 Design targets

- Code 3 and Code 5 targets set at planning stage
- Air tightness targets set later (during detailed design)
    - For the Code 5's – 3.00m^3/m^2/hr at 50 Pa, actual result 2.95. Prior experience and education of sub-contractors important to achieve this to ensure they didn't jeopardise succeeding this. Air barriers around floors ceilings etc. used to assist this.
    - Design target air tightness for Code 3 units was 5 m^3/m^2/hr at 50 Pa, which was exceeded on all but one of the test samples.

10.3.2 Design intent and rationale for decisions on building fabric and technologies

Architect's overarching design intent

A key priority was to take maximum benefit from the south facing location to maximise passive solar gain, and to provide a showcase for passive and renewable energy technologies. While initial concepts briefly explored the possibility for inclusion of passive ventilation, green roofs and wind turbines, these were soon eliminated on practical grounds. The early concept sketches provided by the architect were considered undeliverable when examined retrospectively by the engineering team, but refinements by the architect were made prior to the planning stage. Hence, at the time the engineering team joined the process, the design of the properties had already been simplified to a more typical design.

Lovell design philosophy

A “fabric first” approach was adopted which focussed on achieving high building fabric standards in order to reduce the requirement for more complex renewable technologies.

Selection of building fabric specification

- Selection of a timber frame solution:
    - Timber frame was FSC certified and had high energy performance and sustainability credentials (Architect’s comment)
    - Lovell were familiar with the technology
    - Preliminary CSH assessment indicated that the timber frame would score highly.
    - Wall thicknesses could be reduced using timber frame
    - Achieving a good air tightness result was a key issue; the prefabricated timber frame panels offered a relatively straightforward approach which proved in many ways easier to manage than a traditional build.
- Selection of fabric standards:
    - U-values for timber frame wall fabric were intrinsic to the manufactured products and selection of the U-value was based on the available products rather than trying to find a product to meet a specific target.
    - Lovell led on the U-value/specification side with standards selected in parallel with the selection of building services to ensure that Code targets were met.
    - Intended supplier was “Frame UK” who was on the partnership framework but this was switched to use a supplier more familiar to Lovell.
    - Full details of the U values specified can be found in Section 10.7.

- Air tightness: Prior experience and education of sub-contractors important to ensure they didn't fail to meet Code 3 and 5 air barriers around floors ceilings etc. used to assist this.

Selection of technical solutions to meet Code targets

- The Code 5 units feature a relatively complex heat pump / solar hot water solution to provide heating and hot water to the properties (plus PV). This was selected on the basis of it being the least cost technically feasible option to achieve the required net zero carbon performance for CSH level 5, by comparing a range of possible solutions in SAP and costing each one. At first it was intended to use gas boilers with PV, MVHR and low U values. The heat pump was added to reduce the amount of PV required as roof space was tight to accommodate the amount of PV panels required and the heat pump also gave a better result in SAP than the gas boiler. An external energy / SAP consultant was employed to advise on what was required to achieve Code 5.

- If the calculation was repeated under the new (2009) version of SAP, it is probable that the heat pump solution would not be used, and a gas boiler/PV solution adopted. This is due to the fact that the newer version of SAP is less favourable towards electric heating due to using a higher carbon factor for electricity. SAP 2009 recognises the true benefits of high efficiency boilers and MVHR.

- A summary of the intended control strategy for the Code 5 heating and hot water provision is included below. This will be compared with the actual behaviour of the system in-use:

  - General operational principle: the heat pump is intended to maintain a constant store of heat in the hot water/heating buffer tank, which allows the heat pump on a regular basis at low output – this compensates for the fact that the heat pump has a lower peak heat output than a typical equivalent gas boiler.

  - Heat pump booster: the heat pump has an electric boiler (ELK) on the heating circuits to boost the temperature of the heating when external temperatures are low (around -5° C). At -15° C the heat pump shuts down automatically.

  - Zoning of heating: There are three main zones on the heating system: radiators to bedrooms; radiators to non-bedrooms and ground floor under-floor heating. The under-floor heating has three sub zones (one per room) with independent switching of time and temperature.

- Temperature/timer settings for heating: The system has a relatively high setback temperature (15°C) which is used as the thermostat setting when the heating is “off”. A higher temperature (21°C) is used during up to four “on” periods for each zone which can be independently set. A “boost” button is provided to raise the temperature outside the heating period.

- Hot water temperature is maintained 24/7 – the hot water tank sits inside the heating buffer vessel, minimising losses as some of the “lost” heat can be re-used in the heating system.

- Temperatures: The heat pump output temperature is relatively high (50°C) which reduces efficiency compared to heating only operation. Hot water temperature is typically around 50°C and is pasteurised using the immersion heater on a fortnightly cycle.

- When there is demand for hot water and heating, the hot water takes priority. Once the hot water tank is up to temperature then the heat pump switches to heating mode until this vessel is at the required temperature.

- The solar hot water system heats the bottom of the hot water cylinder where the water is coolest. However, the fact that the hot water tank is enclosed within the heating buffer vessel could result in lesser useful output being gained from the SHW as the hot water tank will be warmer than in a “typical” system with higher losses.

- The Code 3 properties feature a “typical” condensing system boiler arrangement with two zones serving radiator circuits and time and temperature control of hot water and heating.

- MVHR: specifying this technology delivers an improvement in SAP performance, but is also advisable due to the high air tightness standard of the Code 5 properties in order to ensure adequate ventilation is delivered.

    - Uses rigid letterbox ducting routed through stud walls to reach to lower floors & minimise resistance.

    - Joist manufacturers (Finn forest) provide proper mark-ups showing where any drilling can be done etc.

- ITHO designed the ductwork well before start on site to avoid any last minute changes to duct routes.
- Controls strategy is a permanent background and boost. Boost controls are a manual boost on the kitchen wall (wireless, but fixed to the wall to stop it getting lost) and boost linked to bathroom light switch.

10.4 Comparison of design intent/original specification with as-built

- Substantial changes from the initial concept designs through to the planning stage design. The final as built properties were, however, very similar architecturally to the planning stage design – the majority of the changes to the concept design were made very early in the process, calling into question the value of the initial concept – this could have raised unreasonable expectations in TGP before being substantially downgraded due to practical concerns.
- Balcony added over garage to improve the tenant's view into the courtyard
- The initial intent was to have the projecting bays constructed from timber frame as well as the main structure. This was not deemed to be practical so a steel solution was selected as an alternative – marrying this to the building was a potential challenge. Not recalled why this was not extended to three storeys to reduce construction challenge – could have been due to floor area desired.
- Selection of the air source heat pump was made at a time when arguments for future energy security and grid decarbonisation were viewed as tangible arguments against the use of gas (comment by AA Design). SAP 2009 has a much more sophisticated way of assessing boiler efficiency and revised carbon emissions factors, which combine to improve the case for gas boilers compared to heat pumps.
- Value engineering affected a number of areas during the detailed design stage
    - The Code 5's: Reduction in ecology standard for the gardens but otherwise very little change whatsoever.
    - The Code 3 study properties: They should have been Code 5's – so all differences from the Code 5's are effectively value engineering.
    - Planning restrictions on the outside appearance of the properties meant that the frontage to the road had to be maintained as it was at planning stage. The study building's external appearance was retained throughout the value

engineering process, but other adjacent properties had significant alterations in order to reduce the cost of the build:

- Hardie Plank cladding and render to rear of properties replaced with brick
- Artstone window surrounds cut from most windows to lounge only.
- Juliet balconies removed from rear elevations

- The heat pump unit in the Code 5 properties was switched from a NIBE exhaust air heat pump to a NIBE fighter 2015 air source heat pump during the design process, as NIBE retracted their initial statement indicating that the exhaust air heat pump was adequate for the property. The specification of a large solar hot water system is linked to this as it offsets as much of the hot water demand as possible to reduce the amount of high temperature heat required from the heat pump.

10.5 Key aspects of the design which could affect performance

- ECD are used to achieve the improved heat loss under SAP. [Code 5] Air barriers used on the ceiling and walls. No service ducts through the timber frame. Timber frame sections prefabricated off site. In many ways the timber frame made it easier to get an airtight construction – and this was demonstrated by the airtightness achieved.
- Rear steel bays – complex to detail and construct and required specialist acoustic considerations. Steel frame construction adjoining to timber frame was a design challenge and introduces a number of junctions.
- Technical solution for heating/DHW in Code 5 – the combination of heat pump and solar hot water was a challenge for the design and construction team and there are a lot of controls for this system (including five separate room stats and an external temperature sensor!). This made installation and commissioning complex and is likely to make achieving efficient operation complex for the tenants.
- Lots of junctions in the envelope design – the air tightness test results indicated that this was addressed successfully at the time of construction – the additional air tightness testing that will be carried out in the project will provide an indication whether settlement of the wood and steel frame construction will result in degradation of air tightness over time.
- The PV system is mounted on a shallow sloping roof at 3rd floor level. This makes it

impossible for the tenants to clean without dedicated access equipment. Over time dirt build-up on the panels could significantly affect performance, although the semi-rural location will reduce the severity of this compared to central urban locations. Furthermore, the design features three inverters (one 2kW, and two 300W units). This is a less efficient configuration than a single inverter, correctly sized, and introduced a risk that failure of the smaller inverters could go unnoticed as the drop in performance would only be approx. 10%, and the system is out of sight in the loft.

10.6 Perceptions, concerns and positive nuggets

- Performance of the novel elements in practice is a concern as there are a number of items which had not been attempted by the design team before.
- Defects reporting resulted in a very small amount of defects – TGP very satisfied. NHBC inspector was very thorough. Site Manager very satisfied with the quality of output.
- Team agreed that it was a very rewarding project to work on – big sense of satisfaction.
- “Best” – final product very satisfying, a cut above typical buildings – can imagine sitting there with a glass of wine – site manager.
- “Worst” – Architect – steel bays were overcomplicated and could potentially have been done in a less challenging way. Site manager – construction wise had to lift steelwork over the completed building. Best elevation can’t be seen by anyone. M&E designer – mechanical solution used in order to achieve Code 5 standards was too complex.

10.7 Review of SAP calculations

As-built SAP calculations were provided by Lovell for the Code 5 and Code 3 properties. “Design” and “As-built” calculations were not carried out as discrete separate stages in this case, as the selection of key items of the spec was carried out alongside an iterative process of carrying out the SAP calculations. Lovell advised that there was no functional change to the design once the final design iteration of the SAP calculations was carried out.

In order to verify the SAP calculations provided, we reviewed the SAP worksheet and input data against the final version of the specifications for the Code 3 and Code 5 properties respectively, and followed this with on-site investigation of other key issues and discussion with the design team to identify whether deviations were as a result of an error in the SAP input data or a deviation from the intended specification which was not amended in the SAP calculations.

This was carried out separately for each of the house types (Code 5 and Code 3).

The findings of the review are presented in the following sections.

10.7.1 Code 5 property

The Code 5 property examined was Property 5A, the property on which detailed energy and environmental monitoring is to be carried out.

Table 8-5: SAP calculation review against as built information and actual Code 5 property

Item	As-built SAP worksheet	Specification/plans	Actual building	Comments
Sheltered sides	2	Not specified	2	
Sunlight shade	M more than average	Minimal	Brise-soleil and overhanging roof provide shade to southern elevation	
Doors U-value	1.0 W/m².K	Not stated	Doors with a 1.0W/m2k were fitted as detailed in the spec	
Windows U-value	1.0 W/m².K	1.3 W/m2/k	Triple glazed windows with a 1.0W/m2k were installed.	The SAP calculation post-dates the specification which was not fully updated to reflect changes required to meet SAP targets – Chris Charlton, Lovell
Draught lobby	Yes	Yes	Yes	
MVHR	SFP 0.46	ITHO HRU eco4 0.46	ITHO HRU eco4 0.46	

Item	As-built SAP worksheet	Specification/plans	Actual building	Comments
Pressure test	2.95 $m^3/m^2/h$		2.95 $m^3/m^2/h$ – for property 5b as tested at completion	Property 5A was tested 1 year post occupancy, and underperformed compared to the design target (at circa 5 $m^3/m^2/h$). It was not tested at construction stage.
Lighting	100% EE fittings	100% EE fittings (electrical drawing)	100% EE fittings	Tenant in Code 3 property complained that bulbs are difficult to source. However, these fittings were mandatory at the time of construction. This has since been changed to standard bayonet fittings again.
Main walls / other walls U-value	0.14W/m².K	0.14W/m².K (as built elevations)	The in-situ testing verified the U-value to be 0.12W/m².K.	This shows better than expected performance – anecdotal comments from the BSRIA engineer suggest this is the best result he had seen in a U-value test, when comparing design-stage targets and in situ results.
Main roof	0.11W/m².K	0.11W/m².K (spec and as built elevations)	Loft Insulation thickness confirmed	
Garage roof	0.15W/m².K	Not specified ref to SAP calculations	Not accessible	
Floor	0.15W/m².K	0.15W/m².K (spec)	Not accessible	

Item	As-built SAP worksheet	Specification/plans	Actual building	Comments
Suspended floor	0.15W/m².K	Not specified ref to SAP calculations	Not accessible	
Main heating and efficiency	NIBE Fighter F2015-6kW. Eff 250%	NIBE Fighter F2015-6kW Manufacturer states COP 4.2 @7/35 °C and 2.7 at 2/50 °C	NIBE Fighter F2015-6kW	Big claims for operational COP of NIBE unit which seems to be corroborated by the monitoring data, though confidence in this data is low
Heating controls	CHD time and temp zone control, boiler interlock, weather compensator	CHD time and temp zone control, boiler interlock, weather compensator	CHD time and temp zone control, boiler interlock, weather compensator	OK
Heat emitters	Under-floor heating w/electric secondary heating (10%)	UFH (22%)/ radiators (78%)	UFH (22%)/ radiators (78%)	NHER guidance confirms that UFH with gas secondary heating should be specified – this would improve the score further.
Secondary heating	none	None	None	
Thermal store	None	None	None	
Hot water heating	From primary, immersion present COP effective 1.42	From heat pump with immersion	From heat pump with immersion	
Hot water cylinder	Yes, in heated space, with stat, separately timed		Yes, in heated space, with stat, separately timed	
Hot water cylinder insulation	Declared loss 1.68 pipes insulated		The declared loss factor should have been 3.6	The factor used in the SAP referred to a smaller unit and is therefore incorrect In the as-built

Item	As-built SAP worksheet	Specification/plans	Actual building	Comments
Hot water cylinder volume	300l	300l + 450l heating buffer inc. 150 dedicated solar	300l + 450l heating inc. 150 dedicated solar	Cylinder loss may be underestimated but overall performance in reality should be better as hot water storage is within heating buffer vessel. SAP unable to account for this specific system correctly.
Solar hot water present	Yes – 3.1 m2, zero loss coll. eff 0,81, Collector HLC 3.9 Over-shading 0 Dedicated solar vol. 150l Total cylinder vol. 300l	Clearline V30 panel, states 3.0m2, ZLC 0.81, HLC 3.9. No shading Actual cylinder 300l	Clearline V30 panel, states 3.0m2, ZLC 0.81, HLC 3.9. No shading Actual cylinder 300l	Additional heating storage volume of 450l not accounted for in SAP calculations
PV system	Peak power 2.6kW, south, 30 degrees, un-shaded	Peak power 2.6kW, south, 17.5 degrees, un-shaded	Peak power 2.6kW, south, 17.5 degrees, un-shaded	SAP correct to available level of accuracy
Thermal bridges	ECD used – y=0.04	ECD used – y=0.04	ECD used – y=0.04, reported by design team. The y value is a default value – it is unchecked by calculation.	
Produced energy – by technology	754 kWh		Confirm with Lovell what this is for	An additional credit of 754 kWh electricity produced has been included for the appendix Q calculation for the heat pump. See Section 10.8 for a discussion.

10.7.2 Code 3 property

The Code 3 property examined was Property 3A, the property on which detailed energy and environmental monitoring is to be carried out.

Table 8-6: Comparison of SAP calculations with as-built for the Code 3 dwelling

Item	As-built SAP worksheet	Specification/plans	Actual building	Comments
Sheltered sides	2	2	2	2 can be assumed within SAP guidance
Sunlight shade	A average or unknown	Minimal	Brise-soleil and overhanging roof provide shade to southern elevation	
Doors U value	1.2 W/m².K	More than one value in the document – not specified which is used	1.2 W/m2 doors were fitted	
Windows U - value	1.4 W/m².K	1.3 W/m2/k	Could not be verified	Design team confirmed U value 1.37 W/m2/k
Draught lobby	Yes	No	No – Code 3 layout differs from Code 5	This is not correct in SAP – it has no impact on the actual calculation as the actual AP value is used.
MEV	SFP 0.46	ITHO HRU eco4 SFP 0.46	ITHO HRU eco4 0.46	MVHR test will confirm energy use
Pressure test	6 $m^3/m^2/h$	Aimed for 5 as the target	Actual tests on Code 3's 3.03 to 5.23 $m^3/m^2/h$	Our own test will confirm current value
Lighting	5 EE/12 total fittings	Plans - 21 fittings, 16 pendant and 5 batten / ceiling rose	DomEARM audit survey showed 24 fittings	
Main walls / other walls U value	0.21/0.20/0.19 W/m².K	Rendered – 0.21, Hardie Plank clad – 0.19.	U value testing of rendered wall indicated 0.19 W/m².K	Verified & exceeded through testing

Item	As-built SAP worksheet	Specification/plans	Actual building	Comments
Main roof	0.11W/m².K	Proposed 400mm fibreglass and ref. to SAP calculations 0.11W/m².K	Loft insulation thickness confirmed onsite (although slightly disturbed in places	
Roof slope	0.18W/m².K	0.18 W/m2 for sloping/canted ceilings	Not accessible	
Floor over garage	0.2 W/m².K	N/S	Not accessible	
Floor	0.15W/m².K	0.15W/m².K (spec)	Not accessible	
Exposed floor	0.21W/m².K	Not specified – the specification refers to the SAP worksheet to define this value	Not accessible	
Main heating and efficiency	Main 15 HE A 91.3%	Condensing system boiler SEDBUK 91.2 or better	Baxi Megaflo System HEA 15 91.2%	Equivalent
Heating controls	CBI time and temp zone control, boiler interlock	Specification and drawings state 2 zones bedrooms/other.	There are 2 heating circuits each with a room stats/timer	
Heat emitters	Radiators	Radiators	Radiators	
Secondary heating	None	None	None	
Thermal store	None	None	None	
Hot water heating	From primary	From primary	From primary	
Hot water cylinder	Yes, in heated space, with stat, separately timed	In heated space, with stat, separately timed	In heated space, with stat, separately timed	
Hot water cylinder insulation	Foam, 50mm, insulated pipes	Minimum 70mm insulation	Manufacturer’s declared heat loss 1.9kWh/24h	If the manufacturer’s declared factor was used the losses would be lower; no unfair gain achieved

Item	As-built SAP worksheet	Specification/plans	Actual building	Comments
Hot water cylinder volume	210 l	210l and 250l units referenced in specification, with the size to be confirmed by specialised sub-contractor, dependent on house size.	210 l	
Solar hot water	No			
PV system	No			
Thermal bridges	Default robust construction used – y=0.08	Not specified – was driven by SAP calculations and not updated later	Building was designed using accredited construction details allowing default value of y=0.08 to be used	

10.8 Comment on potential issues noted with the SAP calculations

In order to determine the impact of the possible inaccuracies noted in the SAP calculations, a parallel model was created. It was not possible to get an exact match, possibly due to the use of different software versions. We used NHER v 4.2 whereas Lovell used Elmhurst SAP 2005.017.03. Our model did however match to within 0.07kgCO2/annum, so the deviation is considered negligible.

- NHER 4.2 required extra inputs relating to zone 1 area that did not appear in the outputs from the Elmhurst system
- There appeared to be an error in the Elmhurst software's treatment of the MVHR in a highly airtight dwelling (ACH 0.37/hr instead of defaulting to ACH 0.5/hr)
- The treatment of lighting differed slightly – despite both packages having 100% dedicated LEL specified, NHER gave a positive internal gain from lighting, whereas in EES it was negative

The following errors were noted in the "as built" SAP, and corrected in our "corrected" model:

1. Orientation: the main windows in the "as built" SAP were facing north not south. This actually makes the CO_2 performance slightly worse in the "As Built" SAP compared to Verco's corrected model due to reduced solar gains.

2. MVHR: number of additional wet rooms should be 3, not 1 as used in model. This increases ventilation energy use & ventilation heat loss slightly in Verco's corrected model.

3. Declared loss factor for water cylinder was incorrect (should have been 3.6kWh/day not 1.68kWh/day) – this increases the energy used for hot water production significantly by around 400kWh. The value of 1.68 related to the unit used in the original specification, which was not updated in the SAP calculation when the specification changed. This also has a dramatic effect on the SAP appendix Q calculation, reducing the electrical energy saved from 754kWh to 73kWh.

4. Tank volume for water cylinder was also incorrect due to the issue identified in item 3 above– it should have been 300l + 150l solar volume not 150l + 150l solar volume. However, it is noted that this configuration of a hot water vessel enveloped in the heating buffer vessel cannot be adequately described in SAP, there is no guidance on whether the volume of the heating buffer vessel should be included in this volume, or how to address the fact that the solar coil is located in the heating buffer vessel (the lower temperature element) rather than the hot water storage tank.

5. Secondary heating was entered as electricity – it should have been gas room heaters according to section 8 of the NHER assessor's guidance

The effect of all these deviations is not insignificant. The incorrect heat loss factor for the hot water has a big impact on the Appendix Q calculations, meaning that the additional energy savings associated with the heat pump should have been 73 kWh, rather than 754 kWh.

The DER of our SAP model developed to match the "As Built" calculation was -0.20kgCO_2/m^2/yr. The DER of our "corrected" model was 2.51kgCO_2/m^2. Within this calculation, the "corrected" Appendix Q calculation of 73 kWh has been used. This has the effect of downgrading the property from Code for Sustainable Homes level 5, to Code level 4.

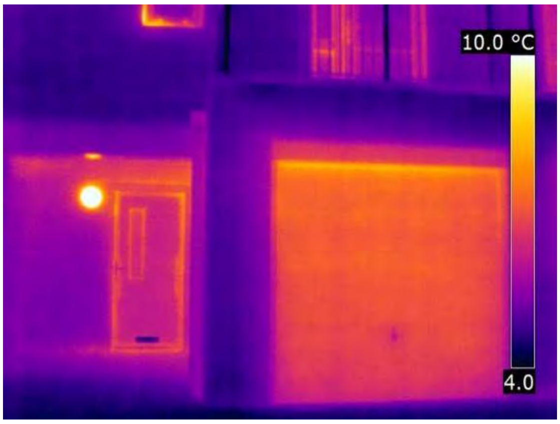
The implication of this is that to achieve Code 5, Property 5A would need an additional 0.6 kWp of solar PV panelling (which corresponds to approximately 6m^2 of panels). This is beyond the realms of technical feasibility due to insufficient remaining space on the south facing roof slope.

The impact of the shortfall in air tightness has also been investigated within the SAP methodology by reducing the air tightness to the as built test results of 5.4 $m^3/m^2/hr$. The impact of this is an increase of 128 kWh (from 640kWh to 768kWh) for the electricity consumption for main space heating electricity consumption (equivalent to a 20% increase).

Appendix C - Fabric testing (methodology approach)

11.1 Thermographic study

The results from the thermographic surveys for the properties at Property 3B, Property 3C, Property 3A, Property 5B, and Property 5A are included below. The thermograms are shown adjacent to a photograph of the same area of the properties. Observations are highlighted below each pairing.



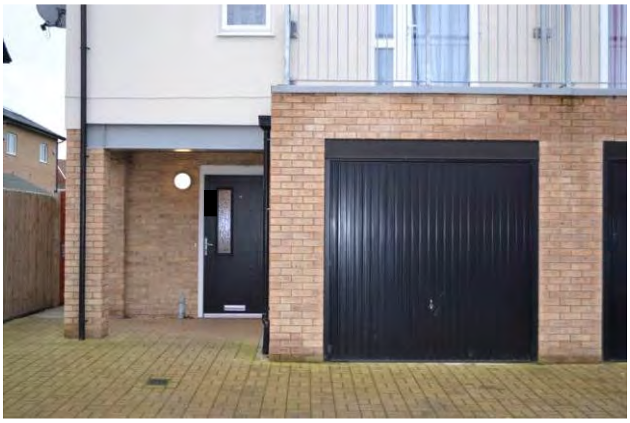


Image 1: Property 3B Front Ground Floor. Observations: Porch area temperature elevated, door had been in use.

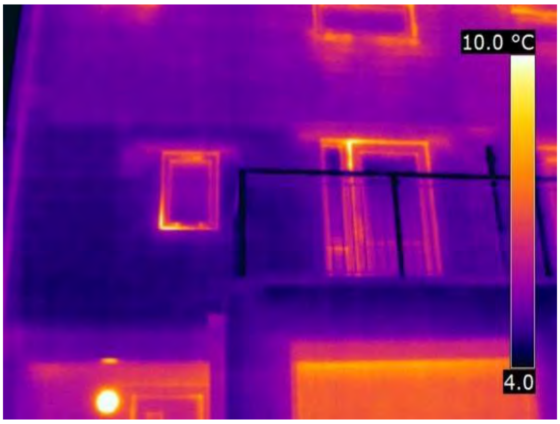


Image 2: Property 3B Front 1st Floor. Observations: leakage to bottom left corner of window and top left of door. Elevated temperature above door.

