Dormary Court

Phase 2 study
In-use and post-occupancy

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

InnovateUK project number	450040 Related study: 450013 (Phase 1)[2]
Project author	Leeds Beckett University for Joseph Rowntree Housing Trust
Report date	2014
[1]InnovateUK Evaluator	Ian Mawditt (Contact via www.bpe-specialists.org.uk)

[2]Johnston, D., Miles-Shenton, D., & Farmer, D. (2015). Quantifying the domestic building fabric 'performance gap.' *Building Services Engineering Research and Technology.* 36(5). 614–627. https://doi.org/10.1177/0143624415570344

No of dwellings	Location	Type	Constructed
Six	New Earswick, York	Mixed	2011

Areas	Construction form	Space heating target	Certification level
Various (see report)	Hemcrete timber-frame system	N/A	Level 4 Code for Sustainable Homes

Background to evaluation

This report outlines the findings obtained from an in-use performance and post occupancy evaluation study undertaken on a small mixed-tenure development of six dwellings. The development comprised two 4-bed detached bungalows for supported living, and four 4-bed terraced family dwellings for rent or shared ownership. Due to monitoring issues, data is incomplete in many areas, limiting the ability of the research team to draw confident conclusions with regard to environmental conditions and energy use. However, internal conditions in both intensively monitored dwellings suggested possible areas for improvement.

Design energy assessment	In-use energy assessment	Sub-system breakdown
No	No (Equipment failures)	No (Equipment failures)

One bungalow and one terraced dwelling were subjected to intensive in-use monitoring of electricity consumption disaggregated by end-use. However, heat meter and pulse meter failures and problems with access to the homes hampered data collection and analysis. Physical tests included air-pressurisation tests, thermographic surveys and MVHR duct flow measurements. The bungalow achieved a mean air permeability of 4.89 m^3 (m^2.h) @ 50Pa, a slight decrease from a test undertaken in 2011. Dwelling 4 (mid-terrace) achieved a mean air permeability of 7.00 m^3 (m^2.h) @ 50Pa, a slight improvement from a test undertaken in 2011. The MVHR systems in both dwellings appeared to be significantly unbalanced. Less intensive monitoring was carried out on the four remaining dwellings.

Occupant survey type	Survey sample	Structured interview
BUS domestic	4 of 6 (66% response rate)	No

Feedback from residents in the BUS survey showed dissatisfaction with their energy usage (both heating and electricity), the mechanical ventilation and heat recovery system, and the fact that a number of the issues that they had identified within the home had been outstanding for a significant period of time. The indoor air quality issues identified by the residents were reinforced by the MVHR duct flow measurement results.General feedback was positive, with the majority of responses returning either 'green' or 'amber' mean scores on the BUS semantic differential scales.

Contents

1 Introduction and overview

1.1 Introduction

This report outlines the findings obtained from an in-use performance and post occupancy evaluation study (project no. 450040) that was undertaken on a small mixed tenure development of six dwellings as part of the Technology Strategy Board's Building Performance Evaluation Competition. All six dwellings were completed in January 2011 at New Earswick, York.

The development, which is being built and managed by a social housing provider, comprises two 4 bedroomed detached bungalows for supported living and four 4 bedroomed 2½ storey terraced family dwellings for rent or shared ownership (see

Figure 1). Details of the dwellings are contained within Table 1 below.

Figure 1 Layout of the development.

Dwelling	Built form
Dwelling 1	Bungalow
Dwelling 2	3 storey end terrace
Dwelling 3	3 storey mid terrace
Dwelling 4	3 storey mid terrace
Dwelling 5	3 storey end terrace
Dwelling 6	Bungalow

Table 1 Dwellings on the development.

In terms of location and amenities, the dwellings are located on a small suburban site on the outskirts of New Earswick, to the North of York, that was previously occupied by a residential care facility. The nearest bus stops are a short walk from the development. Each dwelling in the development has a designated off street parking space and there is access to shared visitor parking spaces at the rear of the development. In addition, a garden shed is located in the rear garden of each of the dwellings that has the capacity for cycle storage.

All six of the dwellings on the development are the subject of the in-use energy and environmental monitoring. Dwelling 1 was the subject of an earlier Technology Strategy Board Building Performance Evaluation Competition post-construction and initial occupation study (project no. 450013). Details of this study can be found within Johnston, Miles-Shenton & Wingfield (2012).

1.2 Scope of the Project

The scope of the project is limited to the in-use performance and post occupancy evaluation stage and consists of a combination of in-use energy and environmental monitoring alongside occupancy studies via the Building User Survey questionnaire. Two separate levels of in-use monitoring have been undertaken on the dwellings: intensive and extensive. Details of these different levels of monitoring are as follows:

- **Extensive in-use monitoring –** This has involved monitoring the dwellings overall gas, electric and water consumption only.
- **Intensive in-use monitoring –** As extensive in-use monitoring with the addition of the following parameters:
  - The total amount of electricity consumed by each of the main electrical circuits in the dwellings. This was used to disaggregate electrical energy use down into the main uses for electricity in the dwelling, namely: MVHR system, lights, appliances and cooking.
  - The total amount of heat supplied for space heating.
  - The total amount of heat supplied for domestic hot water.