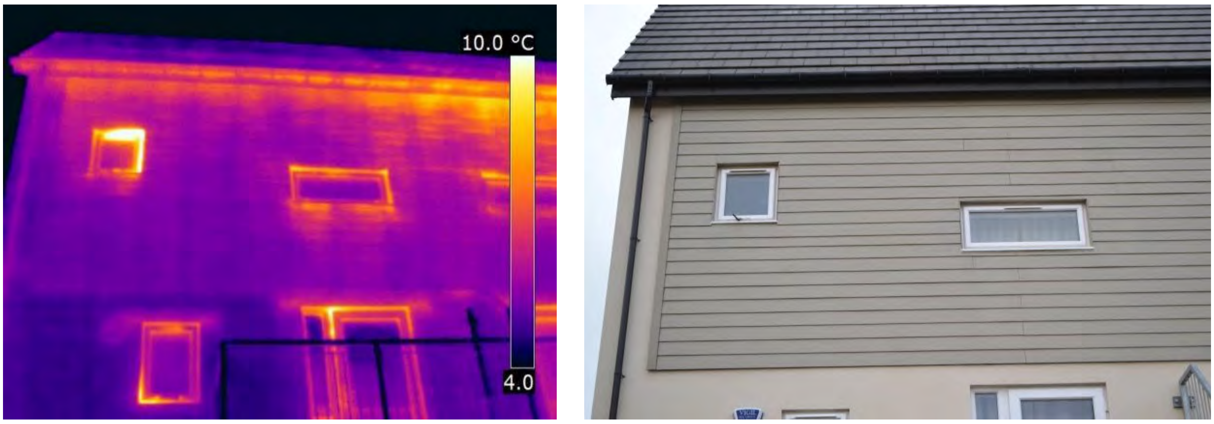


Image 3: Property 3B Front 2^{nd} Floor. Observations: Elevated temperature at top of cladding. Note: cladding is ventilated. Potential leakage at window corners

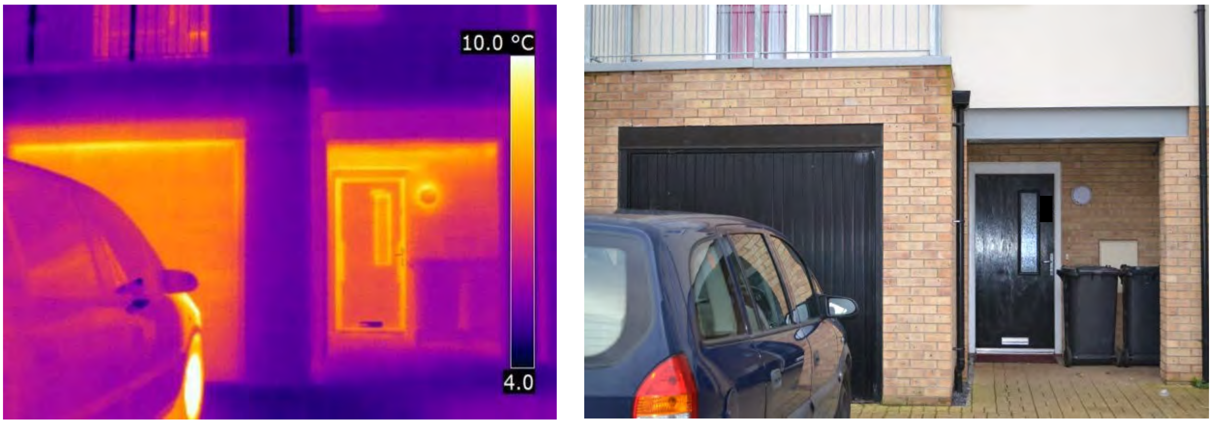


Image 4: Property 3C Front Ground Floor. Observations: Porch area temperature elevated, door had been in use.

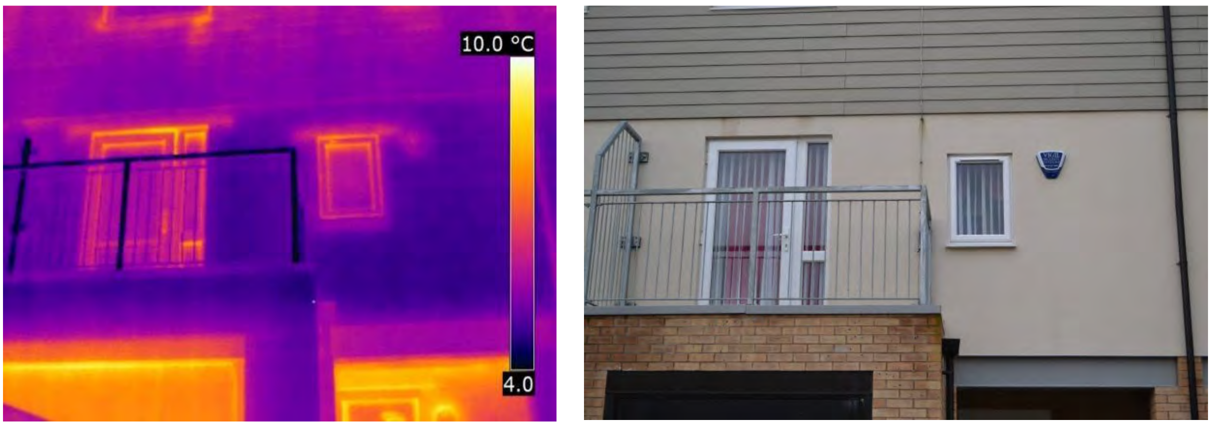


Image 5: Property 3C Front 1^{st} Floor. Observations: Elevated temperatures above windows and door

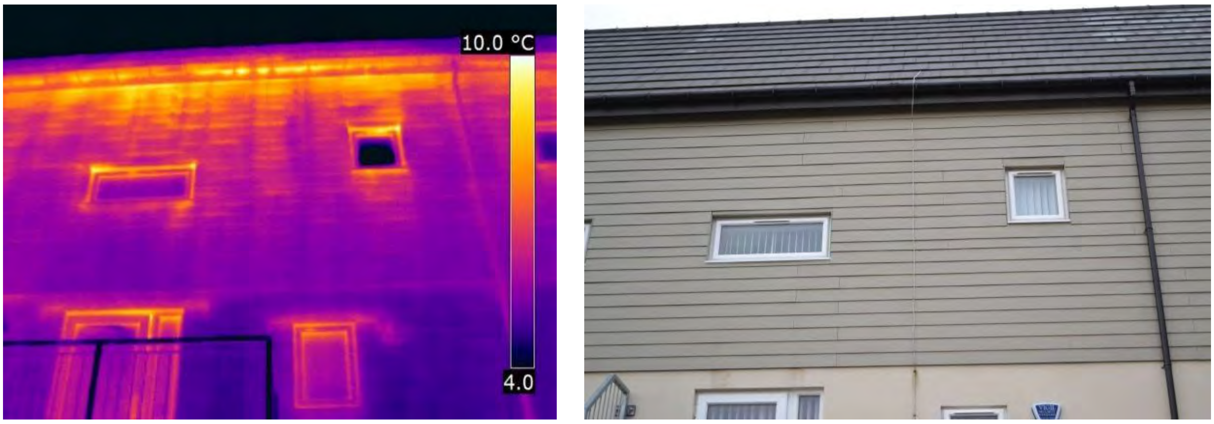


Image 6: Property 3C Front 2nd Floor. Observations: Elevated temperature at top of cladding. Note: cladding is ventilated. Potential leakage at window corners

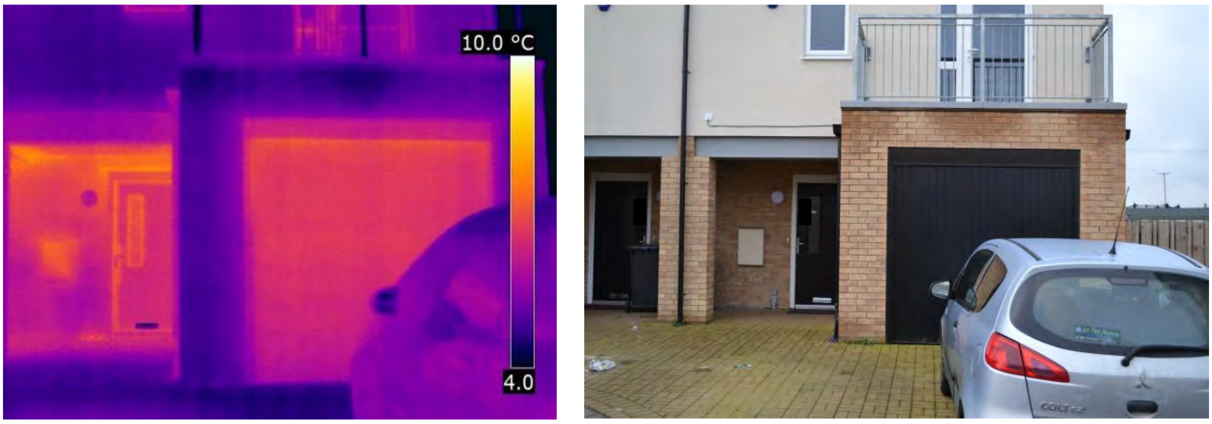


Image 7: Property 3A Front Ground Floor. Observations: Localised temperature elevation at meter box. Porch area temperature elevated, door had been in use.

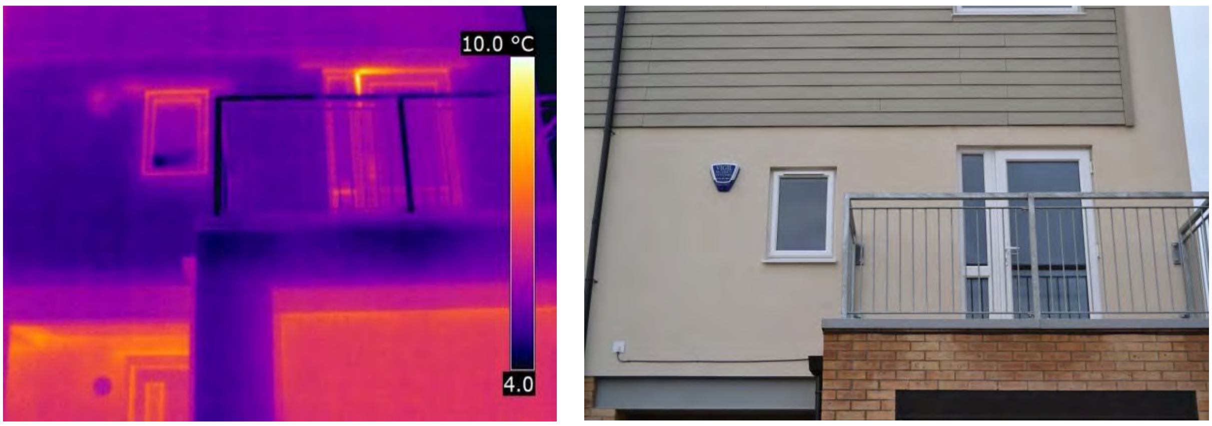


Image 8: Property 3A Front 1st Floor. Observations: Leakage at top left hand corner of door. Elevated temperature above window and door

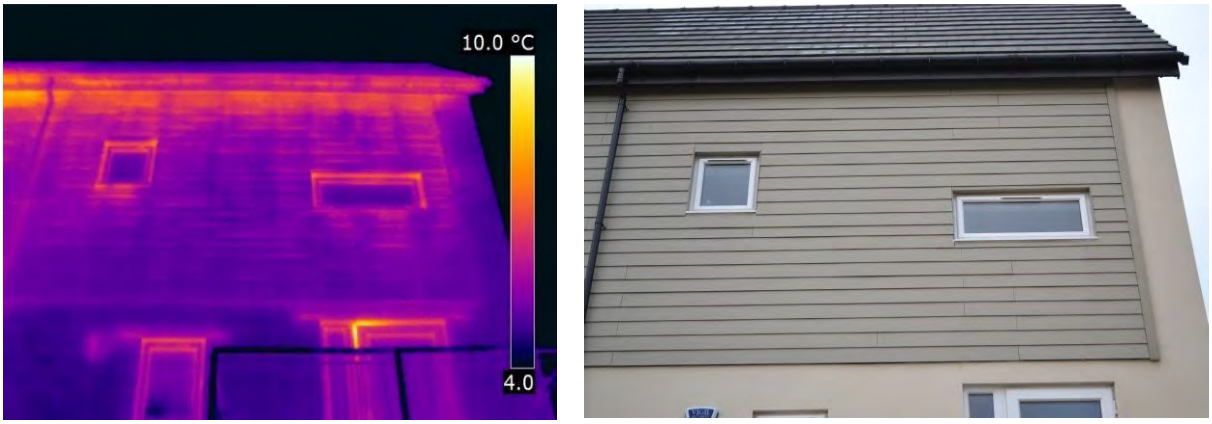


Image 9: Property 3A Front 2nd Floor. Observations: Elevated temperature at top of cladding. Note: cladding is ventilated

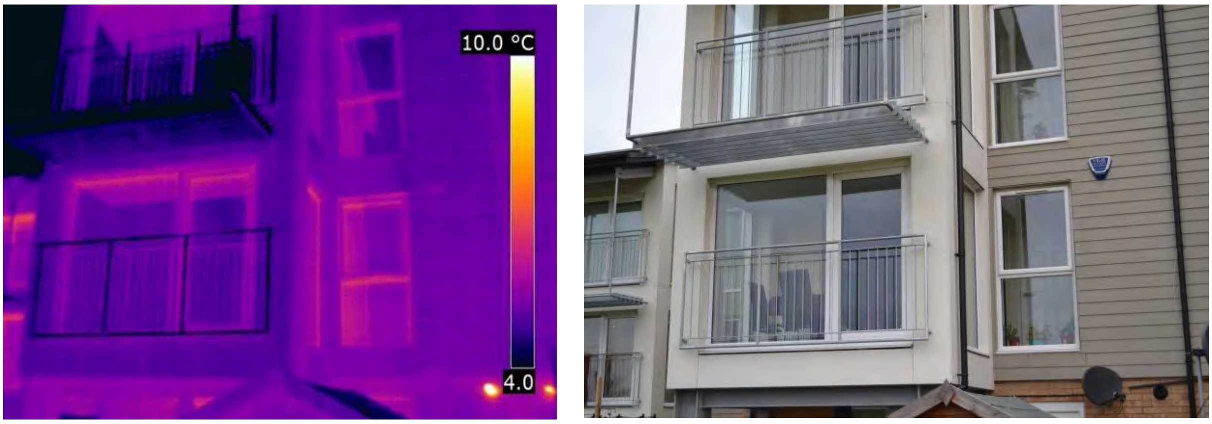


Image 11: Property 3B Rear 1st Floor. Observations: No thermal anomalies observed.

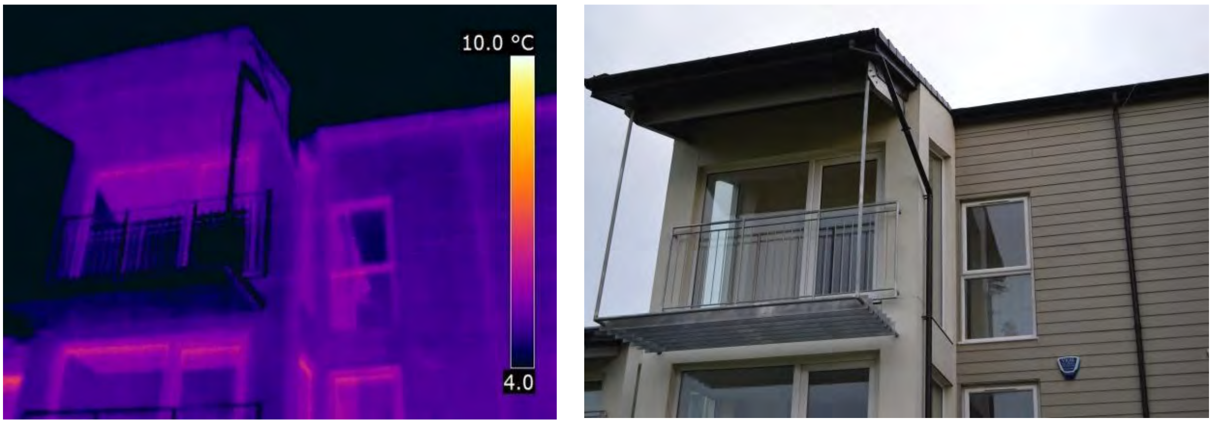


Image 12: Property 3B Rear 2nd Floor. Observations: No thermal anomalies observed.

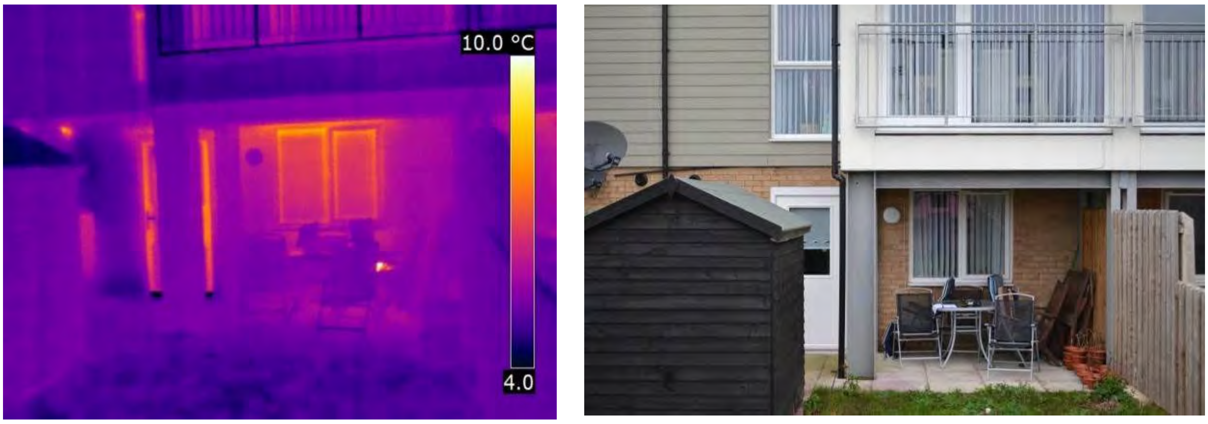


Image 13: Property 3C Rear Ground Floor. Observations: localised temperature elevation above window.

Image 14: Property 3C Rear 1st Floor. Observations: No thermal anomalies observed.

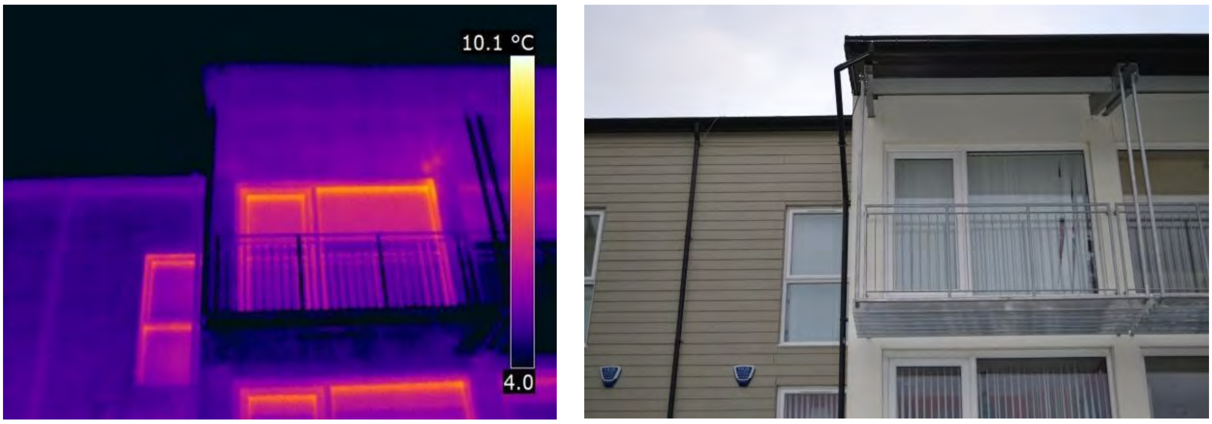


Image 15: Property 3C Rear 2nd Floor. Observations: Minimal localised temperature elevation to elevation top left of window

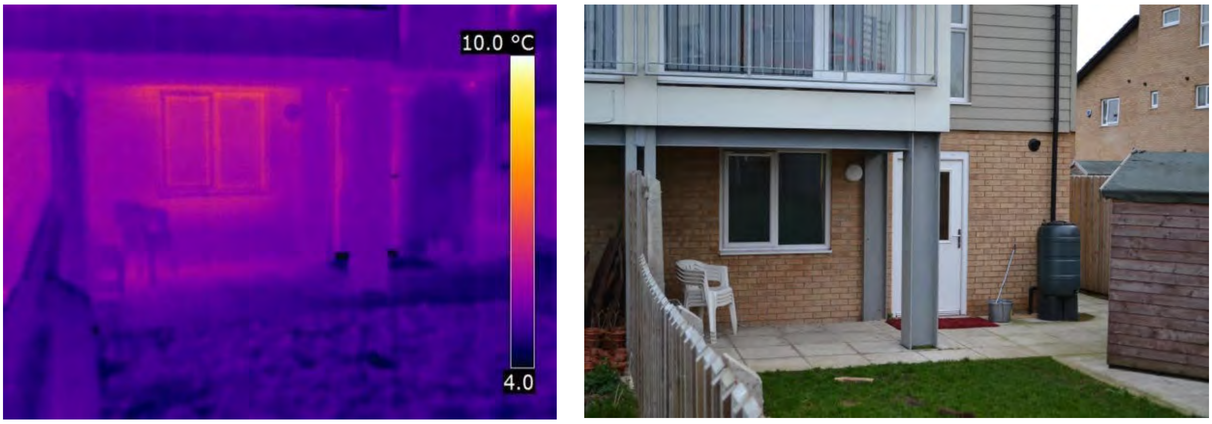


Image 16: Property 3A Rear Ground Floor. Observations: Minimal localised temperature elevation above and below window

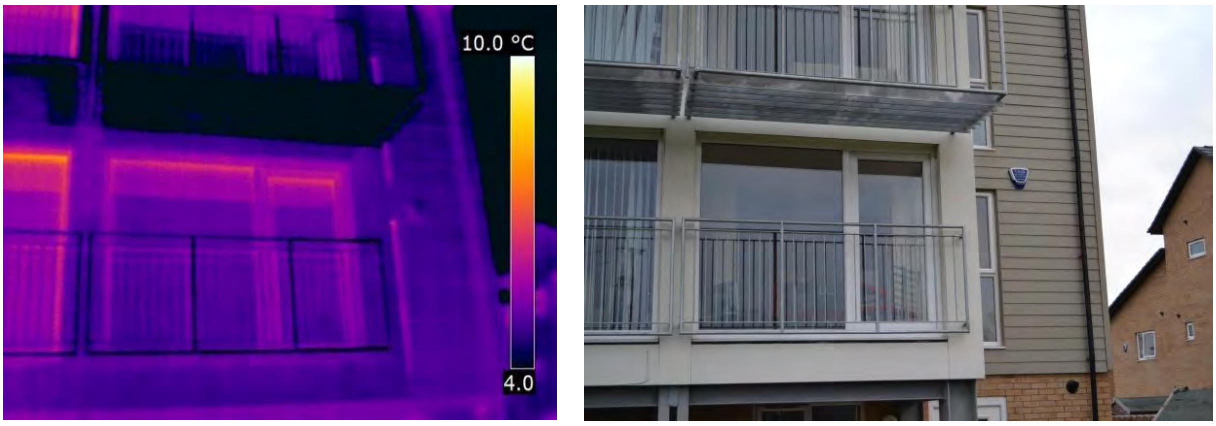


Image 17: Property 3A Rear 1st Floor. Observations: No thermal anomalies observed.

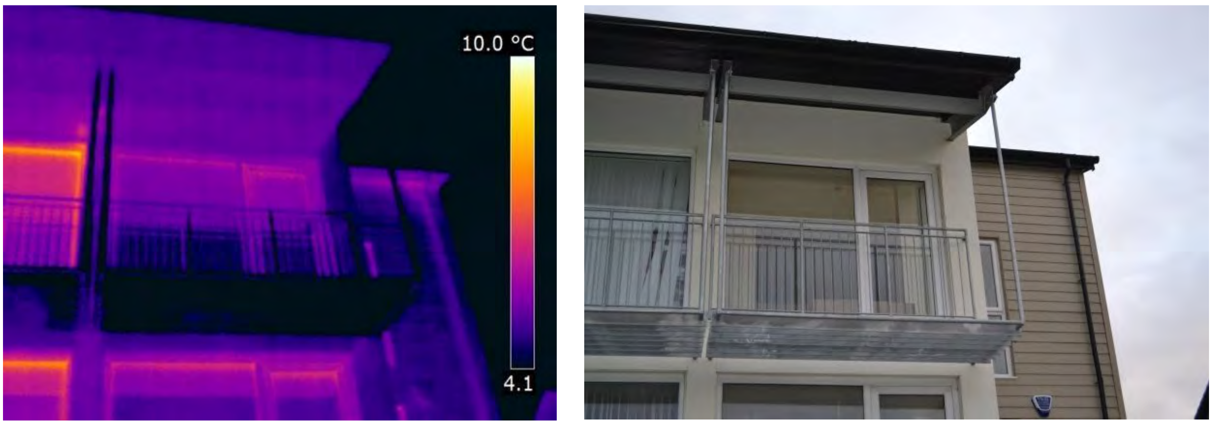


Image 18: Property 3A Rear 2nd Floor. Observations: No thermal anomalies observed.

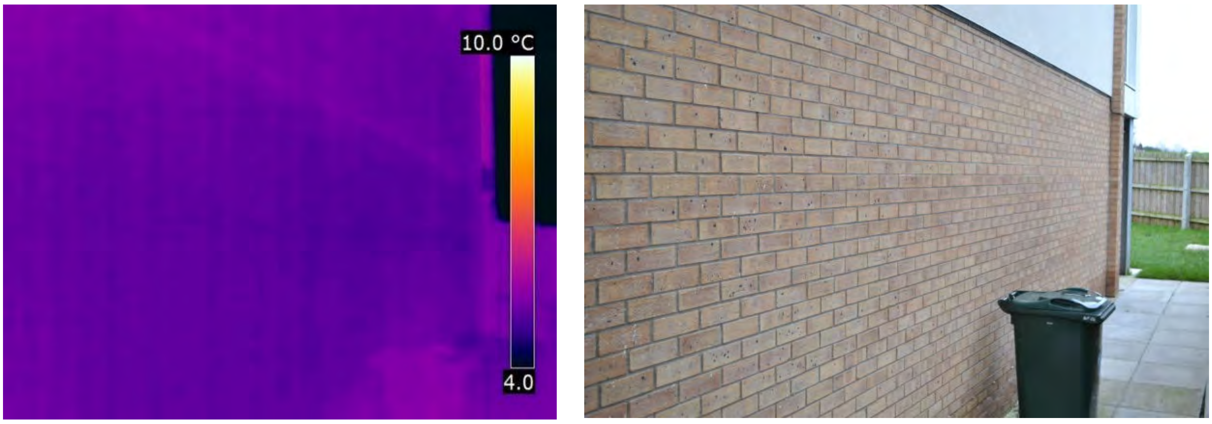


Image 19: Property 3A Side Ground Floor. Observations: No thermal anomalies observed.