As there are two very distinct dwelling types on the development, detached bungalows and terraced properties, with very different occupants (supported living in the bungalows and families in the terraced properties), it was decided that one of the detached bungalows and one of the terraced dwellings would be monitored intensively. As one of the detached bungalows (Dwelling 6) had been the subject on an earlier post construction and initial occupation study, this dwelling was chosen to be intensively monitored. In terms of the terraced dwellings, dwelling 4 was chosen to be intensively monitored. The remaining four dwellings, Dwellings 1, 2, 3, & 5 were all monitored extensively.

A number of physical tests were also undertaken on the two intensively monitored dwellings as a check on fabric and system performance. These included: air-pressurisation tests, thermographic surveys and MVHR duct flow measurements. The results obtained from these tests have been compared to those previously obtained as part of the post construction and initial occupation study.

1.3 Key Findings

Both properties have performed well in terms of air permeability over time. Dwelling 6 (bungalow) achieved a mean air permeability of 4.89 m^3h/m^2 @ 50Pa, which represented only a slight decrease from tests undertaken in February 2011. This suggests that the dwelling has performed well over time, with the slight drop in airtightness most likely due to degradation of seals around external windows and doors. Dwelling 4 (mid-terrace) achieved a mean air permeability of 7.00 m^3h/m^2 @ 50Pa, which suggests a slight improvement from tests undertaken in February 2011. This is thought to be due to a combination of factors, specifically the conditions of the original test not being ideal and the forced closure of internal doors in the latter test due to the presence of a pet dog during testing. Despite these considerations, the two results are comparable. Under ideal conditions, the house would be expected to behave similarly to the bungalow and to have degraded slightly.

The thermal imaging survey undertaken in Dwelling 6 revealed a number of significant discontinuities in the loft insulation layer. These were primarily at the external wall eaves junction, but discontinuities were also observed at the potential partition wall/ceiling junction and around a number of service penetrations in the loft. In some cases, unregulated heat gain appears to be occurring to the heated envelope from the domestic hot water pipes located in the loft space. In addition, the potential party wall appears to be acting as a thermal bypass. Although a number of these issues were identified in the earlier post construction and initial occupation project, little appears to have been done to address these issues. In fact, in a number of instances these issues appear to have got worse.

The MVHR systems in both dwellings appear to be unbalanced, with total supply and extract measurements being significantly different. In the case of Dwelling 6, extract flow rates were lower than supply. This may be the result of extract vent openings being insufficiently open in addition to filters being clogged with dust and cooking residues. Dwelling 6 also displayed weaker flow rates from vents further away from the MVHR system, suggesting an imbalance in the supply of fresh air to the dwelling. Measurements for Dwelling 4 suggested issues across the full system, with over 70% of supply and extract flow coming from two vents located on the 2nd floor, closest to the MVHR unit. Additionally, some vents were seen to have no flow at all, such as the extract in the ground floor WC. As with Dwelling 6, flow rates decreased the further the vent was from the MVHR unit, suggesting an imbalanced supply of fresh air to the dwelling.

Feedback from residents in the BUS survey showed dissatisfaction with their energy usage (both heating and electricity), the mechanical ventilation and heat recovery system, and the fact that a number of the issues that they had identified within the home had been outstanding for a significant period of time. The indoor air quality issues identified by the residents were reinforced by the MVHR duct flow measurement results.

Due to monitoring issues, data is incomplete in many areas, limiting the ability of the research team to draw confident conclusions with regard to environmental conditions and energy use. This section of the final report details the various issues encountered throughout monitoring, and offers solutions where possible. Unfortunately, many issues encountered were beyond the control of the research team. The most significant issue was the inability to gain prompt access to the monitored properties when issues arose. Not being able to quickly resolve issues meant that large amounts of data were lost. Future projects should involve communicating the need for access to resolve issues, and engage with residents to ensure co-operation.

Equipment failure was also an issue, with unforeseen issues including damaged transmitters and incorrect configuration of meters. Whilst in this instance it was not possible to mitigate against the majority of equipment issues, the problems encountered will provide guidance for future projects. For example, although the external box containing the transmitters for electrical consumption claimed to be weatherproof, in future the research team will use additional waterproofing measures to ensure damage does not occur.

Internal conditions in both intensively monitored dwellings suggested possible areas for improvement. In the Dwelling 4, CO_2 levels were noticeably high in the bedroom, which it is suspected is a direct result of the occupant turning off the MVHR system. In Dwelling 6, the bedroom appeared to experience some summer overheating, suggesting that residents may not be opening the windows sufficiently.

1.4 References

JOHNSTON, D. MILES-SHENTON, D. and WINGFIELD, J. (2012) TSB BPE Project 450013 – Dormary Court, York: Post-construction and initial occupation report on a small development of six dwellings, York. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. March 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.

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

2.1 Introduction

The dwellings were built by Mansell Construction Services, now part of Balfour Beatty Construction Services UK, for the client, Joseph Rowntree Housing Trust (JRHT). All six dwellings on the development have been designed to meet the requirements of Lifetime Homes, Secure by Design and the Code for Sustainable Homes Level 4. In terms of overall design, one of the end-terraced dwellings (Dwelling 2) has been specifically adapted to cater for a wheelchair user, whilst one of the bungalows (Dwelling 6) has been designed such that it could be split into two separate 2 bedroomed bungalows at a future date, should there no longer be a requirement for a 4 bedroomed bungalow. In order to do so, the bungalow incorporates some partition walls that have been constructed to the same specification as a party wall. The other bungalow (Dwelling 1) has been designed such that it can be converted into a 1½ storey dwelling, if the need for additional living space arises.

Plans and elevations of the dwellings are illustrated in Figure 2 and Figure 3.

Figure 2 Floor plan and elevations of the detached bungalows (Dwellings 1 and 6).

Figure 3 Floor plan and elevations of the terraced dwellings (Dwellings 2 to 5).

The external walls of the dwellings have been constructed using the Hemcrete® timber frame system from Lime Technology. This comprises a 89 x 38mm timber frame that was filled with 300mm of Tradical® Hemcrete® at a standard density of 275kg/m^3 (see **Error! Reference source not found.**) and then clad externally either in softwood or a lime-based render. Internally, the external walls are lined with 9mm medium density magnesium silicate board and then skimmed with a lime-based plaster. The ground floor comprises a beam and block floor construction with insulation placed above the slab. The roof of the bungalows is of a traditional pitched design with the insulation placed at the rafter level. In the 2½ storey terraced dwellings, the roof is of a room-in-the-roof design. All of the windows are double glazed, argon filled units with one low-emissivity coating and warm edge spacers.

2.2 Design and construction review

No design and construction review has been undertaken as part of this in-use monitoring project, as it has previously been reported in an earlier Technology Strategy Board Building Performance Evaluation Competition post-construction and initial occupation study (project no. 450013).

For completeness, the main conclusions and recommendations relating to the design and construction review that were reported in the earlier post construction study are reiterated below. It should be noted that these relate to Dwelling 6 only.

Overall, the design review and the limited number of observations of the construction that were undertaken revealed a number of issues that, if not adequately addressed, did have the potential to have an adverse effect on the thermal performance of the test dwellings, and may even result in the degradation of the building fabric, due to the formulation of condensation.

An incomplete package of information was provided to the LeedsMet research team for the design review. Unfortunately, the reasons behind this could not be fully ascertained. It appeared that the Client who commissioned the design and construction of the dwellings had not been supplied with a full set of information to inform the maintenance and use of the dwellings. This is a shortcoming in the compliance with legislation. It is evident that sufficient procedures were not in place to ensure that all the necessary information was issued to the relevant parties during and at the end of the construction phase. It is felt that if appropriate measures were put in place, then a number of the issues identified within the design and construction review could have been avoided.

Due to the limited amount of information that was available to undertake the design review, it was not possible to be able to determine the elemental U-values associated with the main construction elements of Dwelling 6 with any certainty. Although elemental U-values were detailed within the mechanical engineering services performance specification (dated February 2010), these were very preliminary U-values and were subject to confirmation by the architect. Only one of the design drawings, drawing No: 07534/C142 A (dated the 27th July 2010), contained any U-value details relating to Dwelling 6. These relate to the windows and the external wall which are stated as being 1.3 W/m^{2}K and 0.19 W/m^{2}K, respectively. The only other piece of documentation containing any U-values was the design SAP worksheet dated 22nd June 2010. The U-values contained within this were 0.19 W/m^{2}K for the external wall, 1.3 W/m^{2}K for the windows, 1.0 W/m^{2}K for the external door, 0.12 W/m^{2}K for the ground floor and 0.10 W/m^{2}K for the roof. It is not known if these U-values are also applicable to the terraced dwellings on the development.

There was also some considerable confusion over the air permeability target for Dwelling 6, as well as the entire development. The original air permeability target specified in the clients construction specification was 2 m^3/(h.m^2) @ 50Pa. This target conflicted with the target contained within the M & E specification (3 m^3/(h.m^2) @ 50Pa), and the target in the design SAP worksheets (4 m^3/(h.m^2) @ 50Pa). Discussions with the contractor regarding the differences between these figures revealed that due to the novel method of construction used to construct the external walls of the dwelling, and the contractor’s inexperience of using this technology, concerns were raised with the client regarding the levels of air permeability that the contractor would be confident in achieving. Following these concerns, the contractor stated that it was agreed to revise the air permeability target upwards to 6 m^3/(h.m^2) @ 50Pa. However, the research team have not found any documentary evidence to support this revision. The only documents that make reference to an air permeability target of 6 m^3/(h.m^2) @ 50Pa are the Air Testing report issued by the external contractor that undertook the pressurisation tests for building regulation compliance. The existence so many differing targets in the documentation resulted in some considerable confusion regarding what the actual the air permeability target for the development should be.