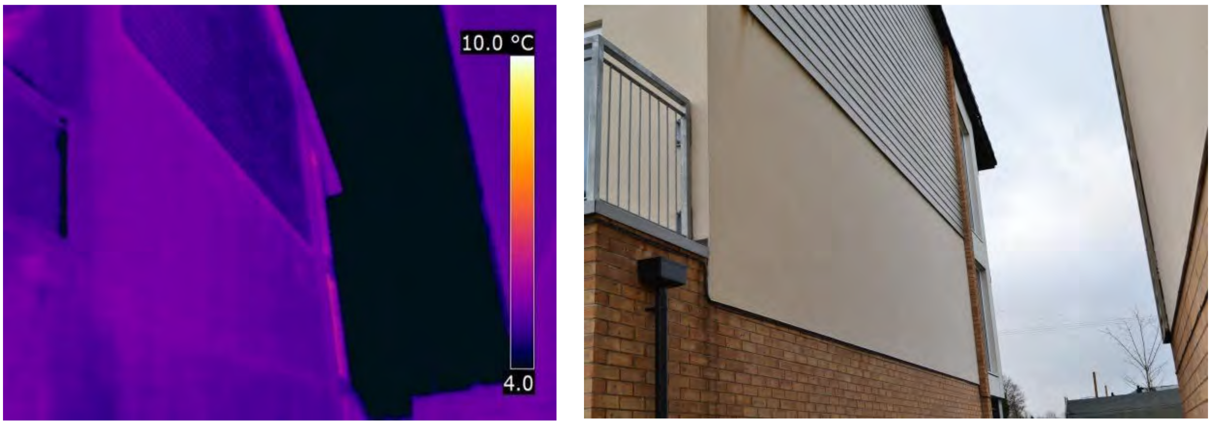


Image 20: Property 3A Side 1st Floor. Observations: No thermal anomalies observed.

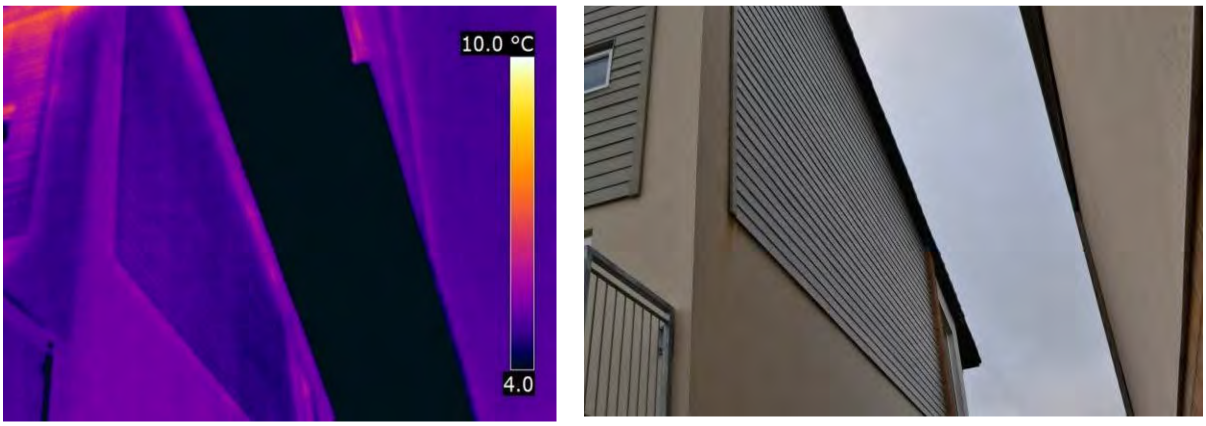


Image 21: Property 3A Side 2nd Floor. Observations: No thermal anomalies observed.

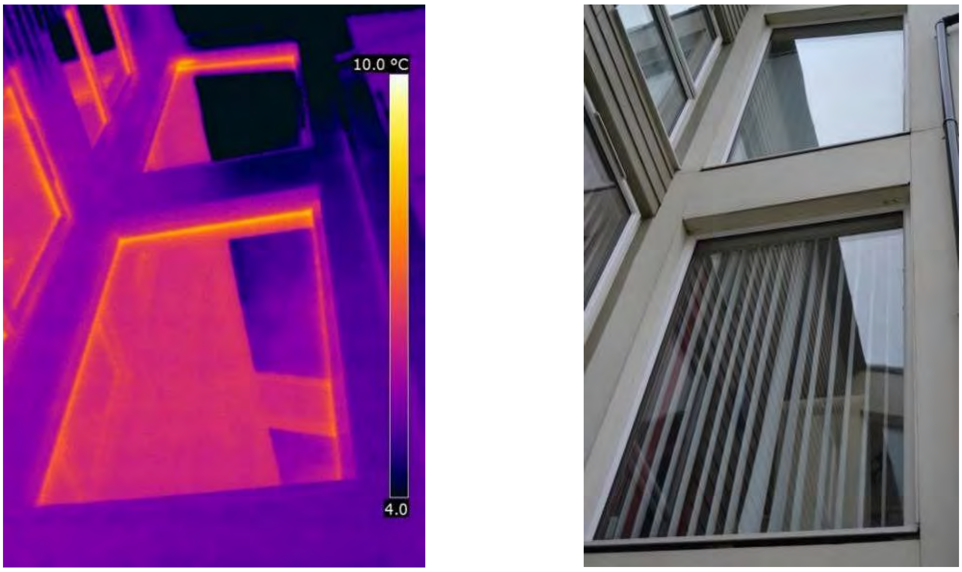


Image 22: Property 3C Rear Side Bay. Observations: No thermal anomalies observed; temperature variations due to reflection.

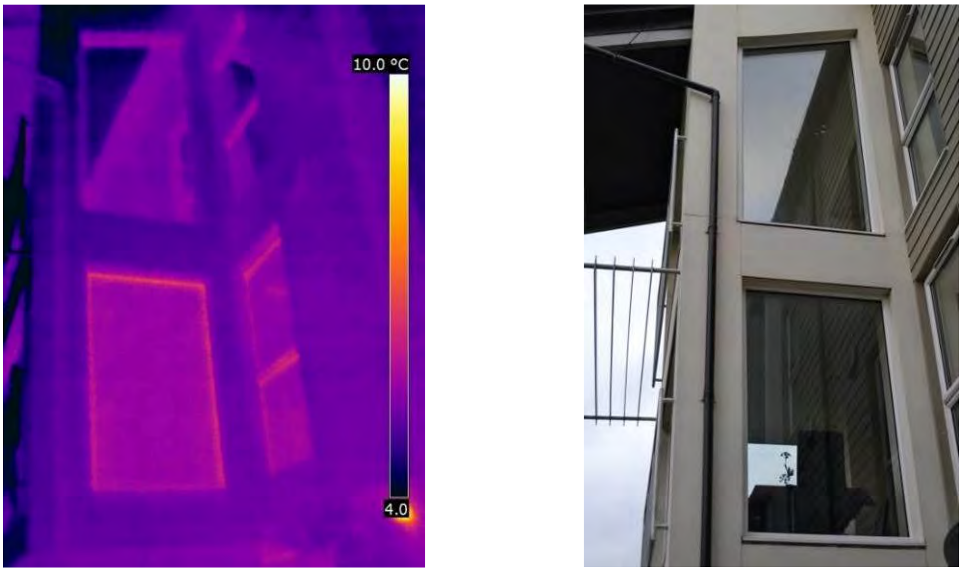


Image 23: Property 3A Rear Side Bay. Observations: No thermal anomalies observed; temperature variations due to reflection.

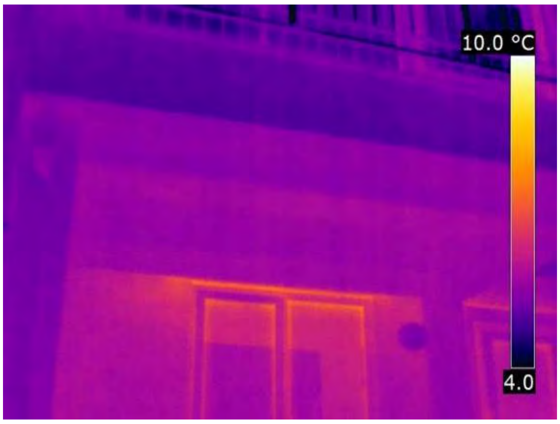


Image 24: Property 3B Rear Bay (Underside). Observations: localised heating above door.

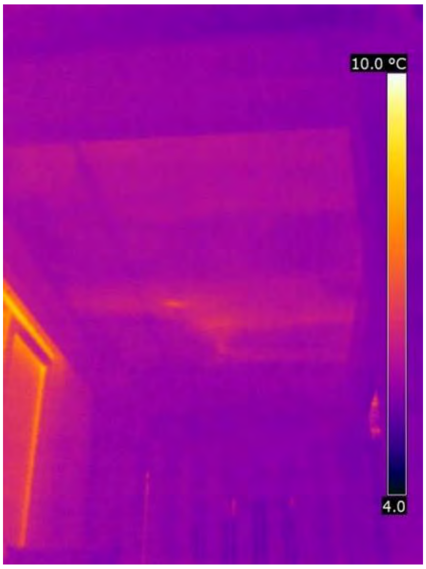


Image 25: Property 3C Rear Bay (Underside). Observations: Small anomaly at centre of panel

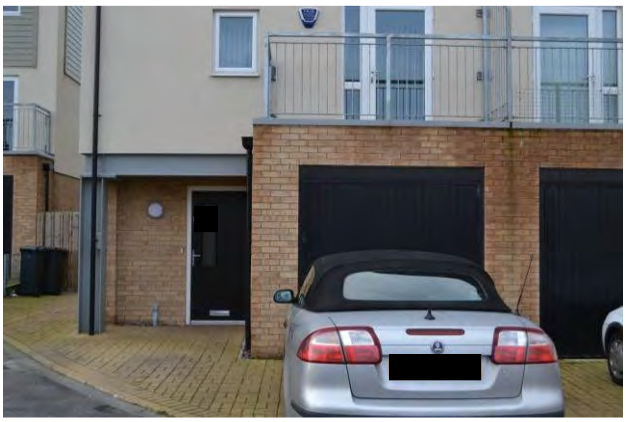
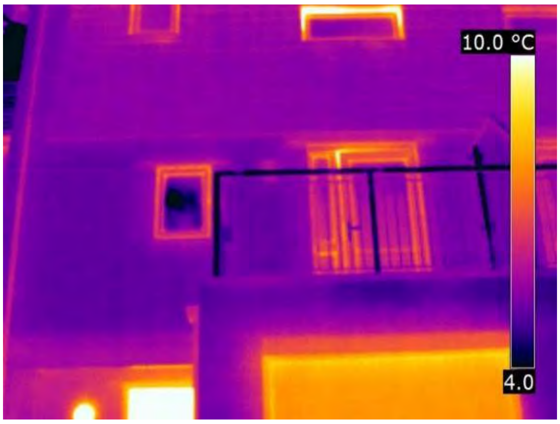


Image 26: Property 5B Front Ground Floor. Observations: Elevated door temperature, recently in use prior to survey.



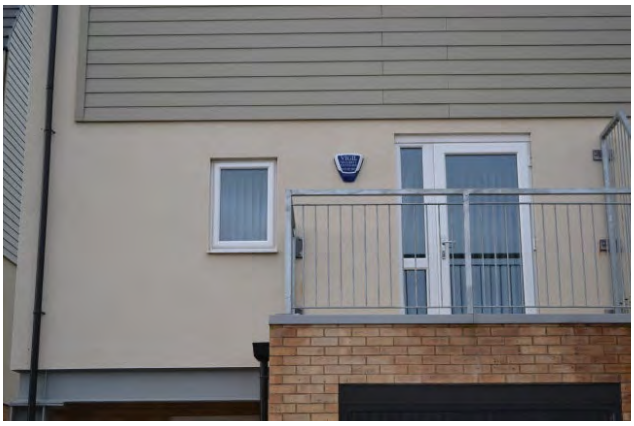


Image 27: Property 5B Front 1st Floor. Observations: Potential leakage at top left hand door corner.

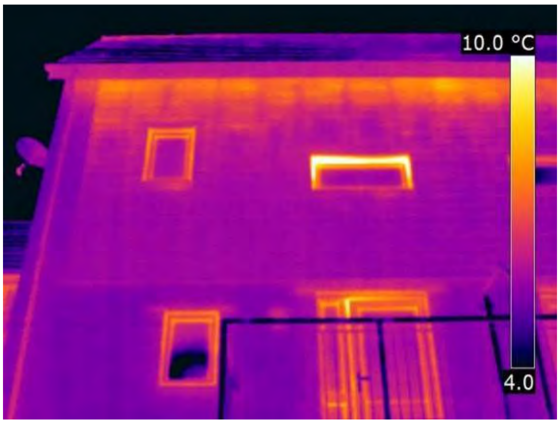
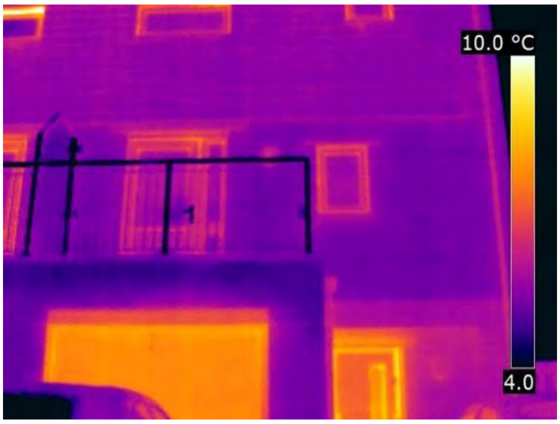


Image 28: Property 5B Front 2nd Floor. Observations: Localised heating at right hand window.

Image 29: Property 5A Front Ground Floor. Observations: Localised temperature elevation around door. Door had been in use.



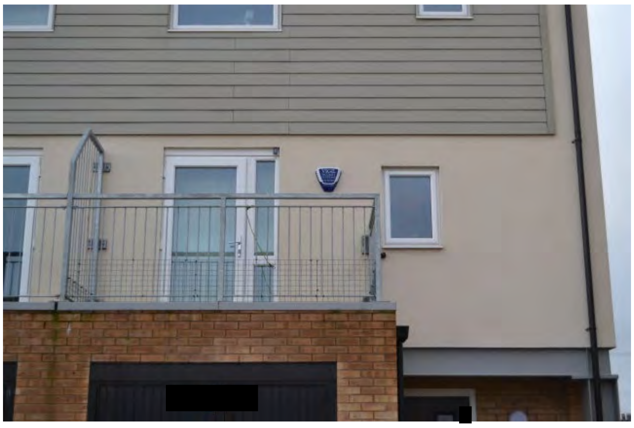


Image 30: Property 5A Front 1st Floor. Observations: No thermal anomalies observed

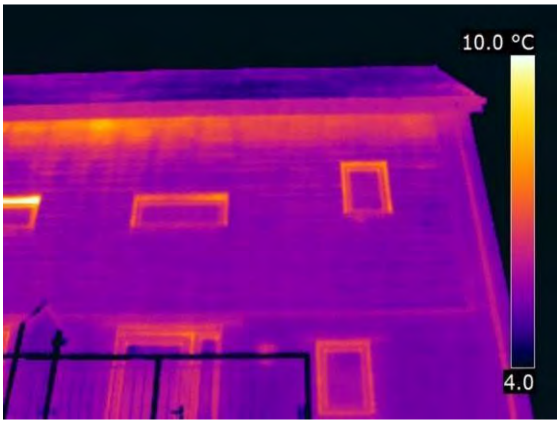


Image 31: Property 5A Front 2nd Floor. Observations: Elevated temperature at top of cladding. Note: cladding is ventilated

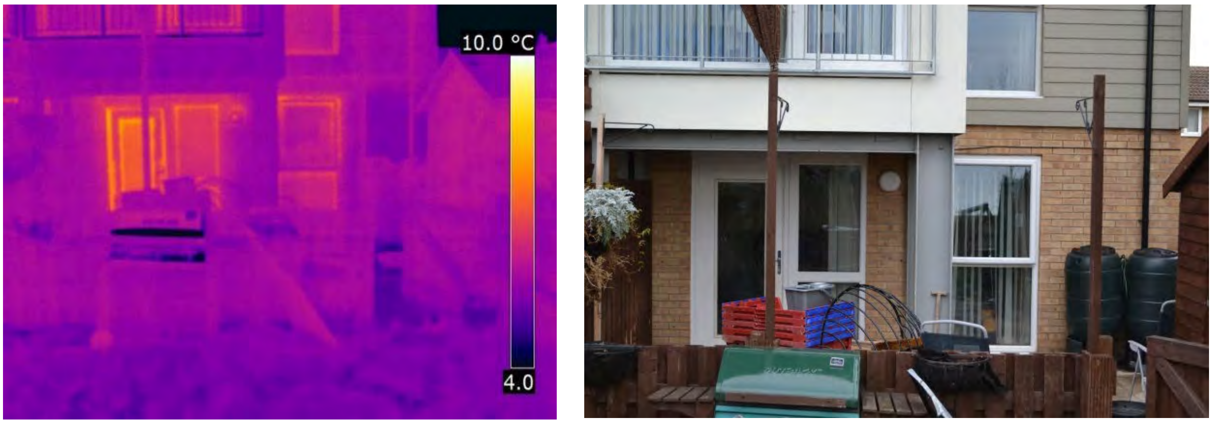


Image 32: Property 5B Rear Ground Floor. Observations: No thermal anomalies observed

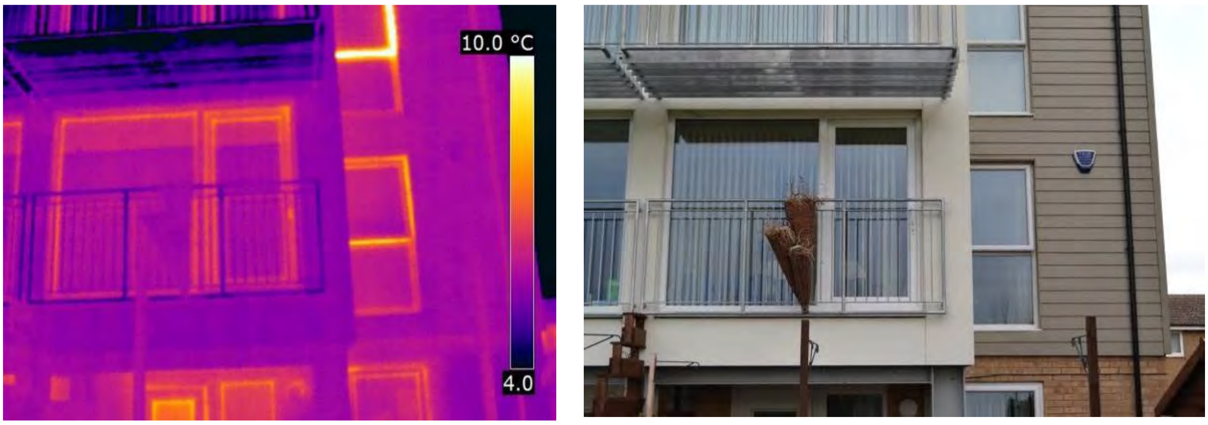


Image 33: Property 5B Rear 1st Floor. Observations: right hand windows partially open no other thermal anomalies observed

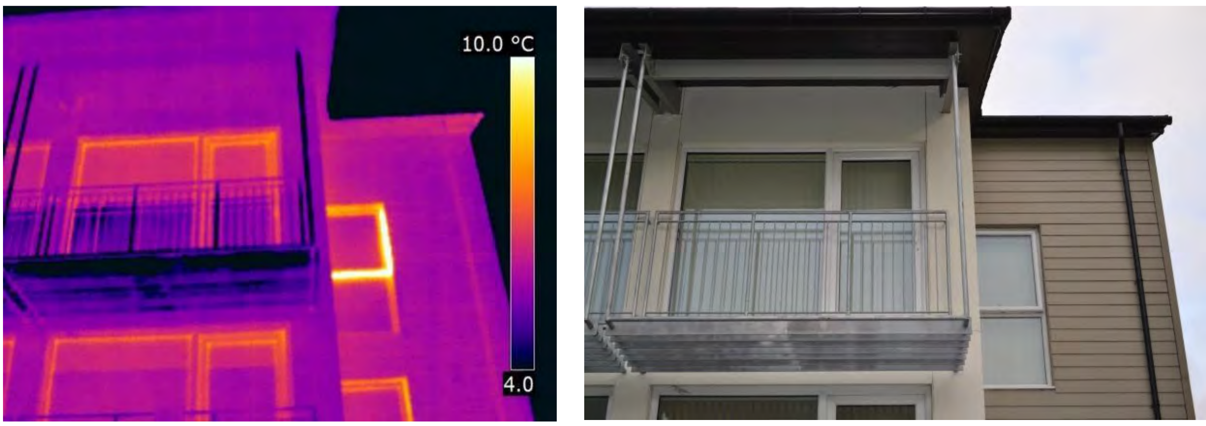


Image 34: Property 5B Rear 2nd Floor. Observations: Right hand window open causing localised heating no other thermal anomalies observed

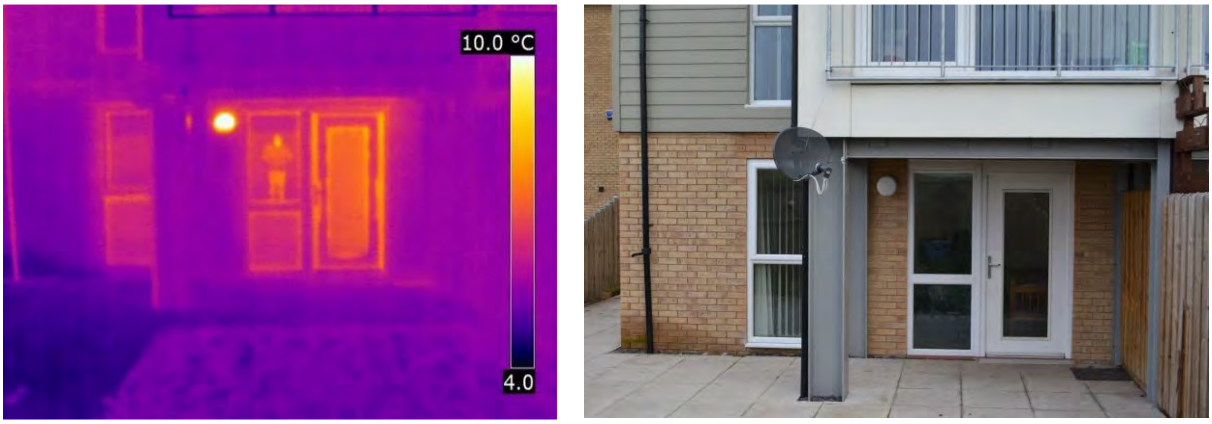


Image 35: Property 5A Rear Ground Floor. Observations: No thermal anomalies observed

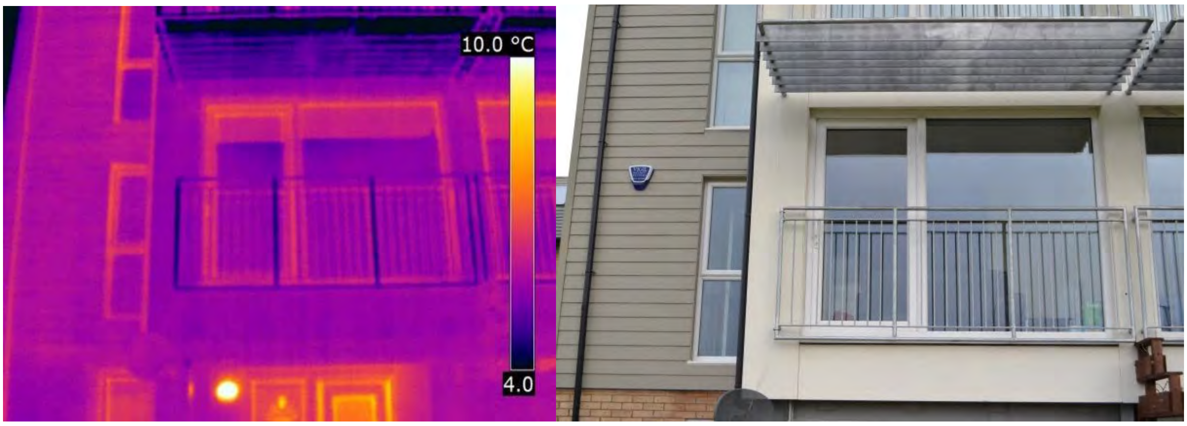


Image 36: Property 5A Rear 1st Floor. Observations: No thermal anomalies observed

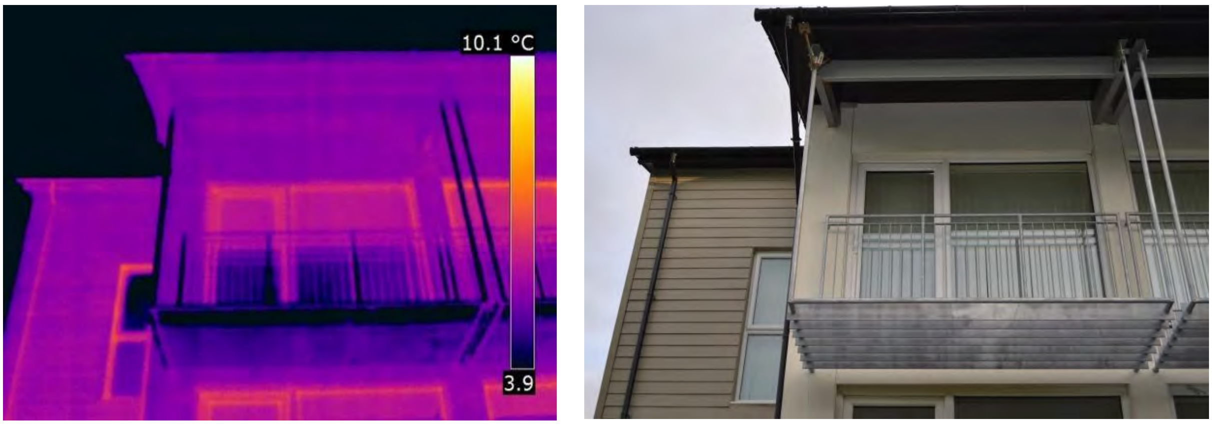


Image 37: Property 5A Rear 2nd Floor. Observations: No thermal anomalies observed

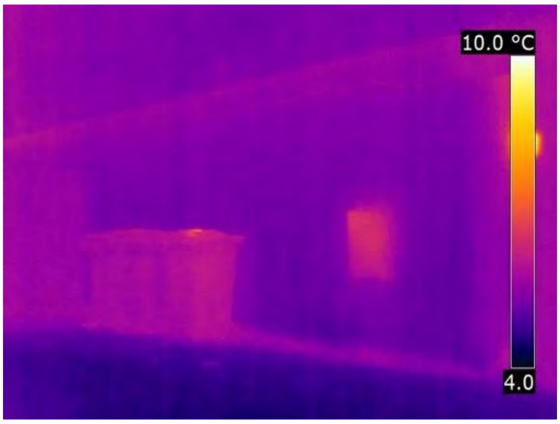


Image 38: Property 5B Side Ground Floor. Observations: Elevated temperature at meter box no other thermal anomalies observed

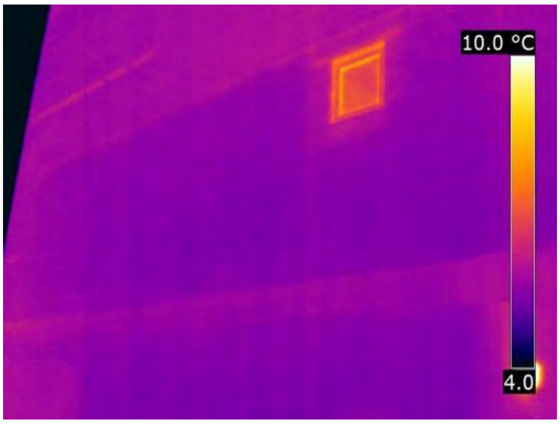


Image 39: Property 5B Side 1st Floor. Observations: No thermal anomalies observed

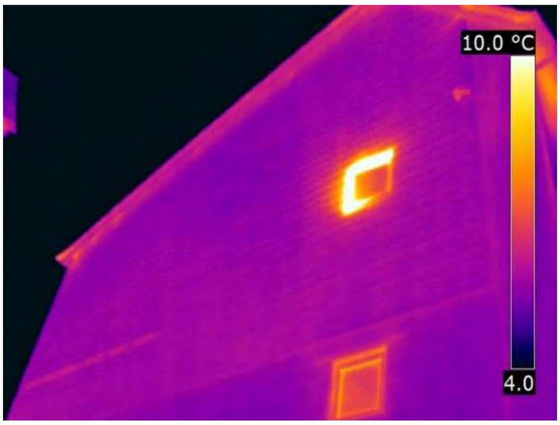


Image 40: Property 5B Side 2nd Floor. Observations: No thermal anomalies observed. Localised heating at window as open.