The design review also highlighted that the primary air barrier was not identified on any of the drawings for Dwelling 6 and no pen-on-section test has been undertaken on this dwelling. In addition, analysis of the drawings revealed that there was the potential for a thermal bypass to exist in Dwelling 6, in the partition walls that were constructed to the same specification as a party wall.

The construction observations revealed a number of issues associated with Dwelling 6. These were as follows:

- The timber fraction of the external wall as-built appeared to be higher than the standard 15%.
- Gaps were observed between the sole plate and the gas membrane, which of not grouted effectively could result in a discontinuity in the primary air barrier.

- The tops of the soil stacks in the kitchen and bathrooms were not sealed at the junction with the plasterboard ceiling, resulting in a discontinuity in the primary air barrier.
- The tops of service voids in the loft space were not sealed in line with the top of the plasterboard ceiling, resulting in a discontinuity in the primary air barrier and the potential for air movement. A number of pipework penetrations into the loft space were also unsealed.
- A number of chipboard platforms have been installed in the loft space to enable access to be gained to the PV inverter and to support the MVHR unit. There is also a platform installed that serves no obvious purpose. All of these platforms have been formed by securing sheets of chipboard directly to the ceiling joists. This has resulted in a significant thermal bridge, as no insulation has been installed beneath the platforms. As some of these platforms have been installed above a wet room, there will be an increased risk of surface condensation and mould growth on the ceiling of this room.
- Electrical cables, pipework and the MVHR ductwork all run along the top of the plasterboard ceiling and up and over the ceiling joists. The loft insulation has then been applied around but not above a number of these services, resulting in significant thermal bridging and the potential for air movement.
- At the eaves, the as-built detail is different to the design detail contained within the GA drawings. The proprietary eaves ventilator that has been installed is too short, so does not extend far enough up the inside face of the pitched roof. As a consequence, the insulation at ceiling level has being stopped short to ensure that there is still a ventilation gap at the eaves. By stopping the insulation short, it does not extend far enough across to cover the top of the Hemcrete® external wall. The result is a significant thermal bridge and the potential for air movement at the eaves.
- In both bathrooms, the shower tray has been sunk into the floor order to achieve a level access shower. The result is a thermal bridge at the shower tray due to the lack of insulation beneath the tray.
- An additional drainage point has been provided in the floor of the laundry room to enable this room to be converted into a bathroom if required at a future date. The result is a thermal bridge at the drainage point.
- The partition wall, built to the same specification as a party wall, has not been edge sealed or sealed at loft insulation level. As a consequence, it forms a thermal bypass.

3 Fabric testing (methodology approach)

3.1 Introduction

As this project was the subject of an earlier Technology Strategy Board Building Performance Evaluation Competition post-construction and initial occupation study (project no. 450013), only a very limited number of building fabric tests and surveys have been undertaken on the monitored dwellings as part of the in-use energy and environmental monitoring study. The fabric testing that was undertaken comprised the following:

- Pressurisation testing and leakage detection.
- Thermographic survey.

The results obtained from these tests have been compared with those results obtained from the earlier post construction study, where applicable.

No coheating test or heat flux measurements have been undertaken as part of this in-use monitoring project, as these tests have previously been reported in the earlier post construction and initial occupation project.

3.2 Pressurisation testing and leakage detection

Pressurisation testing was undertaken on both properties on the 27/8/14. Both tests were undertaken in accordance with ATTMA Technical Standard L1 using an Energy Conservatory Model 3 Blower door and a DG700 pressure/flow gauge. It was not possible to undertake leakage detection using infra-red thermography due to the high external temperatures experienced during the test, which resulted in an insufficient ΔT. Unfortunately, planned leakage detection with hand-held smoke generators was also not possible due to on-site equipment issues with the smoke generator.

Both dwellings were occupied during the tests, with residents asked to keep external openings closed throughout. Residents of Dwelling 4 have a pet dog which had to be kept in the living room with the door closed for the duration of the test, and as such this may have affected the overall airtightness slightly. Table 2 below displays the results of the pressurisation tests. These results are then compared with the results of earlier pressurisation tests conducted in phase 1 of this research in Table 3.

Dwelling 6 (bungalow) achieved a mean air permeability of 4.89 $m^3/(h.m^2)$ @ 50Pa. This suggests only a slight decrease from the final test conducted in February 2011, which is to be expected as the external window and door seals are likely to have degraded over time. This degradation in air permeability over time is commonplace in new dwellings. The bungalow was subject to several pressurisation tests with leakage detection in phase 1 of the project, with remedial action taken following each test leading to improved airtightness levels. Dwelling 4 (mid-terrace) achieved a mean air permeability of 7.00 $m^3/(h.m^2)$ @ 50Pa, which suggests a slight improvement from the test conducted in February 2011. With no additional air tightness measures taken since the last test, the improvement is most likely due to a combination of factors. Firstly, the earlier test was conducted under ‘extreme conditions’ with a high internal/external ΔT due to an inability to control the dwelling heating system, particularly in the kitchen of the dwelling. Additionally, due to the presence of a pet dog on the property during testing, the living room door had to remain closed throughout the test, which will have slightly affected the overall airtightness. In ideal conditions, all doors within the property are to be fully open. Taking the above considerations into account, it is anticipated that if Dwelling 4 was tested under ideal conditions, then the airtightness of Dwelling 4 will have behaved similarly to the dwelling 1, with a slight increase in mean air permeability.

The close comparability of the measurements suggests that the airtightness of both dwellings has performed well over time, with only a slight increase in mean air permeability.

The original airtightness target for the development was unclear, with a target of 2 $m^3/(h.m^2)$ @ 50Pa in the client specification, 3 $m^3/(h.m^2)$ @ 50Pa in the M&E specification, 4 $m^3/(h.m^2)$ @ 50Pa in the SAP worksheets and 6 $m^3/(h.m^2)$ @ 50Pa in the external contractor air tightness worksheets. With this in mind, it is difficult to conclude whether the dwellings were successful in meeting the original design targets. Both houses are compliant with Building Regulations for new build properties, but exceed the suggested air permeability of 3 $m^3/(h.m^2)$ @ 50Pa for properties with MVHR systems.

Dwelling	**Date**	**Depressurisation only ($m^3/(h.m^2)$ @ 50Pa)**	**Pressurisation only($m^3/(h.m^2)$ @ 50Pa)**	**Mean Air Permeability ($m^3/(h.m^2)$ @ 50Pa)**	**Comment**
Dwelling 6	27/8/14	4.92	4.87	4.89	
Dwelling 4	27/8/14	6.12	7.89	7.00	Living room door had to be closed to contain a pet dog.

Table 2 Pressurisation test results.

Dwelling	**Depressurisation only ($m^3/(h.m^2)$ @ 50Pa)**		**Pressurisation only ($m^3/(h.m^2)$ @ 50Pa)**		**Mean Air Permeability ($m^3/(h.m^2)$ @ 50Pa)**		**Comment**
	February 2011	August 2014	February 2011	August 2014	February 2011	August 2014	
Dwelling 6	4.32	4.92	4.63	4.87	4.48	4.89	
Dwelling 4	7.25	6.12	7.81	7.89	7.53	7.00	Earlier test was conducted under 'extreme conditions' with high ΔT. Living room door had to be closed to contain a pet dog in later test.

Table 3 Comparison of pressurisation test results.

Further details regarding the pressure test results can be found within Appendix 1.

3.3 Thermographic survey

The original intention was to undertake a thermal imaging survey on both of dwellings that were being extensively monitored as part of the in-use energy and environmental monitoring project (Dwellings 4 and 6). However, considerable difficulties were experienced attempting to gain access to Dwelling 4 at a time when the external conditions were favourable for thermal imaging. Consequently, it was only possible to undertake the thermal imaging survey on Dwelling 6 only.

The thermal imaging survey was undertaken to establish whether there were any unexpected areas of heat loss within this dwelling that had either not been previously highlighted in the earlier post construction and initial occupation study (project no. 450013) or had not been addressed since completion of that project. The thermal images recorded during the survey were captured using a FLiR T620 thermal imaging camera on the morning of the 24th March 2014 (survey commenced at 10:30am). At the time of the survey, the external temperature was 4.5°C, the external RH was 70.7% and the wind speed was $2.5 ms^{-1}$. Internally, the temperature was 21.3°C with a RH of 44.5%. As it had been foggy on the morning of the 24th, it was not possible to take any external images of dwelling 6.

The images selected for inclusion below were all obtained with no induced pressure applied to the dwelling.