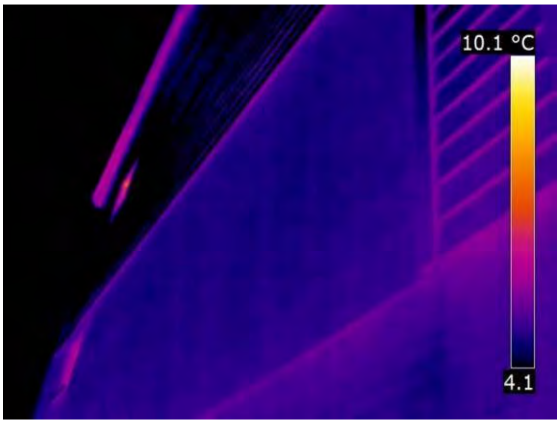
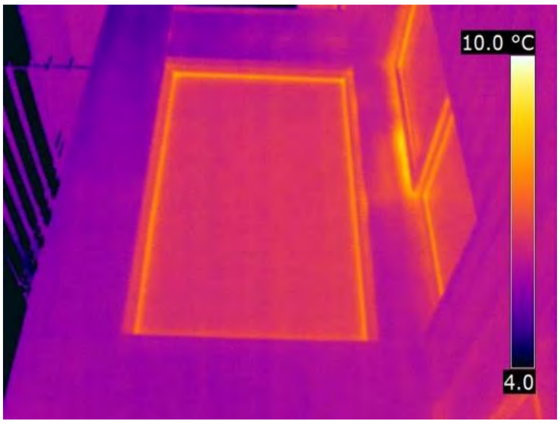


Image 41: Property 5A Side 1^{st} & 2nd Floor. Observations: No thermal anomalies observed



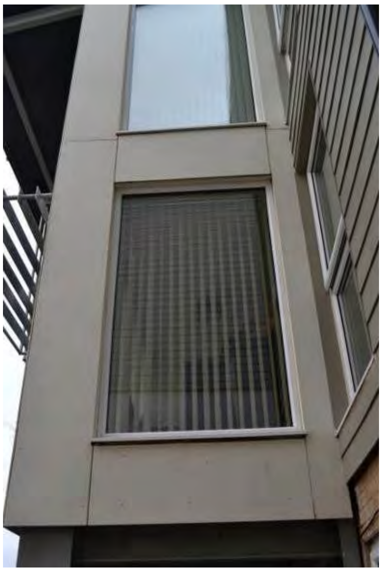


Image 42: Property 5B Rear Side Bay (1^{st}). Observations: No thermal anomalies observed, temperature variation due to reflection

Image 43: Property 5B Rear Side Bay (2nd). Observations: No thermal anomalies observed; temperature variation due to reflection.

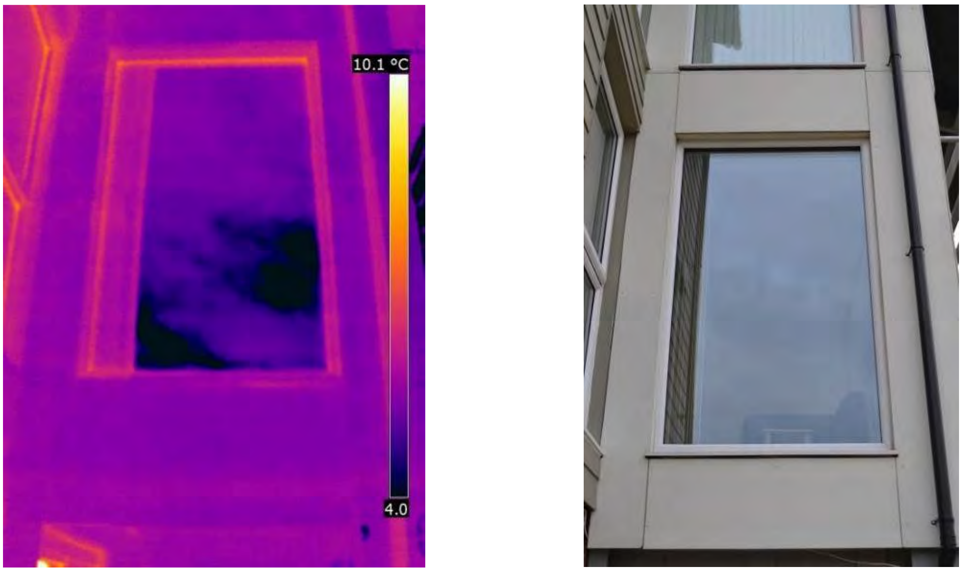


Image 44: Property 5A Rear Side Bay (1st). Observations: No thermal anomalies observed

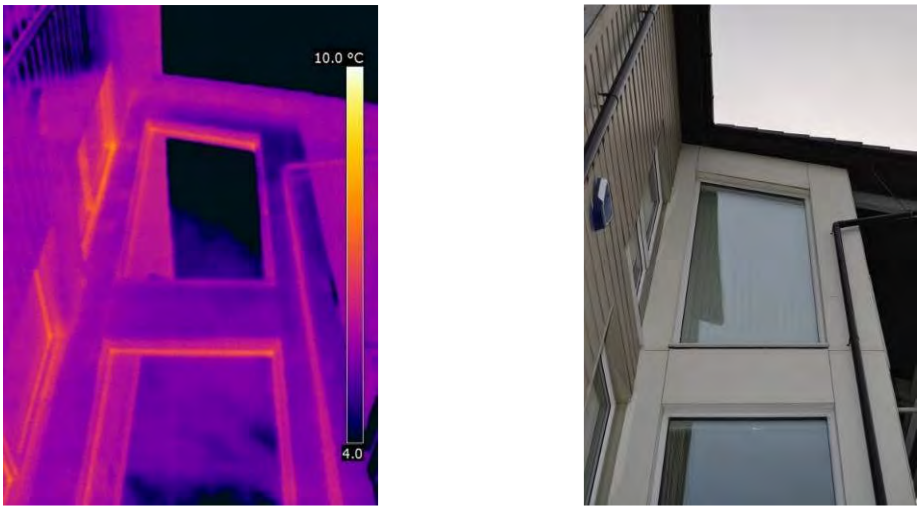


Image 45: Property 5A Rear Side Bay (2^{nd}). Observations: No thermal anomalies observed; temperature variations due to reflection.

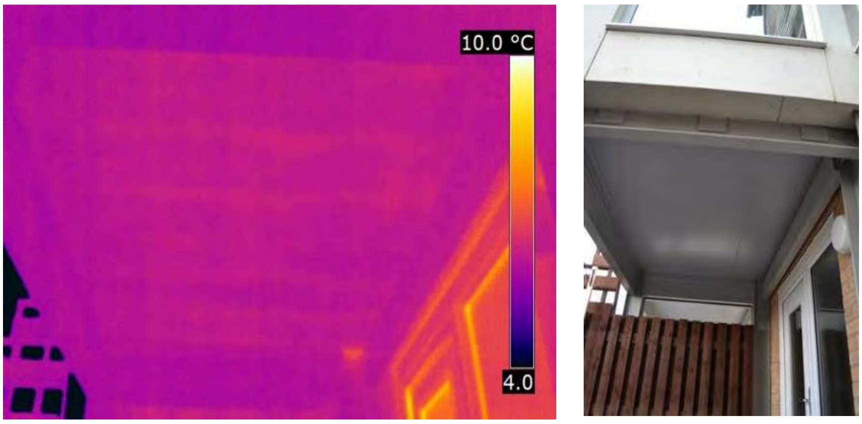
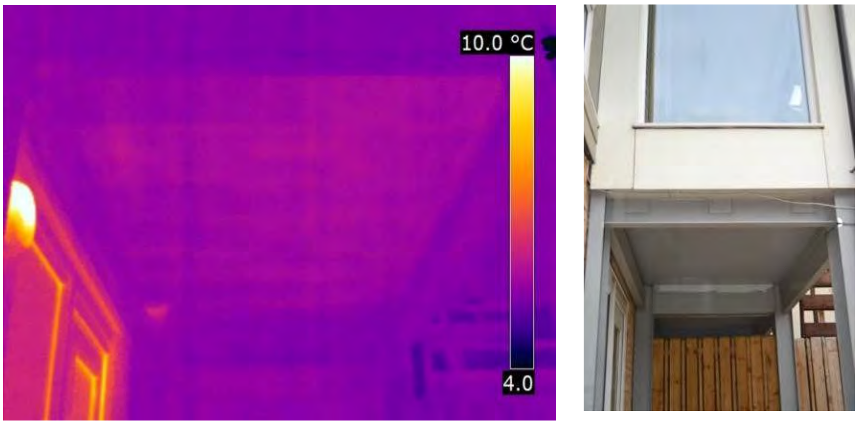
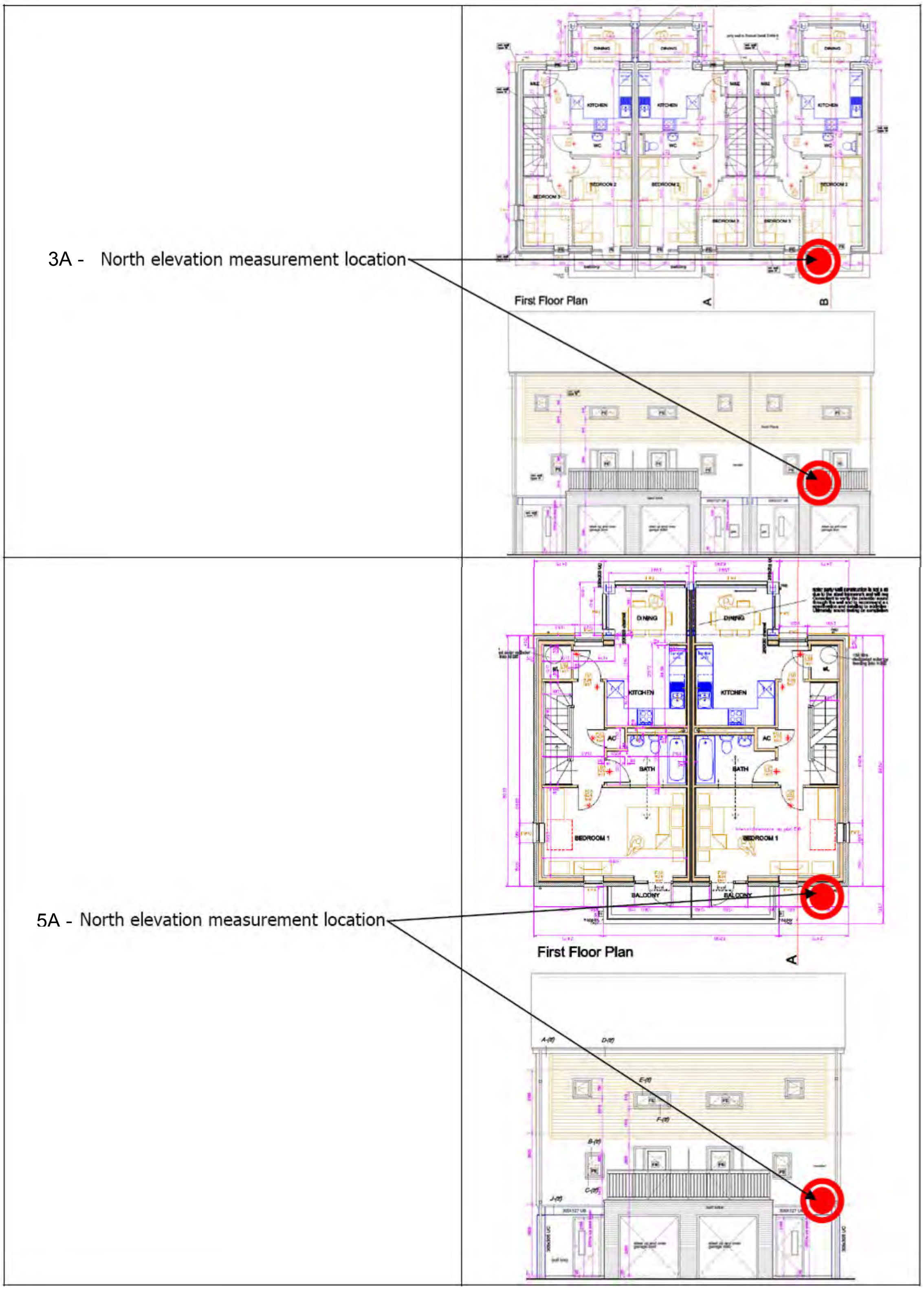


Image 46: Property 5B Rear Bay (Underside). Observations: No thermal anomalies observed



11.2 U-value testing

The following plans detail the locations of the U-value measurement devices:



Appendix D - Key findings from the design and delivery team walkthrough

12.1 Code 5 property

12.1.1 Dwelling operation and usage patterns

Heating

There would appear to be significant issues relating to operation and use for key elements of the 'heating'. In simple terms, it was not clear that controls were properly set, or that tenants had useful instruction[s] to operate the controls.

The house has multiple controls:

- Programmer
- 2No Programmable room thermostats
- 3No programmable thermostats for the underfloor heating

It was suggested that all of the relevant information relating to the controls was provided to GNC (by Lovell), but Lovell were not sure how this information was relayed on to tenants. There had been several offers of training and demonstrations (from Lovell to GNC), but this had not actually been organised/delivered due to last minute cancellations due to attendance issues. When 'challenged' on the use of the UFH programmable thermostat, the tenant said that they had received a copy of the installation manual for the controls but that was all (N.B. this was during the tenant walk through but is cross referenced here). Operation of these thermostats stats was not immediately obvious or intuitive. The controls were not easy to see/read [observation by Arnout Andrews, Verco]. During the tenant walk through the tenant suggested that he thought the controls were at 'factory settings'. However when he tried to demonstrate, it appeared that the 'night' setting for the thermostat in the back room (used as an office) was set at 25.5 C. The tenant in this case is energy aware and has some engineering background.

A full review of all the controls, their current settings and instructions for tenants would be useful.

Ventilation

Ventilation is on permanently with a boost 'button'. This should be relatively straight-forward, however the boost is more complex than a simple button. It has four buttons marked 1,2,3,4 with no explanation of what this means – so this does raise the possibility that the complexity actually results in less control for occupants. The Building Controls Industry Association guide 'Controls for End Users: a guide for good design and implementation' by B. Bordass, A. Leaman, and R. Bunn, states that one of the six key factors for controls design is usefulness of labelling and annotation – it is critical that switches are labelled on the controls, rather than just in the instruction manual.

Lighting

Standard on/off light switches are present in each room. Stairwells have switches for adjacent floors with exception of switching of ground floor hallway lights from first floor.

12.1.2 Maintenance

Reliability & Reporting

There is a 12 month defects period, during which time maintenance was done by Lovell. A list of all reported issues was provided by TGP. None of the design team available had knowledge of any reported problems apart from a single leak. At this stage it would appear that there have not been significant problems with system breakdown.

There was a red warning light showing on the SHW display panel. This was later identified as a system fault (pump trip) introduced at the time of the heat meter installation, which took a long time to rectify. The SHW system did not operate in the first year of the study.

Defects reports for this property were provided by TGP. It was reported that all defects were addressed prior to the end of the defects period and hence they should not impact the monitored performance of the building. During the tenant walkthrough the tenant indicated that the rear patio door was not addressed to his satisfaction and gusts of wind would still lift the lino in this room. The full list of defects follows:

- Bathroom toilet not flushing
- Bedroom and dining room window not sealed from the outside
- Rotary dryer missing from shed/property
- Leak in cupboard in kitchen

- Patio door faulty and draughty (c.f. poor air tightness test)
- Kitchen lights go on and off of their own accord and [text stops here in defect report]
- Some roof slates have come off
- Solar panel equipment in loft flashing
- Ground floor heating pump outside in garden leaking
- Middle bedroom window mechanism is broken, cannot be opened. The tenant reported summer overheating in this space, which may have been amplified by this problem.

Access to help service

The mechanism is very simple. The tenant calls GNC's customer helpline with any problems. GNC send out their own engineers (or during defects they contact Lovell). The more challenging question is whether the engineer sent out (at some future point) will be able to understand (and repair) the air source heat pump, solar PV or solar hot water systems. Again it was not clear that everything was in place. GNC confirmed that they have trained individuals in their maintenance teams (city response) who have been trained in these technologies. It was however noted by all parties that the ASHP/SHW heating solution was very complex and that the only individual who could easily explain it was the heating engineer who fitted it. There should be a 'flag' on the GNC system to alert the call centre that they need to spend a 'special' (i.e. trained) engineer to 'heating' problems at the house. There also needs to be a trained engineer to send.

Lighting

The 'front' (North) bedroom is not well served with natural light (from the small window). This is an unfortunate consequence of the deliberate passive solar design.

MVHR

The ITHO HRU Eco 4 MVHR will need filter cleaning/replacement annually. Note that the initial MVHR test had to be delayed in response to the fact that the filters were very dirty; the filters had not been changed in over a year indicating that this had not been considered in the maintenance schedule for these properties. The issue was raised with GNC for inclusion in on-going maintenance schedules.

12.1.3 Energy and water management

This will be addressed within the monitoring phase. However the property visited would appear to have higher consumption than the SAP outputs might suggest.

12.1.4 Other points

The design has significant aesthetic influence. It is very far from the 'square box' approach to low cost social housing. There are things within the design which would have been done differently if the design influence fell more with the construction team rather than the architects in the project team, in particular simplification of the window types and sizes. This was raised by the Development co-ordinator but it was suggested that this would have been the choice across the construction team.

The steel frame (Southern elevation) creates lots of detailing and interfaces. These are bound to be challenging for insulation, thermal bridging and airtightness. Getting this area right took effort on site (collaborative with builder, architect and site operatives). The operatives stayed on the project so after the first property they had resolved all the issues. Had this not been a 'flagship project' some of these elements would have been changed in value engineering.

It is possible that the 'zoning' of the heating will fall foul of rooms being used differently to their design intent – this is examined further during the tenant feedback section of this report.

12.1.5 What would be done differently next time

The heating solution would be different now. Now that SAP treats ASHP differently, similar outputs could be achieved with a high efficiency gas combination boiler instead of the ASHP and SHW, with a little extra PV. This would provide a much simpler and lower cost solution, as standard radiator heating could be used throughout and the gas boiler is cheaper and better understood by installers than the ASHP system. The driver that resulted in what we have is the SAP 2005 calculation methodology used during the design. This is a clear and interesting illustration of how the regulatory framework drives construction choices.

12.2 Code 3 property

The Code 3 properties are much more 'typical' than the Code 5's. They have a gas system boiler and no renewables. The only 'unusual' feature is that they use MVHR.

12.2.1 Dwelling operation and usage patterns

Heating

The heating system and controls are 'standard', except that there are two 'zones'. This means that the requirements are also standard. The controls are correctly 'factory' set when commissioned and there is information (and possibly instruction) so the tenant can use the controls in the long term.

Heating zones

The heating is split into 2 zones (in both Code types). The layouts are very similar in both Code types too. However, the designed designation of room uses are different, led by issues lifetime homes requirements. The kitchen/dining rooms, living room and bedrooms 1, 2 and 3 are in the same parts of the property in each case, but there are differences in the rear ground floor layout. This means that effectively the same room in the two types is designated differently (living room: bedroom). This meant that members of the design team were struggling to remember (in retrospect) which rooms were supposed to be which. However, this alternative naming of rooms was done for the Code 5 properties to comply with Lifetime Homes requirements. Meanwhile, the tenants use the rooms as they see fit. This has resulted in the theory of the zoning not matching up to the actual use of the rooms. In the Code 3 house the 'living room' by designation contains the room 'stat for the non-bedroom heating circuit, but that room is actually being used as a bedroom. It is difficult to envisage how this issue could be addressed for various building types pre-emptively during the design stage. Perhaps the critical point in this case is that in all the properties visited, the tenants chose to put their kitchen, dining room and living room on the same floor, even in the case where the tenant has mobility issues (which is connected to the thinking behind the lifetime homes standard where a disabled occupant should be able to eat, sleep and wash without use of the stairs). In this case, a recommendation might be for a Lifetime Homes property to be able to have a living room, kitchen, and bedroom and bathroom all on one floor (which in this case would be possible in the non-lifetime homes Code 3 properties but not the lifetime homes Code 5 units). However, there would not enough floor area in the Code 3 properties for all these rooms, due to the (in this case undesirable) constraints from Lifetime Homes.

Ventilation

Ventilation is the same as in the Code 5 properties and the same comments apply.

Lighting

As per the Code 5's – local wall mounted switches (no automatic controls). While this increases the likelihood of lights being left on, occupant response to automatic controls such as PIR's in domestic properties is mixed and there is no reward in SAP for specifying this technology.

12.2.2 Maintenance

Reliability & Reporting

There is a 12 month defects period, during which time maintenance was done by Lovell. It was suggested that Lovell will be able to check records and provide a list of all reported issues & visits. None of the design team available had knowledge of any significant reported problems. At this stage it would appear that there have not been significant problems with system 'breakdown'.

The following defects were reported for this property:

- Fence panel loose and there is a gap between the panels.
- Toilets on ground and middle floor flushing dirty water
- Toilet is flushing but not taking anything away.
- Small hole in lounge ceiling, no washing line in garden
- PVC ground floor window won't close – with impacts on airtightness.
- Back door very draughty as noted in the Code 5 property; likely to impact on airtightness, as above. Was any action taken to address this issue in the initial air tests for building regulations compliance?
- Gutters to rear of property leaking

Access to help service

The mechanism is very simple. The tenant calls GNC with any problems. GNC send out an engineer (or during defects they contact Lovell). As systems in the Code 3 properties are standard this approach should work as normal and evidence from the defects reporting suggests that the issues were addressed successfully.

MVHR

The MVHR will need filter cleaning/replacement. It was not clear that this was properly in place. Note that as with the Code 5 property the MVHR test had to be delayed in response to the fact that the filters were very dirty; the filters had not been changed in over a year indicating that this had not been considered in the maintenance schedule for these properties.

12.2.3 Energy and water management

This will be derived from the monitoring phase of the project.

12.2.4 Other points

The design of these Code 3 properties was led by the intent for the ‘flagship’ Code 5 properties. Once the number of Code 5’s was reduced (post value engineering and subsequent rethinking), the look and layout of these properties had effectively already been set with planning. Hence these properties ended up looking the same but being built with lower cost structural materials (brick instead of timber frame). Retaining the visual identity and redesigning down to lower cost (from Code 5 to Code 3) resulted in quite an expensive way to design (and construct) a Code 3 house.

The steel frame (Southern elevation) creates lots of detailing and interfaces. These are bound to be challenging for insulation, thermal bridging and airtightness. Getting this area right took effort on site (collaborative with builder, architect and site operatives). The operatives stayed on the project so after the first property they had resolved all the issues. Had this not been a ‘flagship project’ some of these elements would have been changed in value engineering.