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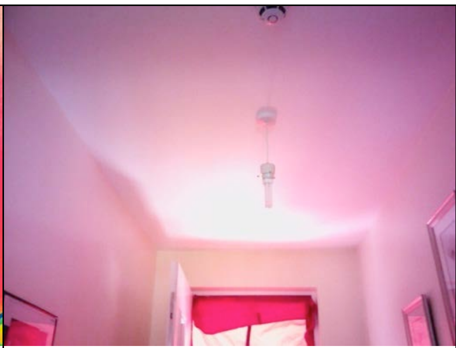
<td></td>
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24th March 2014 10:36
Internal Temp – 21.3 °C
External Temp – 4.5 °C
Internal RH – 44.5%
External RH – 70.7%</td>
</tr>
<tr>
<td colspan="3">Front door
A number of cold spots can be clearly seen on the ceiling of the entrance hall, particularly at the junction with the partition wall. This suggests discontinuities in the insulation layer in the loft space.</td>
</tr>
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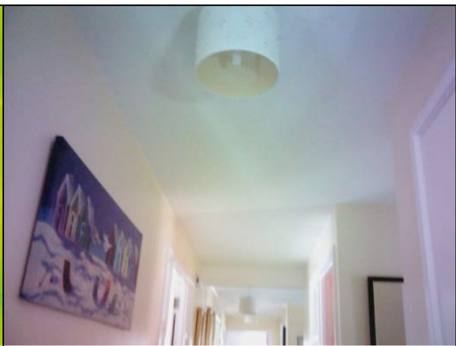
<td></td>
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24th March 2014 10:44
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External Temp – 4.5 °C
Internal RH – 44.5%
External RH – 70.7%</td>
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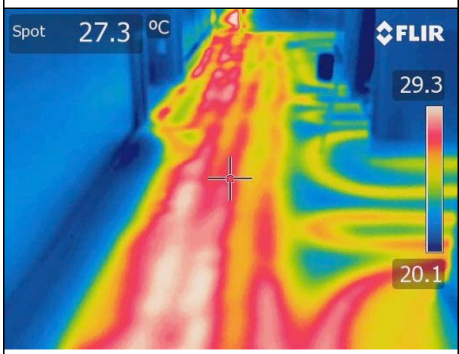
<td>
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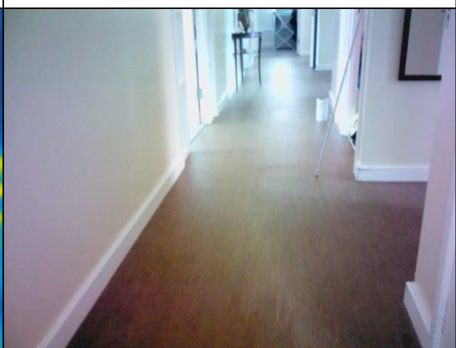
<td></td>
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Internal RH – 44.5%
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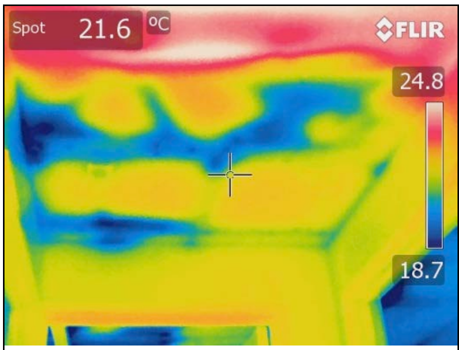
<td>
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<td></td>
<td>IR_2025 and DC_2026
24th March 2014 10:48
Internal Temp – 21.3 °C
External Temp – 4.5 °C
Internal RH – 44.5%
External RH – 70.7%</td>
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<td colspan="3">Main hallway

Looking down the corridor from the consumer unit cupboard towards the laundry room, a number of cold spots on the ceiling are evident, illustrating various discontinuities in the loft insulation layer (IR_1993). An area of unregulated heat gain is also apparent in the middle of the ceiling, which is over 1 metre in length and is approximately 2°C warmer than the surrounding area. It is thought that this heat gain area is a result of heat loss from a poorly insulated or uninsulated domestic hot water supply pipe. Unfortunately, due to Health & Safety reasons (the lack of any form of artificial light or access platform in this section of the loft), it was not possible to investigate this source of unregulated heat gain.

The underfloor heating system can be clearly seen in Image IR_1997.

Discontinuities in the loft insulation layer can also be observed in the hallway ceiling just outside the doorway to the laundry room (IR_2025).</td>
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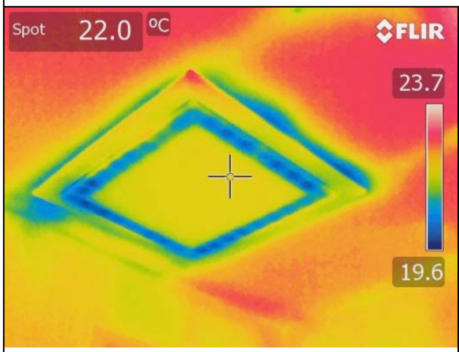
<td>
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<td>IR_1953 and DC_1954
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Internal Temp – 21.3 °C
External Temp – 4.5 °C
Internal RH – 44.5%
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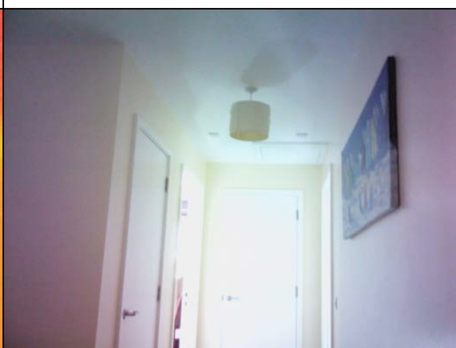
<td></td>
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Internal Temp – 21.3 °C
External Temp – 4.5 °C
Internal RH – 44.5%
External RH – 70.7%</td>
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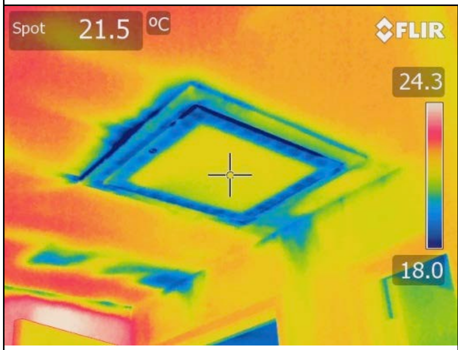
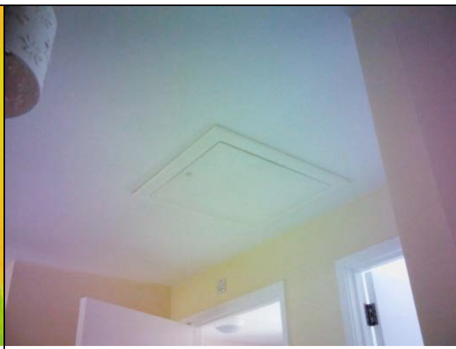
<tr>
<td colspan="3">Loft hatch in main hallway outside consumer unit cupboard

Colder areas are obvious around the opening portion of the loft hatch (IR_1953). There is also some insulation discontinuities or air leakage at the loft hatch/ceiling interface.</td>
</tr>
</table>

IR_1969 also highlights a lack of insulation under the loft access platform that is located to the left of the loft hatch.





IR_2073 and DC_2074

24th March 2014 11:01

Internal Temp – 21.3 °C

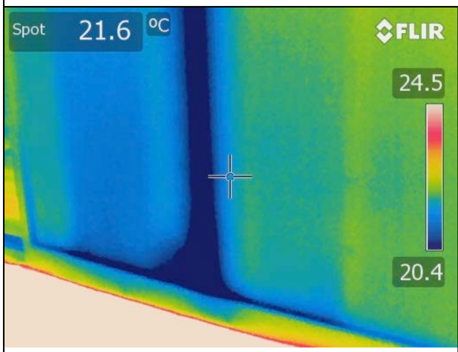
External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%

Loft hatch in main hallway outside carer's room.

Colder areas are obvious around the loft hatch (IR_2073). There are also some insulation discontinuities and/or air leakage at the loft hatch/ceiling interface. Some insulation discontinuities are also apparent above the doorway to bathroom 2.



IR_1957 and DC_1958

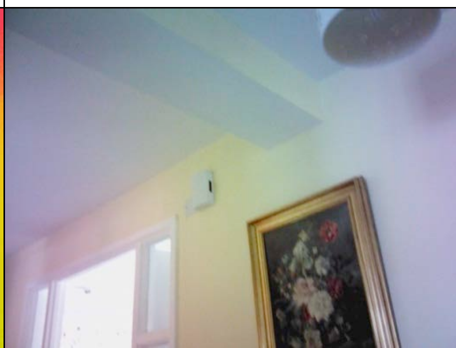
24th March 2014 10:39

Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%



IR_1961 and DC_1962

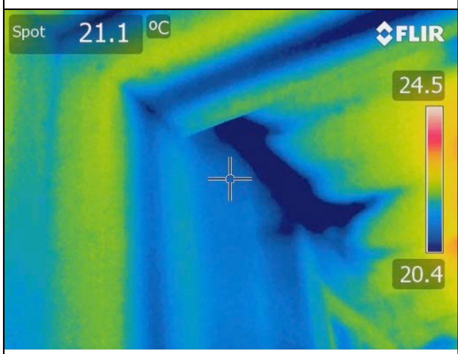
24th March 2014 10:39

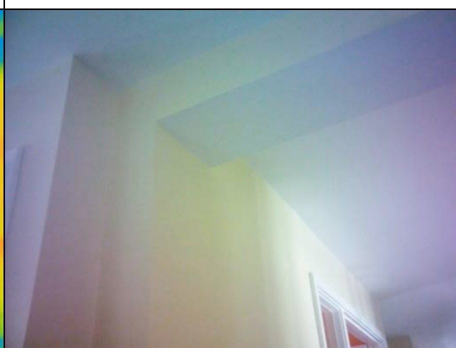
Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%





IR_1963 and DC_1964

24th March 2014 10:40

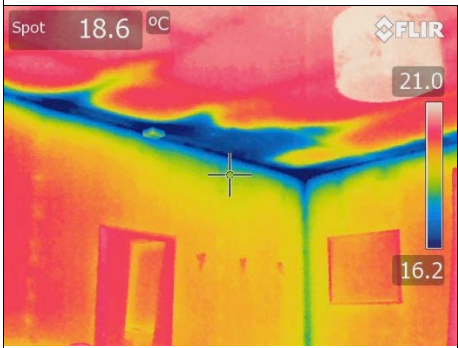
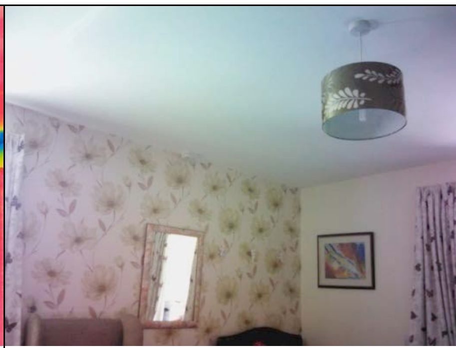
Internal Temp – 21.3 °C