12.2.5 What would be done differently next time

Starting ‘from scratch’ it is possible that these houses may have been significantly different. However the actual design is partly a function of initial design intentions, the property crash and the timing of planning consents. Arguably these properties are faux Code 5’s. However, they are visually interesting, which can be regarded as being something very positive, or something in-efficient – entirely depending on personal perspective. From a simple efficiency perspective a “square box” design with less glazing and a lower surface area to volume ratio would most likely be more efficient in practice, although the SAP methodology would not pick up on this as it compares the design property with a property of identical architectural form. However the unusual architectural design of the property was universally positively received by the design team, TGP and tenants, highlighting the fact that efficiency and attractiveness are often competing goals in property design.

Excepting MVHR (which is becoming more common in new build) the ‘energy’ features are fairly standard in these homes – and for the house-builder they are considered typical and ‘next time’ homes would also be likely to be very similar. The questions are around the additional complications of the design (such as the steel framed bays). The properties are a function of intent and timing. Different drivers or responsibilities would typically lead to a different approach, but this is true of most developments.

Appendix E - Occupant surveys using standardised housing questionnaire (BUS) and other occupant evaluation

13.1 Code 5 properties (Interviews in Property 5B and Property 5A and walkthrough of Property 5A)

Tenant's comments from both properties have been included in this section with two fonts of text used to differentiate between the properties – standard and *italic*. Comments made directly by the tenants have been presented in normal text, interpretation & comment by the BPE team is presented against bullet points.

13.1.1 Dwelling operation and usage patterns

When asked if a handover demo on controls was given: "no, not really. No, being a technical guy, I've worked it out how to use it; if we want an extra boost of water I know how to do it" On handover information pack: "the information pack were not, I'll be honest, not suitable for what I would call a normal person" "they were more installation manuals than anything else and that's how I got my head round it" "one of the issues, and I ended up going online and downloading it, is a user manual for the intruder alarm, there was nothing in it, and it kept going off"

"I'd say it took about a month, month and a half to get my head fully round it. How it works, what it does, what it doesn't do. And then – am I using it right? I don't know"

Asked about if a handover demo would be useful "yes, I mean the girls who were here, to be fair to them, they didn't know how the system worked" "the technology in these, it takes a lot of getting your head round really. But once you've got your head round it it's quite simple I think" "usage wise I've got my head round it and I can turn the heating up, turn it down, water, you know, it's got a booster on it, you keep that on for an hour, two hours, to be honest to get it really hot you have to keep it on for a full day" "with the weather we've had, it doesn't really warm it up sufficiently, you've got to give it that boost"
When questioned on the purpose & operation of the underfloor heating controllers "these have not been touched since they set them up. I spoke to him & he says you're better off leaving it… otherwise if you change them it takes a few days for the floor to warm up" "I must admit it's been very warm down here" "as you can see I won't wear anything but shorts down here"

Asked about the boost for the MVHR system; "there you go" [indicates location on kitchen wall]. When asked if instructions were provided "not that it's very informative on that, cause in fact I don't think there's anything on that to be truthful. I collared the plumber when he turned up" "you can hear it, you've got to be deadly quiet mind you, but you can hear it kick in for that extra 10 minutes to take the smells out"

On the ventilation boost controller: "been told that these are battery operated, no power, so again, who is going to change the batteries" "the reason why I ask the question is that, it's got LEDs on, nothing comes on – it doesn't tell you you've activated it. You can just about hear that kick in; it's a little bit louder"

Interpretation:

- Those with a technical background and the inclination can make sense of most of the control systems, but the information provided in the handover pack is not suitable for the layman. Guidance provided to the tenant has dissuaded them from adjusting the underfloor heating controls.
- A formal handover demonstration was not provided. TGP staff had not been trained in the control system, and the tenant had to take their own steps including discussing the system with the plumber during maintenance visits in order to gain a full understanding of the controls.
- MVHR boost controller is not intuitive to use, and instructions were not provided in the handover pack. This is an important limitation to the usability of the system. It is recommended that the developer seeks better clarification for future developments.
- The tenant's comments indicate that the most energy efficient settings available for hot water do not generate hot water of a satisfactory temperature and it is necessary to use the boost function.

When asked about the zoning of the heating system: "the plumber… I asked why is there two controllers, well actually more of them, 'cause we've got five in theory, and I asked him are they all interlinked? He said no, they are all separate."

On whether information was provided on zoning controls in the handover pack: “All there is, is the controls, how to use them, it didn’t tell you it’s zoned”

- The tenant was not provided with information to permit the property to be used as intended (e.g. all bedrooms on one heating circuit and living space on another).

When asked if it gets too hot in summer: “Yes”
When asked if the opening windows are sufficient to cool it down? “No, it doesn’t cool it down, when it’s warm outside there’s warm air coming in anyway” “I’ll sit with a pair of shorts on and I’m sweating, but I’m warm blooded anyway. But for the missus to be in summer dresses in the winter months is unbelievable”

- The property does overheat in summer (sweating in t-shirt) despite opening all windows but this is considered an acceptable trade-off by the tenants for warm winter temperatures. However, the tenant’s position is unusual as one resident suffers from mobility issues and poor circulation; therefore the others are willing to compromise and endure higher temperatures than most would choose. The tenants also kept the heating on all year round at a set point of 21 degrees, which would reduce any overnight cooling, exacerbating overheating issues.

- Note: the fact that residents are wearing summer clothes in the winter months corroborates with temperature data analysis (internal temperature circa 25 degrees) and the high heating energy consumption at this property.

On pointing out the MVHR outlet in the top floor front bedroom “this is the one, if you stand here, you can hear it blowing” “I don’t think I could sleep with that”

- Significant noise was observed by the BPE team at this location. Re-commissioning of the MVHR system would be recommended in order to attempt to rectify the issue.

When asked about what the rainwater harvesting controller was indicating: “at the moment – with all that rain we’ve had, that’s running on the harvester system”.

- Rainwater harvesting system works and tenant is familiar with operation and controller

- On building occupancy, the tenant’s comments indicate that at least one tenant is in the property the majority of the time – this could lead to increased daytime electrical energy consumption for heating and small power.

On the use of the top floor windows for ventilation & cooling (top floor rear bedroom) "even in the winter months we've had the window open"

- If tenants often open the window in the top floor bedroom in winter this will lead to excess heating consumption. The living area heating circuit thermostat is present in this room so controls *should* be able to prevent overheating in winter caused by the heating system. Minimal electrical equipment was noted in this room suggesting that the room overheats through stack effect of heat rising from lower floors rather than excess heat from the heating system.

When asked: do you understand the heating controls, ventilation etc.: "most of it yes"
Were you provided with information? "I've had to take action myself, given we we've had a plumber out, the plumber didn't really know what he was doing with it himself, he said he needed training up on it because he wasn't trained up on this particular system, I thought what chance have I got?"
"It's confusing for the better ones, to where us trained plumbers are struggling with it" "we looked at the booklets didn't we, read 'em, put them back to factory settings and reset it and that seemed to sort it"
When asked about the MVHR controls & the ventilation system in general: "I haven't had any information regarding that actually, we haven't really used it, but we just open a window"
"we don't open windows because it's stuffy, I just like fresh air" "I often sit there and I can feel it coming through, it's working fine"

When asked if the MVHR controls are used "No, cause I didn't really understand what that was for, so I've never really… I pressed them, but I thought a light might come on or something on the box but it doesn't't" "I don't know what they're for, and if you don't know what they're for and you start pressing buttons"

- *Information provided was difficult to understand and was manufacturer's information only. Face-to-face training was not delivered, due to several cancellations, and instructions on the use of MVHR were not included in this information. There is clear evidence that a lack of training on the use of MVHR systems has resulted in tenants not using them properly and opening windows instead, which will almost certainly* *result in excess heating demand, inefficient energy behaviour, undermining the specification of the system.*

- *Settings on the heating system were restored to factory settings in response to a maintenance request and the tenants have left them alone since. The tenant gave a clear impression that they were apprehensive about making any further adjustments and they are therefore left impotent to act in the event of high energy costs – which they are suffering from.*

When asked about temperatures "this is a very, very, very warm house" Is it too warm in the summer? "No. It's quite cool" "in fact, we've always got windows open" "us other house used to be freezing, and cost about £60 a week in bills"
When asked if it gets too warm or too cold: "I think its warm upstairs, in the bedrooms its warm. It's good"

- *Generally the tenant seemed very satisfied with the internal environment following a maintenance callout to remedy issues with the hot water and heating controls; despite reporting that it was "very warm" this was not considered a problem.*

"natural light's brilliant on the back, darker on the front" "sometimes we have to put a lamp on at the bottom of the stairs 'cause it's a little bit dark" "the kids bedrooms are always a little bit dark, but that's the size of the windows" "with us having girls and being across from other people, they can't see in. They don't always shut the blinds"

- *Natural light very good to rear, less good at front which matches the comments of the tenants of the other Code 5 property. Again the dark space in the ground floor hall was highlighted.*
- *Tenants comments indicated that they were not aware of presence of the rainwater harvesting system or its controls*

13.1.2 Maintenance

When asked about the maintenance service provided by TGP and the response from the house-builder, Lovell, over the defects period:

"The guy who came out, Duncan, he's from head office. Brilliant bloke, every time he came out the missus were loving it, 'cause he came out with a bottle of wine every time"

On callouts from Lovell for maintenance in defects period “fantastic, can’t fault ‘em, er, she normally rings me up, it’s normally marge [name unclear in recording]? I deal with. I can’t praise that lady enough”
“Guinness call centre’s fantastic, you phone them up, again, can’t fault them” “So far the work guys who’ve been round from Lovell’s again, fantastic”

Interpretation:

- Generally the speed of response to maintenance requests was highly praised by the tenant as swift and efficient
- Further comments from the tenant indicated that there had been an issue with the PV system showing errors after power cut. The tenant indicated that a call to TGP customer services was passed to Lovell and resulted in an uncertain response whether a plumber or electrician was required, with threat of call out charge if they sent the wrong person. The tenant commented that “no one seems to know what’s doing what” in the property.

The tenant’s commented on the rear patio door: “when the wind blows outside it lifts this lino, it blows under the door” “there isn’t much clearance on the bottom of this door, if I was to put a carpet down”

Interpretation:

- Tenant’s comments suggest poor sealing of this door unit, which will contribute to poor air tightness test results. This was confirmed during the end of project air tightness testing (March 2014) as an air leakage path with the lining lifting on depressurisation.

Note from BPE team: In an earlier visit to specify the metering systems, the tenant had queried whether filter changes for the MVHR system are TGP’s or the tenant’s responsibility and if this is in a maintenance plan. Further investigation identified that routine maintenance of these units had not been accounted for in TGP’s maintenance plans – in fact no maintenance was carried out on any of the systems in the Code 5 properties in the first 2 years of occupation. It appears that these slipped the net, despite a gas safety check being carried out on a property with no use of gas appliances!

- The tenant's comments indicated that a gas safety check and smoke alarm check has been carried out since the tenant moved in

- A warning light on the SHW was noted by the BPE team during the visit which needs to be checked. This turned out to be a pump error which was not rectified until 16 Sept 2013, following multiple visits by maintenance teams – highlighting a general lack of understanding of the system by maintenance staff.

On the top floor windows: "to get up to that, the window cleaner struggles. He's not been for a while so I'm not sure if he's coming again. We've got somebody coming who does it with the extension poles"

- TGP confirmed that the top floor windows were designed to be cleaned from the inside. However the tenant is either unaware of this or preferred to employ a window cleaner who worked from outside. Tenants should be made aware of this design feature.

"us hot water kept going down at first didn't it, but we've mastered it" "we weren't getting any at all" "we spoke to Guinness and they were quite good actually, they had someone out within a few hours"

- *Hot water failures occurred at first – no hot water. Callout response was swift but respondent was not confident with the system. A combined hot water and heating failure was included in the defects log as the only reported defect at this property.*

Regarding the patio doors: "screws in the doors could do with being bigger" "all the doors dropped"

- *Tenants comments indicated that the Allen bolts holding the door up may have been rounded out on installation and that they couldn't be adjusted properly*

Regarding the external cladding: "we had some problems with the boards on the side, they come off in the first wind, what they've done is obviously they've screwed half a dozen back *on" "that were the longest thing we've ever waited for, once the boards come off under there you could just see wood"*

- *Some cladding boards fell off – tenants indicated that this took around two weeks to repair but was also highlighted as a safety issue by the tenant as the falling boards could have injured passers-by or damaged vehicles. Damage of this nature would not be anticipated within the first year of occupation and raises some concern regarding the quality of finish.*

13.1.3 Energy and water management

- The tenant indicated that they were happy with the electricity bill from BG at first (£60/month) but this has been increased to £118/month. Subsequent analysis of energy monitoring data identified annual electricity import of circa 9,000kWh a year which is concurrent with this monthly cost and is unacceptably high for a property of this nature.

- The tenant's concerns indicated that high bills could cause them to move if they aren't addressed. This tenant did in fact move out just over a year into the project, to a smaller property on the same development. They cited a number of reasons for the transfer of which one was energy bills.

- The tenant suggested they were using 7,000kWh of electricity used in a year (not far off the 9,000 measured) – they thought the bills were high but were not sure what the energy use should be so didn't know if it was normal.

- The tenant's comments indicated that they are energy aware and have compared tariffs to get the cheapest (with price fix)

On water bills "it's only about £26 a month, which is about on par with what we paid at the other place"

- Tenant's comments indicated that they were hoping to get this reduced to reflect RW harvesting but this is complex. Tenants indicated that they use water from the water butt in the garden for watering plants.
- PV generation meter and isolator is in hall but tenants were not told what this was for

Observation by BPE team: The tenant has the house thermostats set to 21°C 24/7 and has the hot water on a high setting (lux) – this is expected to increase energy use and decrease average COP

Second Code 5 property: "our first water bill were £500 for 6 months" "they came out, they put the computer onto it, we'd had a water leak for two months"

- *The tenant's water bill for the first 6 months was particularly high at £500, having queried with the water company it was identified that there was a water leak (not their side) for 2 months; this was resolved with the utility. Tenant's comments indicate that they check their water meter regularly and having a water meter for the first time has made them far more conscious of the amount of water that they use, they now take steps to reduce their family's water consumption.*

Electricity bills "considered to us other house it's half, it's a lot different, that's for everything" "really pleased with the bills" "when it's all settled out it'll be about 20 quid a week here" "us other house used to be freezing, and cost about £60 a week in bills"

- *The electricity bill for the property was reported to be £20 a week; the tenants are extremely pleased with this as in their previous house they were paying around £60 a week.* NOTE: The interviews were conducted at the start of the project. This property was subsequently shown to have annual bills of circa £3,000; at the time of the interview the utility had not identified the high consumption.
- *The tenants indicated that they did have some difficulty when they looked into switching provider (not receiving call backs). They made comments to the effect that they were advising suppliers that they had an eco-home and they felt this was putting them off supplying the property ["eco 5" was mentioned during the interview but this is thought to have been a confusion with Code 5).*
- *The tenant's comments indicated that a leaflet listing alternative energy suppliers was provided when the tenants moved in.*
- *The tenants indicated that they were not invited to an open day with Lovell to help*

them understand how to use their home.

13.1.4 Other points

On the view to the rear from the kitchen “lovely, absolutely fantastic” “Christmas dinner, sat here, looking at that yeah ok it’s not the nicest, but even so it’s a beautiful view”
On the view to the rear from the master bedroom (living room on plan) “with the views – we wake up in the morning, you can’t beat it”

- The architectural design to make use of the edge of plot location has been very well received.

- Observation by BPE team: Storage spaces lacked shelves – has made own. However, sufficient shelving should already be supplied in these rented properties as there is a risk that tenants will obstruct M&E services located in the cupboards if they take this into their own hands. It is recommended that sufficient shelving space is not overlooked in future developments.

- Observation by BPE team: Switched to electric cooker instead of gas – no gas supply now needed.

- The tenant’s comments indicated that noise from bathrooms carry between houses – in spite of the care taken to minimise acoustic transfer through the steel frames

On the outside space: “I’ve moved that shed” “It was a waste of space”
[Garden] “Outside’s fantastic”

- Tenant moved the shed to make garden layout better and more spacious, a bigger garden would be nice

On dining room/kitchen “Could have been a bit bigger considering it’s a four bedroom family house, it’s not a very big dining area. And again, the kitchen’s not very big, for the size of the property and the expected family size”

- Dining area/kitchen small compared to rest of house

On the solar shading “it’s unsightly. I know it’s there for a reason, could it have been incorporated into a balcony?”

- Tenant’s comments indicated that they felt the upstairs toilet is too big – waste of floor space. Also that the sink obstructs access if using a wheelchair.

Of the bathroom on the first floor “no problems whatsoever, great size” “the only downfall is the size of the bath, the depth of it, you can’t, it’s a small bath, have a good soak in it”

- Bath is small but further comments from the tenant indicated that they realised this is for environmental reasons, describing it as a “catch 22” situation

Of the top floor front bedroom “That is for me considering this is the second largest bedroom, the size of the window isn’t adequate” “they’re different sizes, which makes it difficult with the curtains I suppose”

- The specification of varied window sizes, particularly the smaller units on the north façade, results in gloomy bedrooms, and is impractical for tenants when purchasing curtains.

- *The tenant’s comments indicate that they had very high praise for the house and that they felt it was fantastic compared to a normal house.*

When asked about the solar shading: “it’s modern isn’t it. If you look at all the new houses they’re all made like this. It’s a safety feature as well, for the kids. You’ve got bars to the back windows which is great, so they can’t fall”

- *The modern look of the home was well liked, and seen as a safety benefit in a family home.*

“I’ve made a few alterations to the back garden” “I’ve moved the shed to make more room”

- *As in the other Code 5 property the shed was moved from its original position in the garden which was impractical, this needs more thought in future. Observation: fencing was also added for containing pets.*

On the kitchen space:

- *Comments indicated that the tenants felt that the kitchen/diner was big enough but that they could not fit both a tumble dryer and fridge/freezer in the kitchen even though plug sockets are provided for both.*

- *The tenants indicated that they use the washing machine and tumble dryer a lot and* *indicated that they intend to move the tumble dryer in the kitchen and are moving the fridge/freezer into the garage. This is a clear failing in the architectural layout given that the properties are intended for larger families*

13.1.5 How could improvements be made?

The tenant made several suggestions for improvements:

“When you’re coming down you can’t turn this light on, the only place to turn this ground floor light on is here or that door there – there’s no physical way, so you’re having to go down, literally part way and then come back” “safety wise when we had a power cut this place was in total darkness” “there should have been some emergency lighting”.

- The tenant can’t switch on the downstairs hall light from FF – also GF hall very dark – emergency lighting and FF switching suggested

On the draught lobby: “the only thing I can find disappointing in this bit is it should have had some sort of ventilation whether it be a fan, extractor fan, ‘cause no offence man – shoes”.

- Ventilation (extract) in lobby would beneficial to clear shoe odour

On the alarm system “regarding the alarm system, you’ve got no control panel upstairs” –

- Alarm control panel upstairs would be beneficial so tenants could use this at night.

“Why wasn’t there a door entry system fitted? Bearing in mind the living quarters in theory should have been up on the third floor in this one” “they ring the doorbell, you’ve got to run all the way down”

- Where a top floor living area on a three storey property is specified (especially if it is a lifetime homes standard) consideration should be given to users with reduced mobility in order to ensure effective communication with the front door.

“Why isn’t there a window on the staircase?”

- There is a strong case for including a window here. This space is gloomy and combined with the lack of a light switch on the landing for the GF hall, this results in either energy inefficient behaviour (leaving the light on) or a gloomy space, which is potentially a hazard in an emergency.

- The tenant's comments also indicated that they felt a balcony to rear of property would be more useful than front as could see the view

Of the family room (rear ground floor) "you can't really use it as a fourth bedroom because of the door – it's a access means" "it's my office...it's great, before that I had to sit at the kitchen table" "personally they should have built a wall straight across there, had that as the access and had that as a window there"

- The family room in the home, located on the ground floor, is used as an office and relaxation space for the children and works well for this. Tenants felt this could not be used as a bedroom as it is a through route. A corridor wall would be needed, as in the Code 3 properties. This was not designed to be used as a bedroom, so it isn't in itself a design fault, and patio doors offer level access to the garden.

On the layout, commented from the front first floor room which was being used as a living room: "on the plans this was a bedroom, and the upstairs, our bedroom, was the front room" "I find it easier with the children, right you've got the kitchen, everything's… especially with the baby, you don't have to run up stairs all the time to the kitchen" "when the children play out here [front of house] you can watch them"

- *Both properties were using the house in the same way, and did not use the top rear room as the living room.*

- *As with the other Code 5 property, tenants indicated that an intercom would be welcomed to aid in answering the door*

13.2 Code 3 property 3A (walkthrough and interview)

The tenant in this property requested that the interview was not recorded. As such, all comments in this section are the interpretations made by the BPE team on the basis of the tenant's responses within the interview and may not be a precise representation of the tenant's opinion.

13.2.1 Dwelling operation and usage patterns

- Tenants indicated that they have lived in the property since July 2011, and previously lived in small 3-bedroom home.

- Tenants indicated that they are in the home for most of the day with younger family members regularly coming and going.

- Tenant indicated that they find the home adaptable for living in with family and likes the flexibility that the design offers, the size of the bedrooms was particularly well liked.
- Tenants indicated that they are using the home as designed with the exception of the small bedroom on the first floor which is being used as a second living room/TV room for children.
- The tenant indicated that they find everything easy to use in the kitchen,
- The tenant indicated that they did not know anything about the ventilation system and this wasn't explained when she moved in, she was not aware of the booster function in the kitchen and bathroom.
- Tenant reported that there is sometimes a draft coming from the ventilation system. This suggests that the system is imbalanced or has a poorly sited inlet. It is recommended that an engineer is sent to site to investigate.
- The tenant indicate that windows are often opened in the home for ventilation purposes to let fresh air into the dwelling, especially when cooking.
- The tenant's comments suggested that she doesn't really know how to use the heating controls. She indicated that this was not explained to her when she moved in - manufacturer's instructions were provided but these were confusing and difficult to read with English as a second language.
- The tenant indicated that she does not get uncomfortably hot in the summer in the house.
- The tenant's comments indicate that they were not invited to an open day to help tenants understand how to operate their homes. This was offered by Lovell but was not delivered in practice due to scheduling issues between Lovell and TGP. It is recommended that handover sessions are prioritised much more highly with a clear

specification for their content included in tender packages when procuring contractors.

- The main heating control for the home is in the kitchen and the tenant indicated that they put this on as a when required, rather than using the timer control.
- Comments indicated that the downstairs bedroom can get cold in winter – more so than others.
- The tenant indicated that she does not understand how to use the alarm and does not use it.

13.2.2 Maintenance

- The tenant's comments indicate that when ringing TGP about issues in the property a quick response was received and the service provided by TGP and Lovell was good, and the operative was helpful.
- The tenant indicated that since moving in problems with the front door were encountered but once reported this was resolved promptly.
- The tenant's comments indicate that they were unaware of any maintenance activities required for the MVHR system.

13.2.3 Energy and water management

- The tenant's comments indicated higher electricity and gas bills, which were much higher than expected. Around £50/60 a week was indicated, and electricity costs were suggested to be higher than gas. The tenant's comments suggest that they have not looked at switching tariff as they weren't sure if this would affect the energy efficiency and renewable technologies.
- The tenant indicate that they would find it useful to receive energy and water saving and tariff switching advice at the 6 weekly visit to help to save money on energy and water bills.
- The tenant indicated concern that her water bill is much higher than neighbours at

£18 per week and does not think that their water use is excessive (this could be due to a leak?)

- The tenant indicated that they were unaware of the rainwater harvesting system until the tenant contacted TGP to report problems with the toilet not flushing properly. When asked, the tenant could not advise where the control system is for the rainwater harvesting system and has never been shown how it works.

13.2.4 Other points

- Tenant indicates that they particularly like the view from the kitchen
- Observation - The small bedroom on first floor is being used as a second living room for children.
- The tenant indicate that they make use of both the balcony and garden
- Comments suggest that the aesthetics of the house are well liked and tenant has received many compliments from friends and family visiting her home.
- Tenant's comments suggest that they are really happy with the amount of storage space in the home.
- Tenant's comments suggest that the amount of natural light and glazing is well liked.
- Observation - TV in children's lounge left on when not in use.
- Observation – hot and stuffy on top floor.
- The tenant indicated that she was struggling to get hold of dedicated energy efficiency light bulbs – the specification of these fittings was driven by SAP requirements in the design.
- The tenant's comments suggest that they have reported a concern around the windows in the bedroom on the top floor shaking and rattling in the wind.
- Noise from outside was indicated to be an issue, even when the windows are closed.

No noise from adjoining neighbours was suggested. Internal noise was indicated as an issue with noise between floors audible.

13.2.5 How could improvements be made?

- Tenant's comments suggested that the living room might be best placed where the kitchen is currently located (to benefit from views) with the kitchen on the north side
- A more user friendly guide for heating controls and the house alarm are required.
- At the handover the tenant's comments suggest that she was simply provided with her keys and a handbook which contained manufacturer's instructions for installed systems. More needs to be done at the handover stage to make sure that tenants understand how to use their homes; this will require educating TGP staff as currently their awareness is low. A clear strategy for who provides which handover services would also be advisable, including:
    - A tenant friendly handover pack would be beneficial to support the technical manuals (with general descriptions of equipment and controls)
    - A face to face demonstration of *all* controls to the tenants, including where errors would be shown on PV, SHW, heat pump and rainwater harvesting systems to assist them when reporting issues. Even if training sessions are cancelled, then TGP must be persist to ensure it is delivered.
    - What needs its batteries changing, who is responsible for it and how often this is required.
    - A full maintenance schedule with appropriate intervals for each task should be provided by the contractor for TGP's maintenance team, including any consumables required (e.g. MVHR filters) - a simple copy for the tenant might be beneficial also.
- The tenant indicated that she would have appreciated someone sitting with her after sign up to help her understand how to reduce her energy and water consumption and

also make sure that she is on the best tariff so that she is not overpaying for her electricity and gas. In this case, it was indicated that because of the language barrier face to face advice was preferred as opposed written guidance.

13.3 BUS survey analysis

Figure 0-1: BUS survey slider results explanation

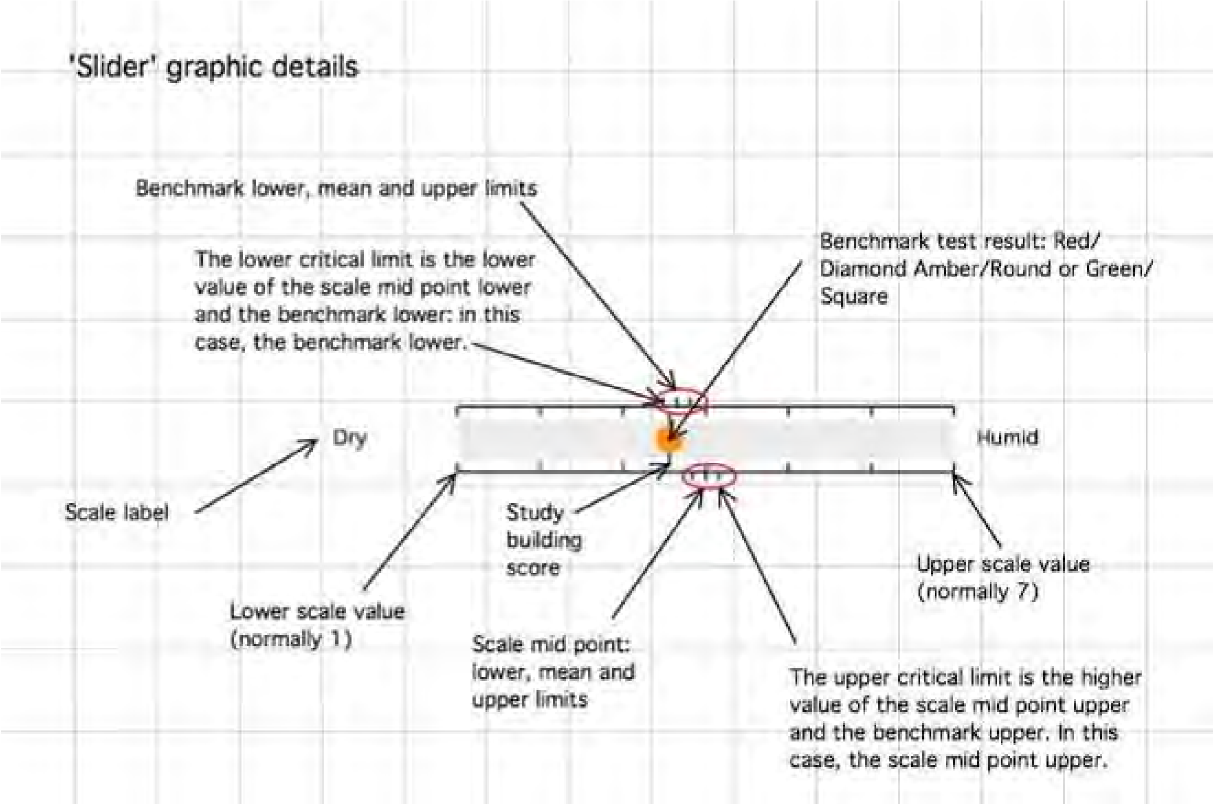
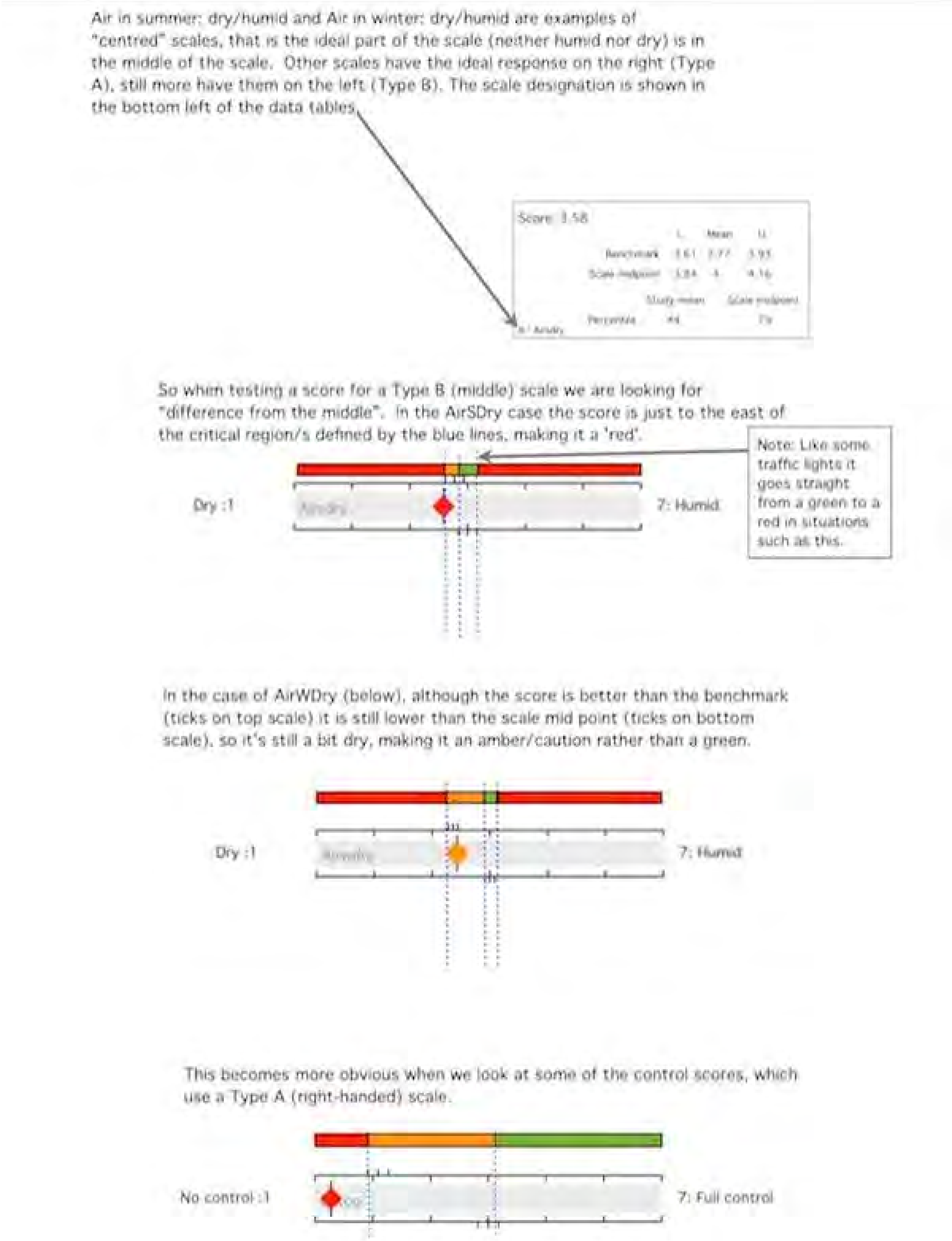
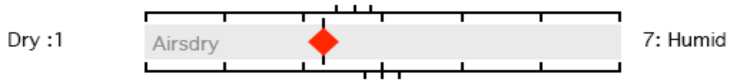
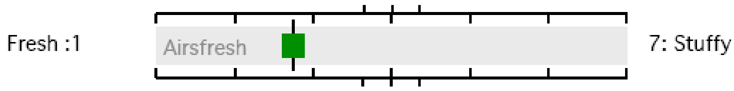
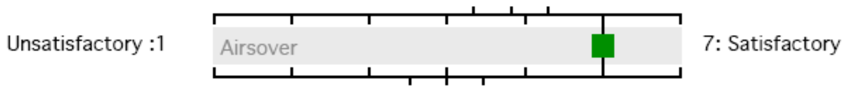
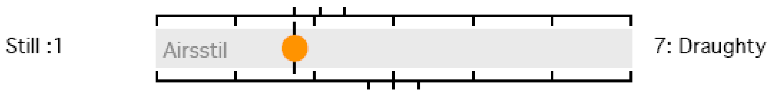


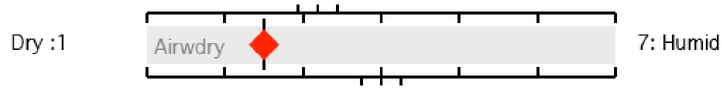
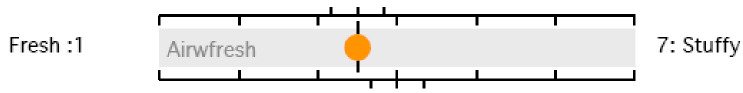
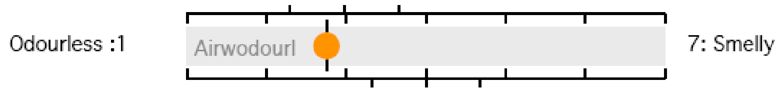
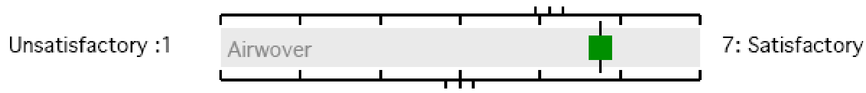
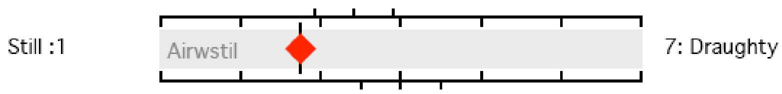
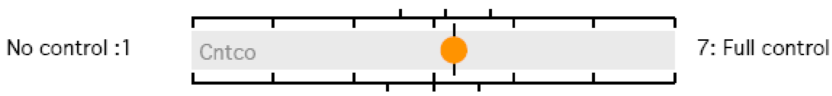
Figure 0-2: BUS survey sliders –further explanation

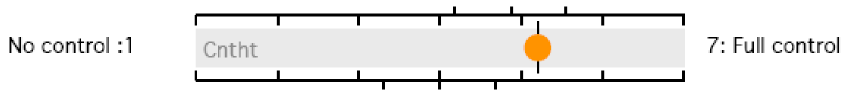
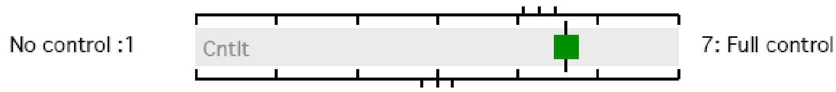
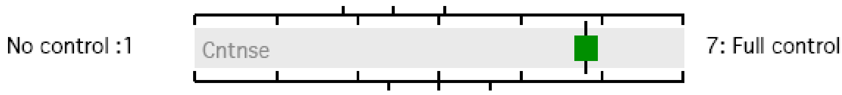
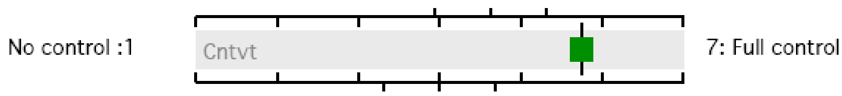
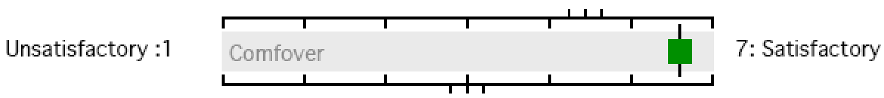


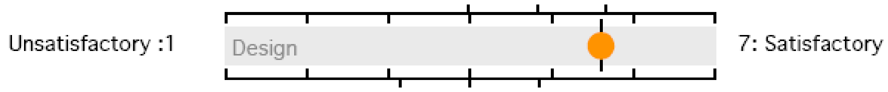
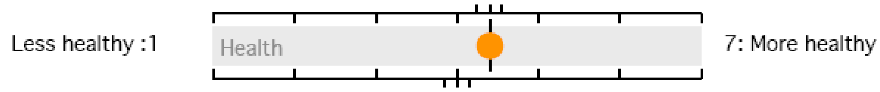
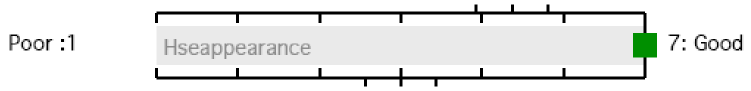
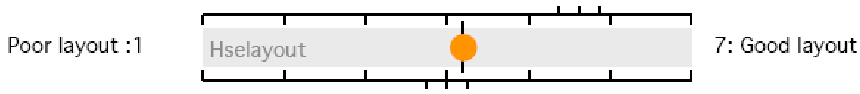
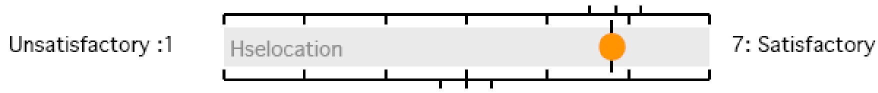
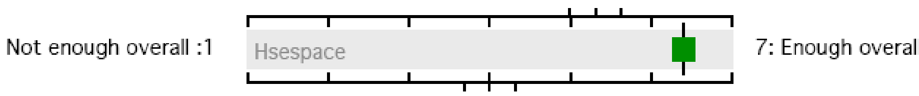
Within the following analysis, results with useful insights are focussed on.

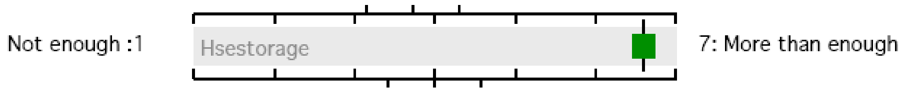
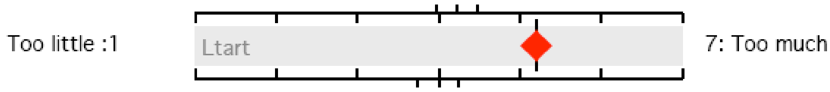
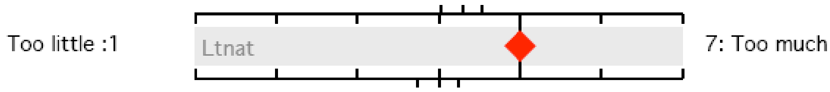
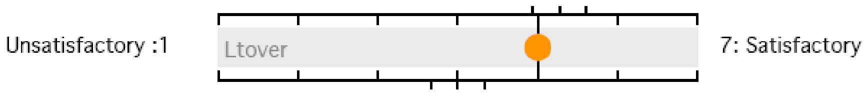
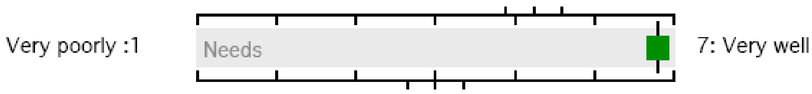
Table 0-1: Full BUS survey results

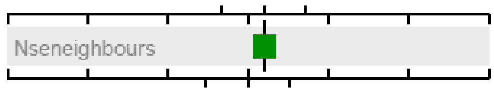
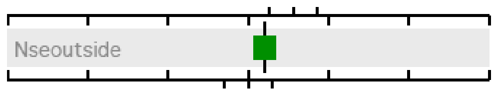
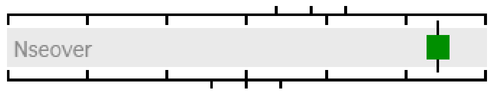
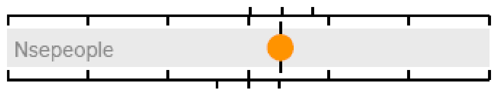
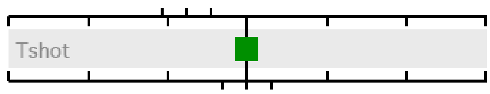
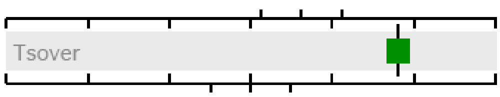
BUS survey category	BUS survey analysis
Air in summer: dry/humid	 Discussion: The results fall within the lower quintile of the BUS data set, showing that the properties are too dry during the summer. This may be caused by the Code 5 properties both being mechanically ventilated. Current industry feeling is that MVHR systems cause dry air. Retrofitting a humidity device could help to combat this issue.
Air in summer: fresh/stuffy	 Discussion: the results fall within the highest quintile of the BUS data set, showing the properties are well ventilated.
Air in summer: odourless/smelly	 Discussion: the results fall within the highest quintile of the BUS data set, showing the properties are well ventilated.
Air in summer: overall	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project, and is likely due to the high design air permeability specifications and MVHR.
Air in summer: still/draughty	 Discussion: The results are at the lower end of the standard range, reduced MVHR flow rates are likely to be a factor here.

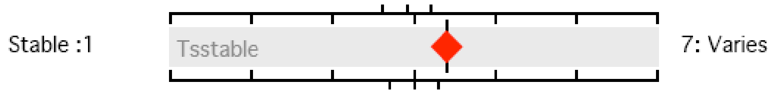
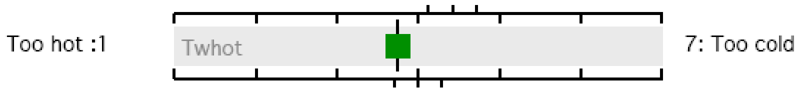
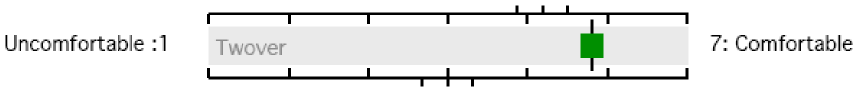
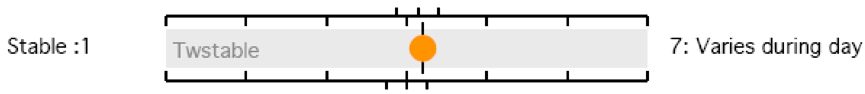
Air in winter: dry/humid	 Discussion: The project received the lowest results from the BUS data set, showing that the properties are too dry during the winter. The Code 5 properties are both heated to a relatively high temperature all day, all year round which could lead to dry air in these properties. Internal winter temperatures in the Code 3 property being monitored are not excessive; hence this may be a less significant factor. The MVHR may also be contributing to the dry air feel – this is a common issue.
Air in winter: fresh/stuffy	 Discussion: The results are average for the BUS sample set and indicate that the air is to the positive side of acceptable. .
Air in winter: odourless/smelly	 No significant comments on this value.
Air in winter overall	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project, and is likely due to the high design air permeability specifications and MVHR.
Air in winter: still/draughty	 Discussion: The results fall within the lower quintile of the BUS data set, showing that the air within the properties is too still during the winter. Closed windows in winter, and the shortfall in MVHR air flow rates could explain this issue.
Control over cooling	 No significant comments on this value.

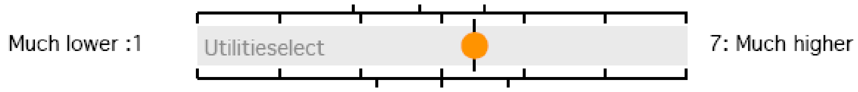
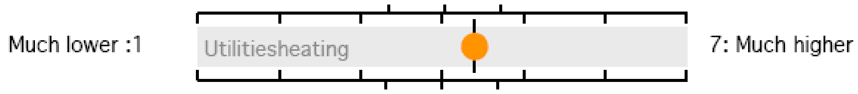
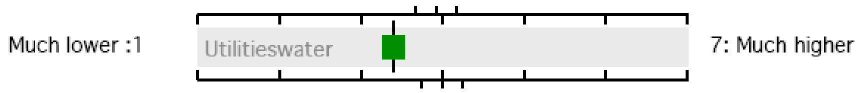
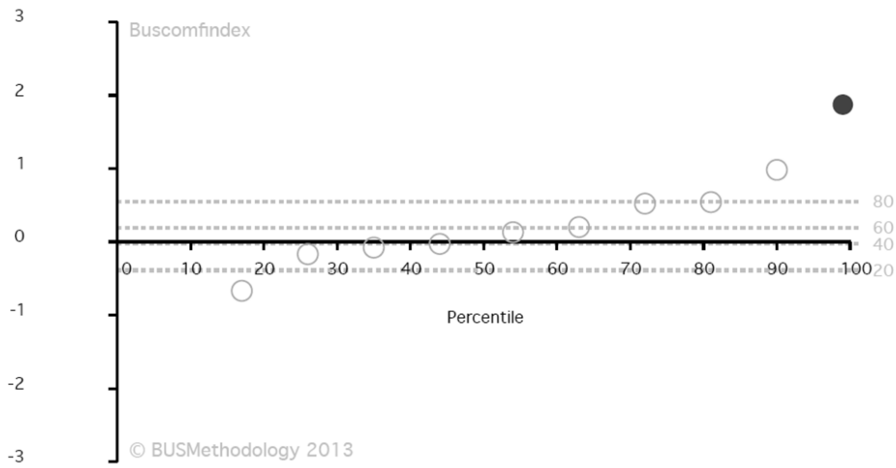
Control over heating	 No significant comments on this value.
Control over lighting	 Discussion: the results fall within the highest quintile of the BUS data set, showing the tenants feel they have good control over the lighting. This is in conflict with the tenants indicating that there is too much artificial light – if they could dim the lights, then this criticism would not apply.
Control over noise	 Discussion: the results fall within the highest quintile of the BUS data set, showing the tenants feel they have good control over the noise levels. This is likely due to the specifications of the windows.
Control over ventilation	 Discussion: the results fall within the highest quintile of the BUS data set, showing the tenants feel they have good control over the ventilation levels. MVHR controls were not well understood (if at all) when tenants were interviewed, so this is more likely to relate to tenants opening windows when they feel a need for ventilation – this could tie in with increased heat load in the Code 5 properties..
Comfort: overall	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project, and indicates that despite confusion over controls (especially in the Code 3 units) the properties are comfortable for the tenants.

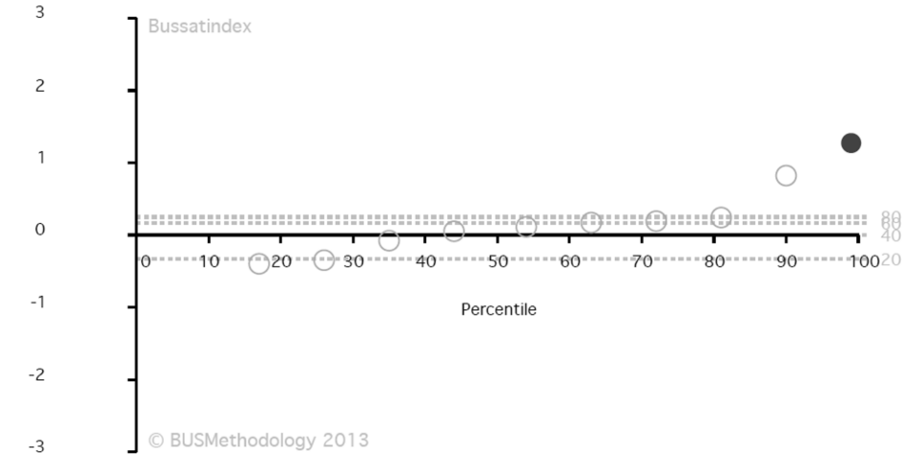
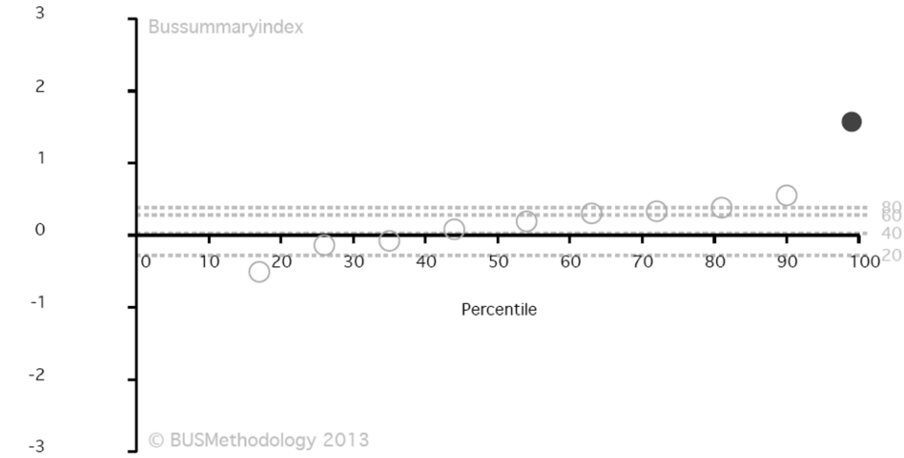
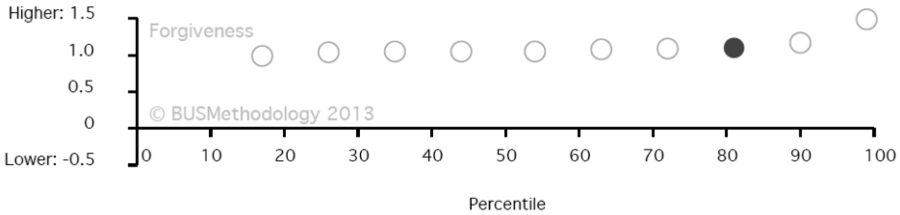
Design	 Discussion: The results are at the upper end of the standard range reflecting the attractive architectural design and spacious nature of the properties.
Health (perceived)	 No significant comments on this value.
Appearance from the outside	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project and correlates with interview comments that the properties are visually very attractive.
Layout	 No significant comments on this value.
Location	 No significant comments on this value.
Space	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project as it shows building was designed to give the tenants sufficient space.

Storage	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. Code 5 properties benefit from storage space in the top floor M&E cupboards whereas Code 3’s benefit from two of these cupboards being unused.
Lighting: artificial light	 Discussion: The project received the lowest results from the BUS data set, indicating that there is too much light from artificial sources. Dimming lights would offer a solution to this problem.
Lighting: natural light	 Discussion: The project received the lowest results from the BUS data set. There was also perceived to be too much natural light. The tenants may be referencing excessive glare, which can be a common issue with large windows. If this is the case, the installation of glare reduction coatings to the windows would help.
Lighting: overall	 No significant comments on this value.
Needs	 Discussion: The results show the highest levels of satisfaction from the BUS results database. Due to the storage space and services design, the tenants’ needs are met very well.

Noise from neighbours	Too little :1  7: Too much Discussion: The results show a good level of satisfaction when compared with the scheme-wide BUS results. This is likely due to the specific attention paid to acoustics during the design process to prevent noise transmission through the steel structures between properties.
Noise: noise from outside	Too little :1  7: Too much Discussion: The results show a good level of satisfaction when compared with the scheme-wide BUS results. This is likely due to the high specifications of the external walls, windows and doors. The properties are also located at the edge of the estate.
Noise: overall	Unsatisfactory :1  7: Satisfactory Discussion: The results show the highest level of satisfaction when compared with the scheme-wide BUS results.
Noise: noise from other people	Too little :1  7: Too much No significant comments on this value.
Temperature in summer: hot/cold	Too hot :1  7: Too cold Discussion: The results show a good level of satisfaction when compared with the scheme-wide BUS results. This is likely due to the high specifications of the external walls, windows and doors. The properties are also located at the edge of the estate.
Temperature in summer: overall	Uncomfortable :1  7: Comfortable Discussion: The results show the second highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project, and is likely due to the high build specifications.

Temperature in summer: stable/varies	 Discussion: The project received the poorest results from the BUS data set, showing that the internal temperature varies too much in the summer. This is likely to be due to the large area of south facing windows causing temperature spikes during certain periods when gains are high. This is in spite of the inclusion of shading measures in the design (roof overhang and brise-soleil to the rear of the properties) and the properties passing the overheating test contained in the SAP building regulations assessment. Where a design incorporates a very high degree of passive solar design, a more comprehensive assessment of overheating may be required such as thermal modelling rather than reliance on the simple assessment contained in SAP.
Temperature in winter: hot/cold	 Discussion: The results show a good level of satisfaction when compared with the scheme-wide BUS results. This is a positive result, especially considering the confusion the Code 5 tenants had regarding heating controls. However, the monitored energy data indicates that comfortable temperatures are being delivered at a high energy use and cost to the tenants in three of the four properties.
Temperature in winter: overall	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results, an excellent result in comfort terms
Temperature in winter: stable/varies	 No significant comments on this value.

Utilities costs for electricity	 Discussion: The results are within the standard range for the BUS survey, but indicate that tenants consider the bills to be slightly higher than previous properties. This could be skewed by the fact that the Code 5 properties are electrically heated.
Utilities costs for heating	 Discussion: The results indicate that tenants consider their heating costs to be slightly higher than previous accommodation indicate that
Utilities costs for water	 Discussion: The results show the highest level of satisfaction from the scheme-wide BUS results. This is a positive result for the project, and is likely to be linked to the fact that their water use is directly metered. However, metered data does not indicate that rainwater harvesting systems are generating any substantial savings in water usage.
BUS Comfort Index	 The project receives the highest score under the BUS Comfort Index, from the scheme-wide BUS survey data set. This is an excellent result for the project.

BUS Satisfaction Index	 The project receives the highest score under the BUS Satisfaction Index, from the scheme-wide BUS survey data set. This is again an excellent result for the project and reflects the feeling that the properties are a cut above the normal social housing stock.
BUS Summary Index	 The project receives the highest score under the BUS Summary Index, from the scheme-wide BUS survey data set.
Forgiveness Index	 The project receives a good score under the BUS Forgiveness Index, from the scheme-wide BUS survey data set.

Appendix F - Monitoring methods and findings

This section presents the results of detailed analysis of monitoring data collected during the first year of the project. Further analysis of data from the second year's data is presented in the main report; this section only refers to the first year analysis & does not take the later findings into account.

14.1 Property 3B

14.1.1 Whole building performance and comparison with expectations for year 1

Property 3B is performing better than expected by SAP predictions in terms of gas consumption, as shown in Table 0-2. This calculation includes gas consumption for cooking, as calculated within the Code for Sustainable Homes (CSH), which may exaggerate the good performance of this property. Issues with the electricity monitoring installed were not fully resolved until September 2013, despite multiple visits by the contractor – so no data was available for the first year.

It was not possible to install a water meter due to access constraints, so water performance cannot be analysed.

Table 0-2: Property 3B consumption data

	Metered data yr 1	SAP / CSH (actual occupancy)	SAP / CSH (predicted occupancy)[7]	Percentage difference from predicted (%)
Total gas consumption (kWh)	5,809	7,606	7,465	-22%
Total electricity consumption (kWh)	n/a	3,958	3,407	n/a
Total water consumption (l)	n/a	153,300	108,607	n/a

14.2 Property 3A

[7] SAP methodology has been used to calculate the predicted regulated energy demand. Methodology from Code for Sustainable Homes (CSH) has been used to calculate the anticipated energy consumption for cooking and appliances (unregulated emissions), and for water consumption. The calculations from CSH have been done for both the predicted occupancy (2.8 people) and the actual occupancy (4 people, in this case).

14.2.1 Whole building performance and comparison with expectations for year 1

Property 3A does not appear to be performing in line with the SAP predictions, as shown in Table 0-3.

Table 0-3: Property 3A consumption data

	Metered data yr 1	SAP / CSH (actual occupancy)	SAP / CSH (predicted occupancy)[8]	Percentage difference from predicted (%)
Total gas consumption (kWh)	12,342	8,377	7,872	+57%
Total electricity consumption (kWh)	4,926	5,704	3,404	+45%
Total water consumption (l)	158,134	268,275	108,607	+46%

Gas consumption is 57% higher than predicted. Metering data indicates that the boiler is operating less efficiently than predicted (approx.76% versus SAP efficiency of 93%), which accounts for 1,642kWh of the discrepancy.[9] The heating consumption is significantly higher than the SAP prediction, as shown in Table 0-4, whereas the hot water demand is in line with SAP predictions.

[8] SAP methodology has been used to calculate the predicted regulated energy demand. Methodology from Code for Sustainable Homes (CSH) has been used to calculate the anticipated energy consumption for cooking and appliances (unregulated emissions), and for water consumption. The calculations from CSH have been done for both the predicted occupancy (2.8 people) and the actual occupancy (7 people, in this case).

[9] Due to the quality of the data monitoring, the boiler efficiency has been based on a combination of data from the online portal, and on-site visits, to improve accuracy.

Table 0-4: Property 3A demand data

	Metered data yr 1	SAP / CSH (actual occupancy)	SAP / CSH (predicted occupancy)	Percentage difference from predicted (%)
Heating (heat kWh)	3,999	2,824	2,824	+42%
Hot water (heat kWh)	3,612	*3,640*	3,640	-1%
Immersion (elec. kWh)	1,470	0	0	∞
Lights and appliances (elec. kWh)	3,456	5.074	3,404	+2%
Cooking (gas kWh)	2,381[10]	1,449	945	+152%

The metered data shows that 42% more heat is delivered to space heating than SAP predicts. Possible contributors to this are the fact that the property's air tightness is lower than the design value used in SAP (7.78 $m^3/m^2/hr$ vs. target of 5 $m^3/m^2/hr$), that the tenant sometimes opens windows for ventilation rather than using the MVHR (anecdotal evidence from site visits suggests this) or other fabric issues. See Section 3 for further detail and insight from the fabric testing; the thermography study and U-value testing.

Significantly more gas is used for cooking than predicted by SAP. The Code for Sustainable Homes (CSH) occupancy assumption for this property is 2.8 people, whereas there are 7 residents in this property in reality. With occupancy of 7, CSH predicts gas consumption for cooking of 1,449 kWh, so there is still a 64% higher consumption rate than would typically be expected. However this is considered within reasonable bounds, as the occupant is typically in the property all day and often cooks in the afternoons.

The electricity consumption is 45% higher than predicted for "typical occupancy, but given that there are more people living in the property than SAP would assume, this is likely due to increased appliance loads, and as shown in Table 0-3, occupancy of 7 would give a predicted electricity consumption of 5,704 kWh, for this property, which is higher than the monitored consumption. The BUS survey indicated that the residents are rather energy conscious, so it is reasonable that the electricity consumption is lower than expected for occupancy of 7.

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[10] This figure has been calculated using a pro rata method on the consumption during a very short period of the year, due to the loss of the gas incomer meter.

Table 0-4 shows the consumption from the immersion heater is much higher than expected. All of the immersion heating consumption is for the first half of the year. At the beginning of the year the tenants advised that they had the controls set up so that the hot water only came on when the tenants pressed the 'boost' button on the heating controller, which may have led to high immersion usage to maintain the thermostat temperature. When the immersion ceased to be used, the hot water demand supplied by the boiler increased accordingly, and the total monthly DHW use remained consistent, suggesting that the controls have been adjusted.

14.2.2 Breakdown of energy consumption within the property based on sub metering data for year 1

It is clear from the sub-metering data that there is a significant discrepancy between the total incoming electricity, and the sub-metered consumption. We believe that this is due to a combination of unmetered appliances and circuits, and an issue with the accuracy of the meters installed. Sub-metering in the properties uses Current Transformer (CT) clamps fitted around the live cables from the distribution boards in the properties, which appear to have difficulty registering smaller loads.

This unmetered consumption accounts for 31% of the total electricity use of the property, as shown in Figure 0-3. To further analyse the unmetered consumption, a number of unmetered consumption sources have been suggested in Table 0-5. Estimates have been made to account for unmetered consumption and areas where we suspect that the meters are under-reporting consumption in Table 0-5. However, this still leaves 500 kWh of unmetered consumption, due to unexpected metering inaccuracies. The quality of the monitoring is discussed in section 14.5.1. The issues encountered with the electrical sub-metering do not affect the ability to draw valid conclusions regarding the overall performance of the property, but do limit the in-depth analysis. The inaccuracies of the sub-metering are outside the realm of error margins.

Figure 0-3: Property 3A electricity consumption by end use (kWh)

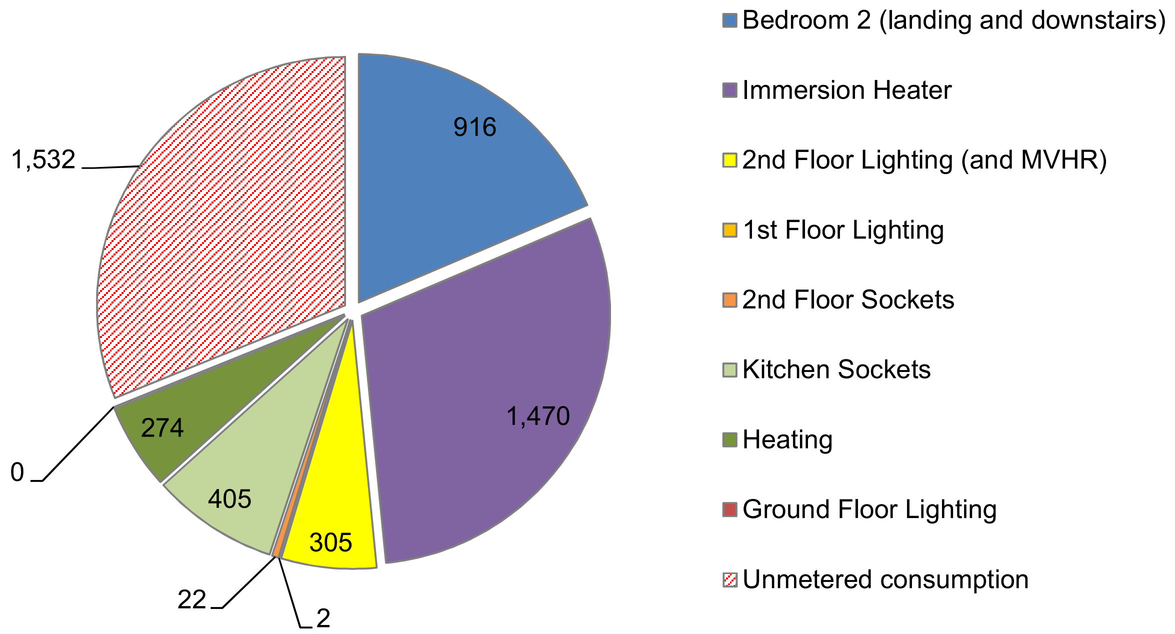


Table 0-5: Property 3A – unmetered consumption

	Estimated consumption (kWh)	Notes
Eco Vat rainwater harvesting	153	assume 40l per person/day for toilets and washing machine = $102m^3$ x 1.5 kWh/m^3 (industry standard)
Smoke alarms	131	assume 3 @ 5W each
Door bell	88	assume 1 @ 10w
Heating controllers	40	assume 2 @ 20W each
2nd Floor Lighting (and MVHR)	180	estimate due to inconsistency in metering[11]
1st Floor Lighting	160	estimate underreporting, based on Property 5A consumption
Ground floor lighting	130	estimate underreporting, based on Property 5A consumption
Second floor sockets	150	Estimated under-reporting, based on other sockets & connected loads. Note, possible significant hairdryer use could push this much higher (bedrooms for mother & 2

[11] The sub-meter 'MVHR' reported a consumption of 323kWh. This is a sub-circuit of the circuit monitored named '2nd Floor Lighting (and MVHR)', which reported a consumption of 305kWh for the monitored year. This is clearly not possible based on the consumption of the sub-circuit.

		daughters on this floor)– 2kW for 20 minutes/day could be 250kWh/year
Total possible unmetered	**1,032**	**21%**
Remaining unaccounted	**500**	**10%**

Energy performance compared to the DomEARM tool audit survey is presented in the Appendix section 14.2.4.

14.2.3 Assessment of the performance of individual systems for year 1

The tenant stated, during the BUS survey and interview, that their bills were higher than expected, especially the electricity bills. This observation corroborates the metered electricity consumption. However, now that the tenant has corrected the hot water controls and is no longer using the immersion to supply the hot water demand, electricity bills should now be in line with expectations.

Boiler: Analysis of the gas and heat meters (boiler gas consumption, heating system consumption, and hot water system consumption) shows that the boiler in Property 3A has an efficiency of 76% for the 12 month period.[12] This is significantly below the SAP assumption (93%) and manufacturer's data of 91.1%. The metering data this is based upon has been corroborated against physical readings and is therefore believed to be robust to within reasonable bounds of error. There are a number of reasons why the boiler might under perform. Oversizing and commissioning issues are the most likely suspects, which could result in the boiler cycling on and off for short periods, reducing efficiency – unfortunately this study did not cover the commissioning phase so this cannot be confirmed.

MVHR: The MVHR system sub-metered data shows a consumption of 323kWh for the year, compared to the SAP predicted consumption of 169 kWh for the system. This indicates an underperformance of 91%.

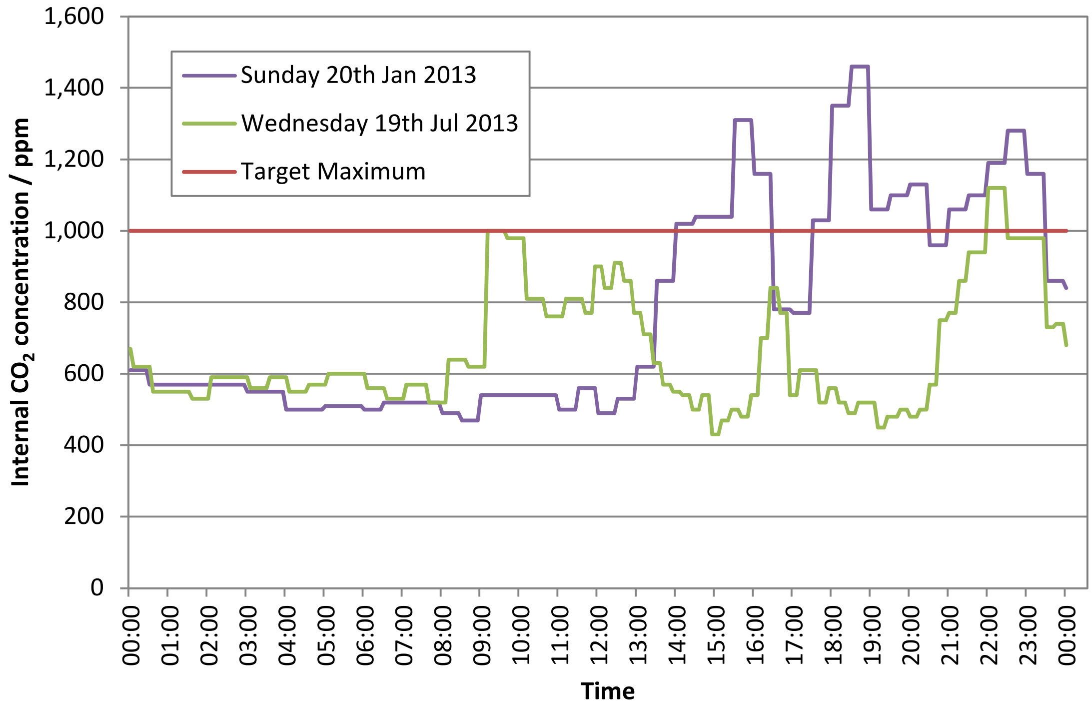
To assess the MVHR system the internal CO_2 concentration has been analysed. For the period with data coverage (17/09/2012 – 30/06/2013), the average CO_2 concentration is 719 ppm. In 14% of the measurements, the concentration was greater than 1,000 ppm.

[12] Due to the metering issues, the monthly heating output from the boiler is not available for mid-November to mid-February. However, estimates have been made based on the on-site meter reading on 15th February 2012, and degree day data.

While there has not been a great deal of research on CO_2 levels in homes, 1,000ppm is often used as a trigger point for supplementary ventilation in schools. If the CO_2 concentration is above this limit for long periods, it can affect concentration/mental acuity and at very high concentration (10,000ppm+), more severe effects are observed. Peaks are caused by a large number of inhabitants in the property, or gas cooker use, particularly in air tight properties like Property 3A. The internal CO_2 concentration is shown for two sample days in Figure 0-4. There are generally peaks around the times for cooking (lunch and supper), and when most of the residents are in the property in the late evening.

The profile of CO_2 concentration in this property looks to be within acceptable margins, however the tenant's lack of understanding of the MVHR boost controls may be contributing to the peaks in the afternoon.

Figure 0-4: Internal CO_2 concentration of Property 3A



14.2.4 Property 3A DomEARM analysis for year 1

When the metered electricity data is compared against the audit data from the DomEARM tool, it can be seen that the property has a 12% higher consumption higher than expected, as shown in Table 0-6. However, the audit data seems to significantly overestimating the gas consumption – this is because it is unlikely that the DomEARM tool accounts for this property being built to a high specification. When the heating consumption is compared to the CSH level 4 and level 6 benchmarks within DomEARM, as shown in Table 0-7, the gas consumption is still significantly higher than expected, and the electricity consumption is 32% higher than expected.

Table 0-6: Property 3A: metered data compared with DomEARM audit data

	Metered data		Audit data
Electricity kWh	kWh	kWh/m²	kWh/m²
Heating		0.0	0.0
Hot water	1470.38	12.3	0.0
Refrigeration - HVAC		0.0	0.0
Ventilation	323.38	2.7	3.7
Lighting	306.68	2.6	1.4
Total Small Power	2826.03	23.6	28.7
Other		0.0	3.0
Total electricity	4926.47	41.05	36.65
Difference to actual %	+0%	+0%	-11%
Non-electricity kWh			
Heating	5437.45	45.3	259.9
Hot water	4523.33	37.7	42.0
Cooking Appliances	2381.11	19.8	3.2
Other		0.0	0.0
Total non-electricity	12341.90	102.85	305.08
Difference to actual %	+0%	+0%	+197%

Table 0-7: Property 3A: metered data compared with DomEARM CSH level 4 and level 6 benchmarks

	Actual		**CSH 4**		**CSH 6**	
	Non-elec.	Electricity	Non-elec.	Electricity	Non-elec.	Electricity
Space Heating	259.9	0.0	42.0	0.0	42.0	0.0
Water Heating	42.0	0.0	34.9	0.0	32.2	0.0
Space Cooling	0.0	0.0	0.0	0.0	0.0	0.0
Lighting	0.0	1.4	0.0	4.9	0.0	4.9
Fans and Pumps	0.0	3.7	0.0	0.0	0.0	0.0
Cooking	3.2	0.2	13.8	0.0	13.8	0.0
Computer equipment	0.0	3.3	0.0	0.0	0.0	0.0
Consumer electronics	0.0	19.0	0.0	0.0	0.0	0.0
Refrigeration Appliances	0.0	3.9	0.0	0.0	0.0	0.0
Wet Appliances	0.0	2.3	0.0	0.0	0.0	0.0
Total small power	0.0	0.0	0.0	20.8	0.0	20.8
Other	0.0	3.0	0.0	0.0	0.0	0.0
Total	**305.1**	**36.6**	**90.8**	**25.7**	**88.1**	**25.7**

14.3 Property 5B

14.3.1 Whole building performance and comparison with expectations for year 1

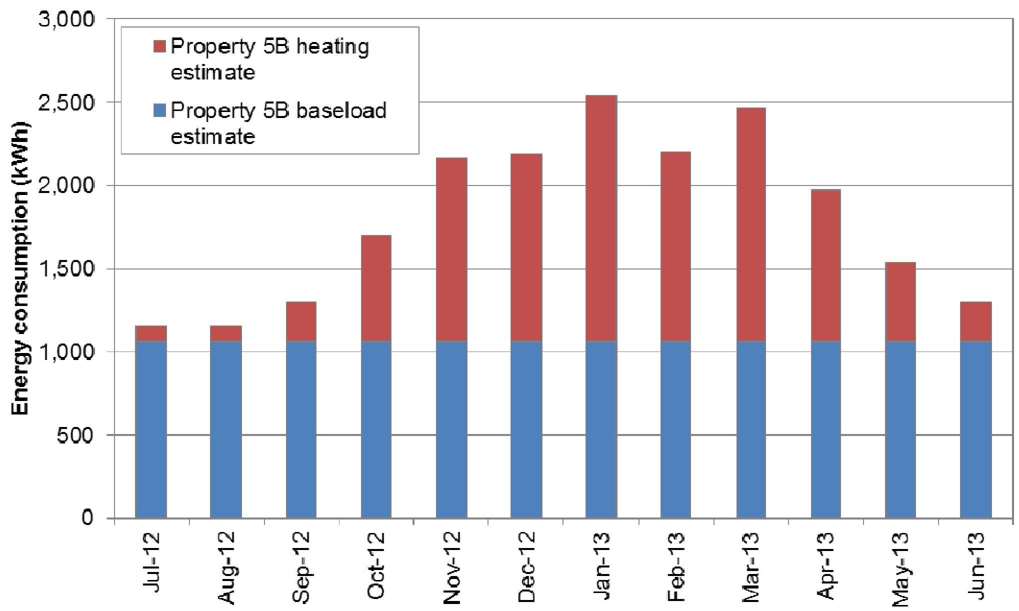
Property 5B has only basic utility metering in place. The data available for this property indicates that it is using dramatically more energy than predicted by SAP, as shown in Table 0-8. The tenants have been contacted to attempt to verify the energy consumption, which if correct could result in bills of approximately £3,000 a year.

Water consumption is higher than predicted using CSH. However, the prediction is for 2.8 occupants, whereas Property 5B has 7 occupants. The water consumption is lower than expected for 7 occupants, perhaps this is because 5 of the 7 residents are minors and thus use less water than a typical adult.

Table 0-8: Property 5B consumption data

	Metered data	SAP / CSH (actual occupancy)	SAP / CSH (predicted occupancy)	Percentage difference from predicted (%)
Total gas consumption (kWh)	n/a	n/a	n/a	n/a
Total electricity consumption (kWh)	21,692	7,537	5,707	+280%
Total water consumption (l)	178,244	204,400	82,535	+215%

Figure 0-5: Estimated heating use at Property 5B



14.3.2 Breakdown of energy consumption within the property based on sub metering data for year 1

The property is not fully sub-metered, so estimates on the energy demand for heating and electrical base-load have been made (based on degree day data), as shown in Figure 0-5 and Table 0-9.

Table 0-9: Property 5B electricity demand profile

	Metered data	SAP / CSH (actual occupancy)	SAP / CSH (predicted occupancy)	Percentage difference from predicted (%)
Heating and hot water (kWh)	8,953	2,277	2,277	+293%
Lights, appliances, and cooking (kWh)	12,739	5,260	3,430	+271%

A closer investigation of the annual profile for this property indicates that a substantial proportion of the electricity consumption may be used for heating, as there is a strong seasonal profile. This would suggest almost 9,000 kWh electricity/year used for heating – if the heat pump was operating efficiently this could be 27,000kWh of heating delivered. This is an implausibly high figure, over 10 times the estimated heating demand, and a fault with the heat pump must be suspected if the energy consumption can be verified against the bills.

The remaining consumption (over 12,000 kWh) is still very high; while a faulty heat pump with high use of immersion for hot water might explain some of this the remaining use for pumps, fans and appliances would still be substantial.

It is noted that the tenant in this property professed a particularly low level of confidence in use of the heating controls – they had been set by a maintenance engineer in response to a fault callout and left like that (heating not coming on – reported as being due to thermostat being set too low). Therefore, an inability to set system controls as desired may be contributing to high energy consumption. Consultation with tenant will be undertaken.

14.3.3 Assessment of the performance of individual systems for year 1

The PV system generated 2,282 kWh of electricity during the monitored year, which is a higher performance than the predicted generation of 2,167 kWh. Based on the electricity export sub-meter, the residents only export 15% of this, which means they are making good use of the generation capacity, because SAP 2005 assumes the property will export 50% of the generated energy to reduce the energy bill costs (though all of credit for carbon abatement is assigned to the property). This performance relative to SAP is consistent with performance seen on other projects Verco have worked on, and the PV performance calculation used in SAP is viewed by many to be conservative.

14.4 Property 5A

14.4.1 Whole building performance and comparison with expectations for year 1

Property 5A also has some outstanding issues with the metering configuration; however, the property is not performing as expected, as shown in Table 0-10:

- The property is using approximately double the electricity consumption predicted by SAP; reasons for this are discussed in section 14.4.2.
- Water consumption is higher than expected for expected occupancy (2.8 people), but for the actual occupancy (4 people) the water consumption is lower than expected.
- Gas is not used in this property.

Table 0-10: Property 5A demand data

	Metered data	SAP / CSH (actual occupancy)	SAP / CSH (predicted occupancy)	Percentage difference from predicted (%)
Total gas consumption (kWh)	n/a	n/a	n/a	n/a
Total electricity consumption (kWh)	11,247	6,304	5,707	+97%
Total water consumption (l)	100,147	116,800	82,535	+21%

14.4.2 Breakdown of energy consumption within the property based on sub metering data for year 1

The sub-metering shows that the energy consumption for the hot water system is in line with expectations, as shown in Table 0-11. However, based on a meter reading taken of the DHW heat meter on-site on 15th February 2013, it appears that not all of the hot water consumption data is being passed into the online portal. During the site visit, the DHW meter read 1,318 kWh, and the reading in the data portal is 1,246 kWh. This 5% underreporting is corroborated by the general 5% discrepancy between the heat pump output and the sum of the heating and DHW output meters. This may be caused by the data logger missing pulses from the DHW heat meter and further checks will be carried out on site.

The immersion heater has been used occasionally which means the overall hot water consumption is an additional 5% greater than the consumption anticipated by SAP. Furthermore, the consumption for the immersion heated only recorded data for the final four months of the monitoring year because the monitor was not installed correctly at first.

This means the consumption for the immersion heater may be significantly underestimated – an estimation of this has been made in Table 0-12.

The heating demand and electrical demand from lights, appliances, and cooking are all significantly higher than expected, as shown in Table 0-11. A significant aspect of this is due to excess energy used by the heat pump – the tenants keep the property very warm (at approximately 25 °C) and are in the house continuously throughout the day. However, as discussed later, the heat pump appears to be operating efficiently; excessive energy use may therefore be due to commissioning or controls issues (controls calling for heat when it is not needed) or high losses from the system, rather than the heat pump unit itself.

Table 0-11: Property 5A demand breakdown

	Metered data	SAP / CSH (actual occupancy)	SAP / CSH (predicted occupancy)	Percentage difference from predicted (%)
Heating (kWh)	10,687	2,202	2,202	+385%
Hot water (kWh)	1,997[13]	1,995	1,995	0%
Immersion (kWh)	108[14]	0	0	∞
Lights, appliances, and cooking (kWh)	7,116	4,027	3,430	+228%

It is clear from the sub-metering data that there is a significant discrepancy between the total incoming electricity, and the sub-metered consumption. This is likely to be in part due to unmetered appliances and circuits, and partly due to the inaccuracy of the meters installed. This unmetered consumption accounts for 34% of the total electricity use of the property, as shown in Figure 0-6. To further analyse the unmetered consumption, a number of unmetered consumption sources have been suggested in Table 0-12. Estimates have been made to account for this underreporting in Table 0-12. However, this still leaves 1,197 kWh of unmetered consumption, due to unexpected metering inaccuracies. The quality of the monitoring is discussed in section 14.5.1. The issues encountered with the electrical sub-metering do not affect the ability to draw valid conclusions regarding the overall

[13] This figure is approximately 5% below actual consumption, due to the data logger missing pulses from the DHW heat meter, as discussed above.

[14] This figure is only for the final four months of the monitoring year a sub-meter was not installed until 15th February 2013

performance of the property, but do limit the in-depth analysis. The inaccuracies of the sub-metering are outside the realm of error margins.

Figure 0-6: Property 5A electricity consumption by end use (kWh)

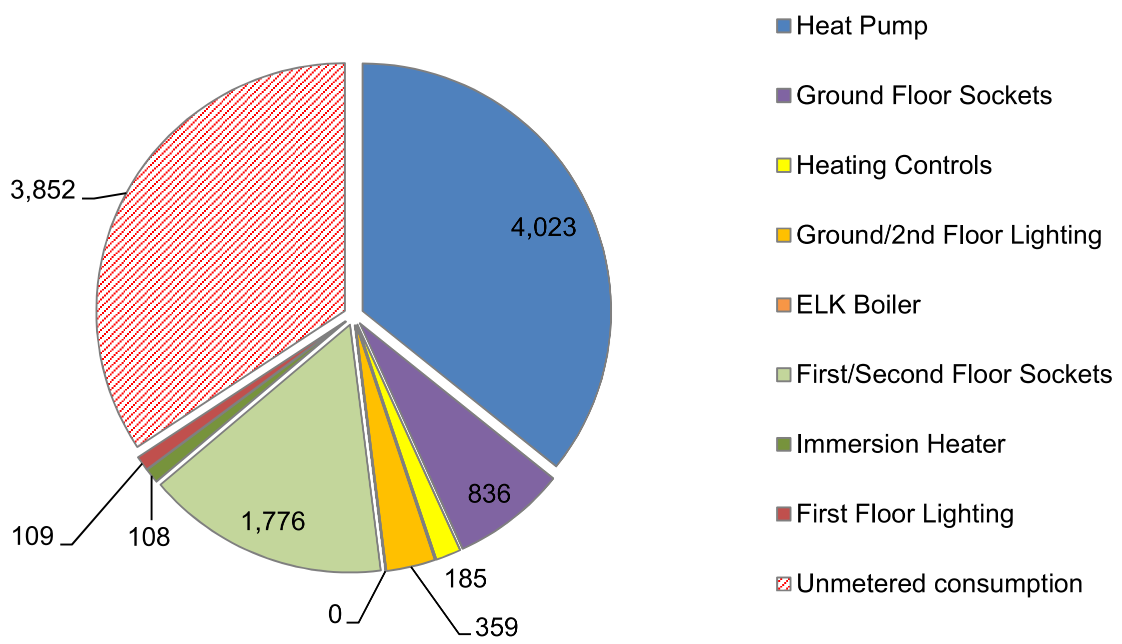


Table 0-12: Property 5A – unmetered consumption

	Estimated consumption (kWh)	Notes
Cooker	848	BREDEM
Immersion heater	490	estimate: meter not installed before 15th Feb 2013
Eco Vat rainwater harvesting	88	assume 40l per person/day for toilets/washing machine = 58m^3 x 1.5 kWh/m^3 (industry standard)
Smoke alarms	131	assume 3 @ 5W each
Door bell	88	assume 1 @ 10w
Solar pump	n/a	not functioning
Under-floor heating controls & thermostats	438	5 units @ 10W each
First floor lighting	50	Possible under-reporting
Sockets	522	Plus 20% based on DomEARM comparison
Total possible unmetered	**2,655**	**24%**
Remaining unaccounted	**1,197**	**11%**

When comparing property performance with SAP, it is should be noted that there are a few discrepancies with the SAP assumptions, and the as-built specifications:

- SAP assumes that the COP of the heat pump is 2.5, whereas the manufacturer's specification gives a COP of between 2.1 (at external temp 7^{o}C and flow temp 35^{o}C) and 4.2 (at external temp -7^{o}C and flow temp 50^{o}C). In this case, the heat pump runs at a high temperature to supply the hot water at all times. Mixer valves are used to regulate temperatures on heating circuits. Manufacturer's COP at 7^{o}C external and 50^{o}C flow temperature is 3.27, which is probably a realistic target. By this logic, the SAP calculations are over estimating the electricity demand for the heat pump by around 30%.

- The heat emitter in the SAP calculations is assumed to be under-floor heating throughout the property. However, installed specification is under-floor heating for the ground floor, and radiators for the first and second floors. This impacts the efficiency of the heating pump system, and the overall performance of the heating system. A simple pro rata adjustment of the efficiency adjustment factors within SAP could be used to correct this. For this property, a more accurate SAP estimation of the electricity demand of the heat pump for heating is 1,175 kWh rather than the 881 kWh predicted by the current SAP results.

- The SAP inputs do not properly account for the volume of the combined volume hot water cylinder/heating buffer vessel, meaning that the cylinder losses may be underestimated. Hot water performance may appear better than expected, because heat from the heating buffer vessel can conduct into the hot water vessel at times when the heating system is fully charged and the hot water temperature is low.

- SAP does not account for the losses from the heating buffer vessel located on the first floor, although this is a relatively small unit. There is also a large amount of distribution pipework between the elements of the heating system which could contribute to excess losses.

A further comparison between SAP and the as-built specifications is presented in Table 8-5.

Energy performance compared to the DomEARM tool audit survey is presented in the Appendix, section 13.3.

14.4.3 Assessment of the performance of individual systems for year 1

PV system: The PV system generated 2,444 kWh of electricity during the monitored year, which is a higher performance than the predicted generation of 2,167 kWh. Based on the electricity export sub-meter, the residents only export 9% of this, which means they are making good use of the generation capacity, as SAP assumes the property will export 50% of the generated energy. This performance relative to SAP is consistent with performance seen on other projects Verco have worked on. .

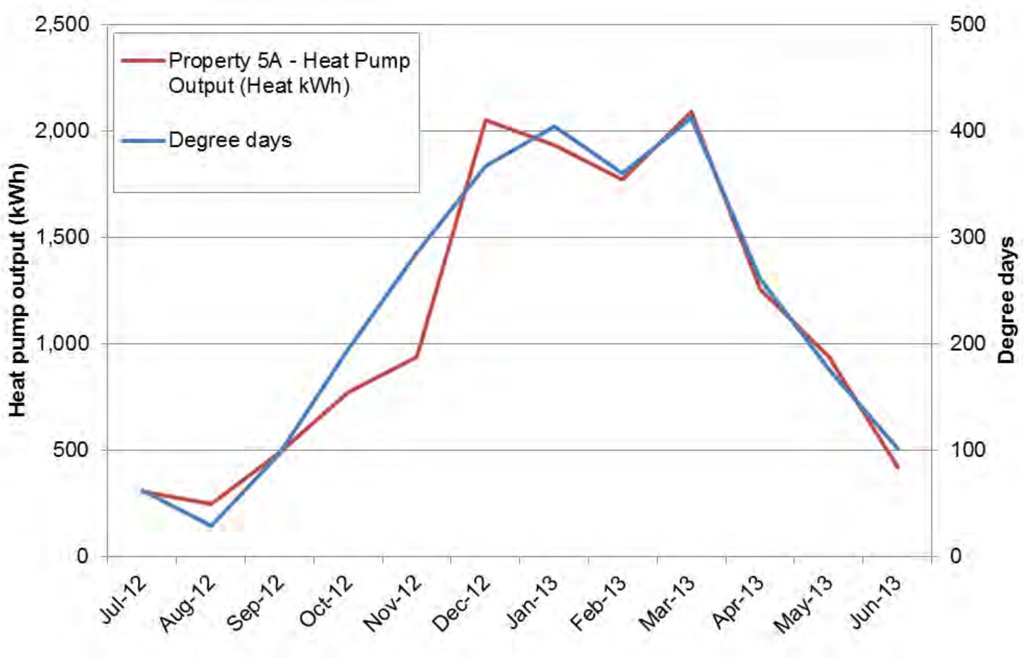
Air source heat pump: The COP for the for the NIBE F2015-6 air source heat pump in Property 5A has been analysed to be 3.3.[15] This closely matches the manufacturer's

[15] Due to the metering issues, the monthly consumption data for the heat pump output is not available. However, estimates have been made based on the heating and hot water output data for months with sufficient data available. As stated, this gives a COP of 3.3, which matches the COP for the full year if the available data is combined with on-site meter reading on 15th February 2012.

specifications for the system as installed/commissioned (although a higher COP of 4.21 could be achieved if the heat pump was used in heating only mode at lower temperature output). When the immersion heater is included, the heating and hot water system efficiency is 310%, which is considered to be a good result for an ASHP system in a new build property. This makes the heat pump/electric immersion combination significantly more carbon efficient per unit of heat generated than the gas boiler in Property 3A. However, the metering arrangement does not allow accurate assessment of standing losses in the system – which may be significant due to the much more extensive plant and pipework installed.

Figure 0-7 shows that there is a very strong relationship between the degree days (to base 15.5^{o}c) and the heat demand of the property. Given the well-insulated nature of the property, we would expect the heating season to be shortened and the heating demand to fit the profile of degree days to a lower base temperature (an extreme example is the Passivhaus concept which results very little heating demand and a very short heating season). However, the heat demand is much higher than predicted by SAP, due to the high internal temperatures. This is offsetting the impact of the high insulation levels, and leaves the house with a “typical” heating profile.

Figure 0-7: Heat pump output compared to degree days



Analysis of the 5-minute metered consumption of the heat pump shows that the power demand of the system topping out at 1.9 kW, which is in line with the technical specifications of the NIBE F2015 6kW system installed, which states that the maximum power demand of the system is 1.9kW.

The tenant keeps the house heated to a constant 25°C throughout the year (6°C higher than SAP). This could account for a significant increase in heating demand:

- Degree days to base 15.5^{o}C (Doncaster airport, Jul 2012-Jun2013): 2423dd
- Degree days to base 9.5^{o}C (Doncaster airport, Jul 2012-Jun2013): 950dd

Hence the increased internal temperature could have increased heating demand by a factor of 2.5. This would change the SAP calculated demand from 2,000 kWh to 5,000 kWh, but still leaves 5,000 kWh of the metered consumption unaccounted for. Explaining the cause of this excess consumption is challenging, given the apparent efficient performance of the heat pump in delivering heat.

We also examined the impact of deviation from the SAP occupancy and heating profile on heating consumption from a software based approach and with rules of thumb;

- use of the BREDEM derived calculations present in the "NHER Assessment" element of the NHER software used (which allows adjustments for occupancy period & heating temperature
- Comparison against degree days and accepted rules of thumb for increased temperatures.

When examining the results of the BREDEEM derived NHER calculation it was noted that the heating demand of the property stated was lower than SAP/DER results. The findings are summarised in the table below:

Change in heating profile	**Impact on heating - NHER**	**Impact on heating – rules of thumb**	**Value used**
SAP typical heating pattern to NHER extended pattern	+ 8.5%	No rule of thumb	+8.5%

NHER extended heating to NHER sheltered heating (23 deg)	+38.5%	+10% heating energy per degree Celsius increase. Average internal temp in DER is 19.3 degrees hence increase to 23 degrees is a 37% increase in heating energy	+38%
Allowance for increased heating to 25 degrees	Not possible in NHER	A further 20% increase. Compounded the 37% and 20% increases make 64% increase in heating from temperature alone.	+20%
Overall impact	N/A	N/A	**79%** increase in heating energy

Given the close agreement between the BREDEM method and the rule of thumb for extending temperatures we are satisfied to use this to assess the temperature rise to 25 degC

In our SAP calculation the heat demand of the property as-built (with amended air tightness) was 2,223kWh/annum. This would be increased to 3,980kWh/annum with the above uplift applied. This remains dramatically less than the metered heating delivered to the property, which was over 10,000 kWh per year.

Possible explanations for the dramatic difference between these two figures are as follows:

1. Inability of the calculation method to account for large deviations from “typical” use
2. Tenants opening windows while the property is being heated – probable if the heating is left set to a high temperature overnight and has no chance for the fabric to cool to offset solar gain in the daytime).
3. Underperformance of thermal elements (U-values) – testing to be applied
4. Transfer of energy from the heating buffer vessel to the hot water buffer vessel at times when the hot water temperature is low. This is a unique feature of the heating/hot water design in this property which could account for a substantial variation in the measured heat delivered to the heating and hot water end uses. In

practice, the hot water should be warmer than the heating vessel, and net heat flow would be in the opposite direction, however this is dependent on the times

Further insight is expected when the evidence from the second year of occupation is analysed.

Solar hot water system: It is not possible to assess the solar hot water system due to the water pump suffering a fault at the time of the meter installation which was not rectified during the first year monitoring period. This is a key lesson learned from the project – solar hot water system function should be assessed annually with a boiler inspection, as it is all too easy for a non-functional or faulty system to go unnoticed – warning lights are hidden in the cupboard behind some shelving erected by the tenant.

14.4.4 Property 5A DomEARM analysis for year 1

When the metered data is compared against the audit data from the DomEARM tool, it can be seen that the property is performing 47% better than expected from the audit survey as a whole, excluding heating consumption, as shown in Table 0-13. However, the audit data seems to significantly overestimating the heating consumption – this is because it is unlikely that the DomEARM tool accounts for this property being built to a high specification. When the heating consumption is compared to the CSH level 4 and level 6 benchmarks within DomEARM, as shown in

Table 0-14, the consumption is still significantly higher than what would be expected for a level 4 or 6 gas-heated property, as is the small power consumption.

Table 0-13: Property 5A: metered data compared with DomEARM audit data

	Metered data		Audit data
Electricity kWh	kWh	kWh/m²	kWh/m²
Heating	3385.20	29.7	105.8
Hot water	644.80	5.7	8.2
Ventilation	486.77	4.3	2.0
Lighting	467.14	4.1	1.8
Total Small Power	6,269.75	54.9	64.3
Other		0.0	3.8
Total electricity	11253.66	98.61	185.89
Difference to actual %	+0%	+0%	+89%

Table 0-14: Property 5A: metered data compared with DomEARM CSH level 4 and level 6 benchmarks

	Actual		CSH 4		CSH 6	
	Non-elec.	Electricity	Non-elec.	Electricity	Non-elec.	Electricity
Space Heating	0.0	105.8	50.9	0.0	50.9	0.0
Water Heating	0.0	8.2	19.8	0.0	18.3	0.0
Space Cooling	0.0	0.0	0.0	0.0	0.0	0.0
Lighting	0.0	1.8	0.0	4.9	0.0	4.9
Fans and Pumps	0.0	2.0	0.0	0.0	0.0	0.0
Cooking	0.0	1.9	0.0	5.8	0.0	5.8
Computer equipment	0.0	8.2	0.0	0.0	0.0	0.0
Consumer electronics	0.0	32.6	0.0	0.0	0.0	0.0
Refrigeration Appliances	0.0	18.9	0.0	0.0	0.0	0.0
Wet Appliances	0.0	2.6	0.0	0.0	0.0	0.0
Total small power	0.0	62.8	0.0	15.7	0.0	15.7
Other	0.0	3.8	0.0	0.0	0.0	0.0
Total	**0.0**	**185.9**	**70.7**	**26.4**	**69.2**	**26.4**

14.5 Recommendations and points for further investigation

14.5.1 Monitoring quality

The quality of the sub-metering has been poor. As shown in this analysis, there has been a range of monitoring issues:

- The tenant in Property 3A having the gas meter replaced with a card meter. Our logger was removed by the utility and not returned to the tenant, and the new meter was not a pulse meter so cannot be logged. Clearer (and repeated) tenant guidance may have prevented this.
- Wireless transmitters falling off the walls and displacing their batteries resulting in loss of signal
- Incorrect circuits being fitted with monitors
- Incorrect assignment of consumption
- Extensive calibration issues
- Data deletion from the monitoring results database

- Apparent issues with sensitivity of the electrical sub-metering, leading to uncertainty in the accuracy of data from these devices

These issues undermine confidence in certain elements of the data and analysis presented, as well as preventing a full analysis being conducted on every metered circuit.

Due to the monitoring issues, it is not possible to make robust conclusions about the performance of a number of systems at this time:

- Property 3B electricity consumption (electricity meter only installed recently – but a full year 2 dataset will be collected)
- Property 3A cooking consumption (gas meter no longer providing data)
- Property 3A electrical sub-metering breakdown (poor quality of data)
- Property 5A electrical sub-metering breakdown (poor quality of data)

It is hoped that a number of these issues can be resolved for the following year, to allow a more robust in-depth analysis.

14.5.2 MVHR testing

The measured flow rates have been compared with the design flow rates for each room, see Figure 4 1 and Figure 4 2.

MVHR performance in both properties varies in relation to the building regulations design requirement. At the constant rate, both properties receive slightly lower whole house extract than the design target with the shortfall more notable in Property 5A at 19%. At boost rate, both properties receive extract rates in excess of building regulations requirements.

Air supply rates in Property 3A fell substantially below the design target by 40% and 24% for low and high rate respectively whereas in Property 5A the supply rate was marginally low for the constant rate (-16%) and exceeded the design by 10% at high rate.

During the testing it was noted that there is a significant amount of excess flexible ductwork in the loft spaces of both properties, which contribute increased resistance to the system and reduce the effective ventilation rate. This could introduce water traps at the lowest point of loops in the ducting. Breaks in the continuity of insulation on rigid ductwork were also noted in one property. The unit installed in Property 5A is not fixed to the wooden backboard and is being supported by its own ductwork.

In terms of maintaining indoor air quality, it is noted that both properties when tested presented poorer air tightness than the design target, so the additional infiltration would ensure adequate ventilation overall – this is corroborated by the BUS surveys indicating that air in the properties is quite fresh rather than stuffy in both summer or winter.

In Property 3A the bathroom boost button doesn't appear to function. However the boost does operate when the light is switched on, indicating that this control is unnecessary in this case (as the whole house boost can be manually operated from the kitchen).

The measured flow rates have been compared with the design flow rates for each room, see Figure 0-8 and Figure 0-9 in section 14.5.2 of the appendix. It appears that the rooms receive very varied ventilation rates: some are significantly under-ventilated, some are adequately ventilated, and one room is significantly over-ventilated. If all the rooms in a property were under-ventilated to a similar degree, this might raise concerns with the excess ducting in the loft, or fan underperformance in the unit itself. However, since the results are so varied, it is more likely that the units were not commissioned to match the building regulations calculation, there is excess resistance in specific air pathways, or that there has been tenant interference with the duct settings (it was noted during testing that the ducts were not locked off).

A very substantial shortfall in the extract rate in the kitchen of Property 3A is particularly notable. Greasy cooking deposits on the kitchen extract terminal were noted during a site visit – a build-up of cooking residue might be an explanation for some of the shortfall. The adjacent bathroom on floor 1 appears to be receiving a significant excess extract rate, so rebalancing of the system is required.

Note: TGP has now put in place MVHR and heat pump service providers for future support.

Figure 0-8: MVHR extract ventilation rate testing

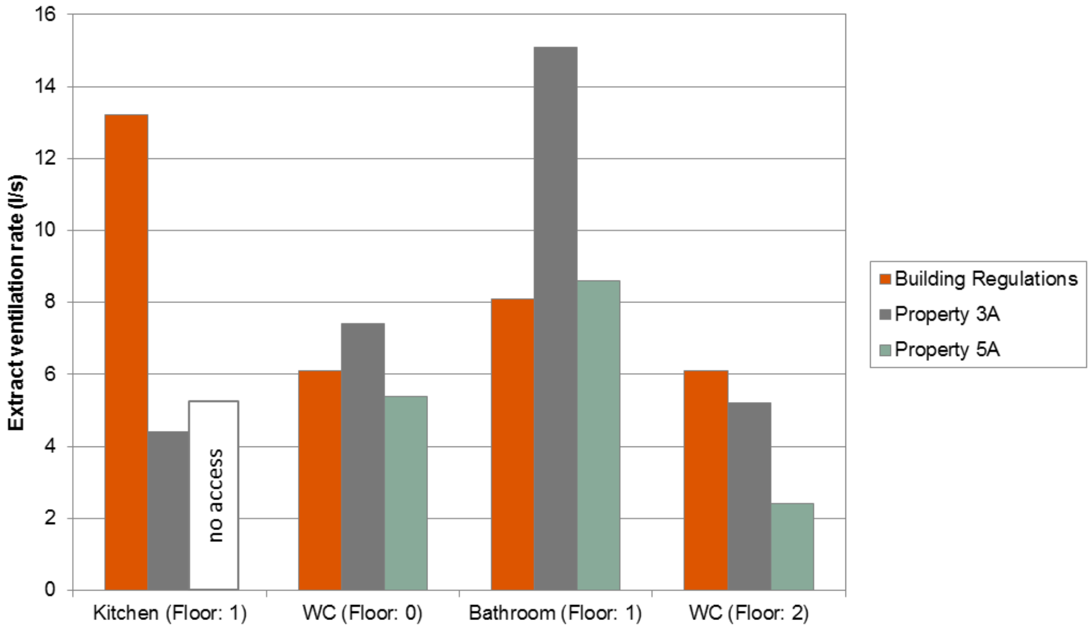
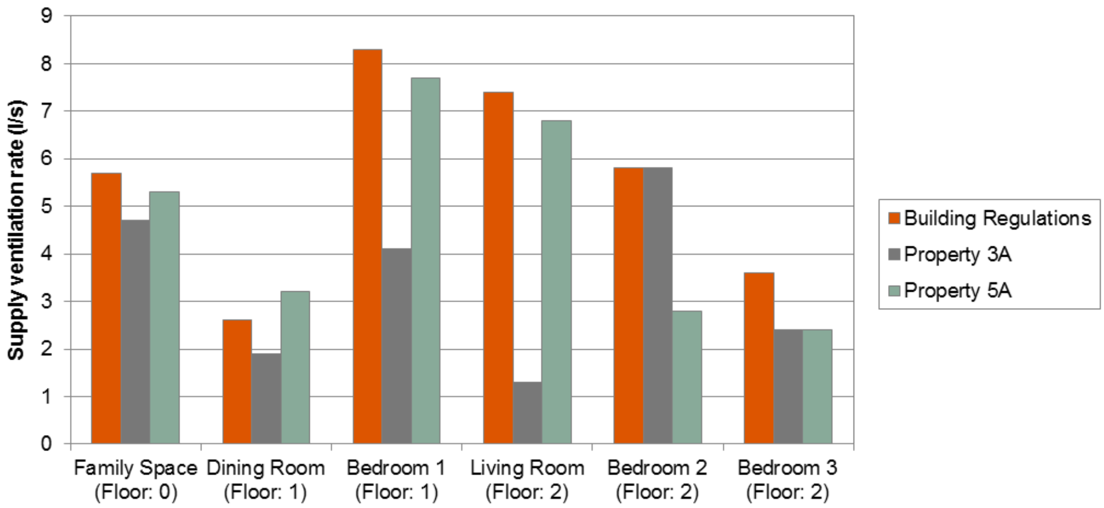


Figure 0-9: MVHR supply ventilation rate testing



14.5.3 Tenant engagement

There are number of issues that will be picked up in a site visit in August, to allow for a review of control settings and face-to-face contact with tenants. Where possible, interventions will be made (e.g. setting controls in a more efficient manner) and the impact of changes to be examined in year 2 data.

A refresher training session should be given to the tenants, because the BUS surveys highlighted that knowledge of how to use the systems correctly was limited.

14.5.4 Lessons learned

Solar hot water system function should be assessed annually with a boiler inspection, as it is all too easy for a non-functional or faulty system to go unnoticed.

Direct wired meters offer greater sensitivity and accuracy than the CT clamp meters used in the sub-metering in this project. It is recommended that only direct wired meters are used for circuits with low load.

Tenant interference with metering installations is difficult to prevent – in this case a meter was removed by the utility. Clear guidance and checking up may assist in identifying problems early.

A full wiring diagram of the property would be immensely useful in identifying which items are connected to which circuits – this is particularly relevant for smaller, constant use items like UFH controls, thermostats, etc. which may use small but significant amounts of power.