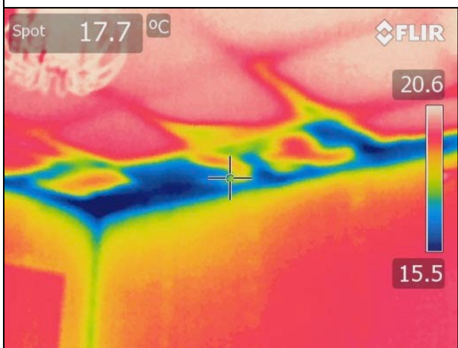
External Temp – 4.5 °C

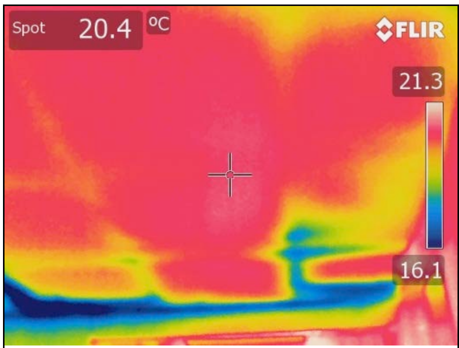
Internal RH – 44.5%

External RH – 70.7%

<table>
<tr><td colspan="3">Potential party wall in main hallway

In the main hallway, the cavity of the potential party wall clearly shows up as a cold strip that runs up the wall (IR_1957), across the corridor (IR_1961 and 1963), and then back down the other side of the wall (IR_1963). This cold strip suggest that there is an unplanned heat loss mechanism operating at the potential party wall, which is bypassing the thermal insulation layer.</td></tr>
<tr><td>
</td><td></td><td>IR_1975 and DC_1976
24th March 2014 10:42
Internal Temp – 21.3 ^{0}C
External Temp – 4.5 ^{0}C
Internal RH – 44.5%
External RH – 70.7%</td></tr>
<tr><td>
</td><td></td><td>IR_1977 and DC_1978
24th March 2014 10:42
Internal Temp – 21.3 ^{0}C
External Temp – 4.5 ^{0}C
Internal RH – 44.5%
External RH – 70.7%</td></tr>
<tr><td colspan="3">Bedroom 1

Discontinuities in the loft insulation at the eaves are clearly illustrated on both the gable wall (IR_1975) and the rear elevation (IR_1977).</td></tr>
<tr><td>
</td><td></td><td>IR_1981 and DC_1982
24th March 2014 10:42
Internal Temp – 21.3 ^{0}C
External Temp – 4.5 ^{0}C
Internal RH – 44.5%
External RH – 70.7%</td></tr>
</table>



IR_1983 and DC_1984

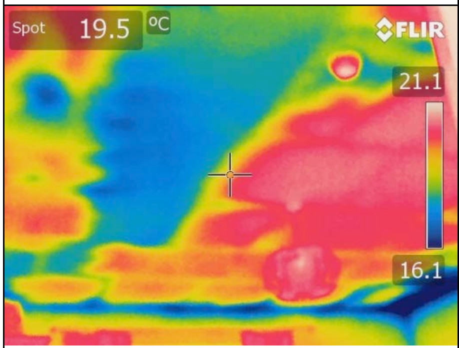
24th March 2014 10:42

Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%



IR_1985 and DC_1986

24th March 2014 10:43

Internal Temp – 21.3 °C

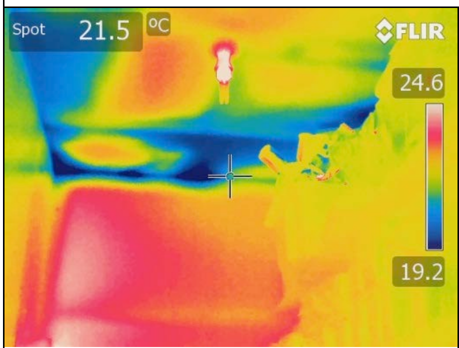
External Temp – 4.5 °C

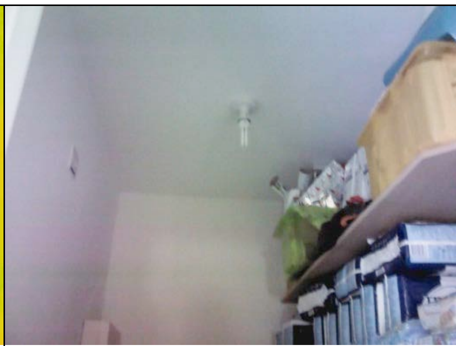
Internal RH – 44.5%

External RH – 70.7%

Bedroom 2

Discontinuities in the loft insulation at the eaves are clearly apparent on both the gable wall (IR_1981 and IR_1983) and the front elevation (IR_1985). The lack of insulation below the loft access platform is also clearly illustrated in IR_1985.





IR_1989 and DC_1990

24th March 2014 10:43

Internal Temp – 21.3 °C

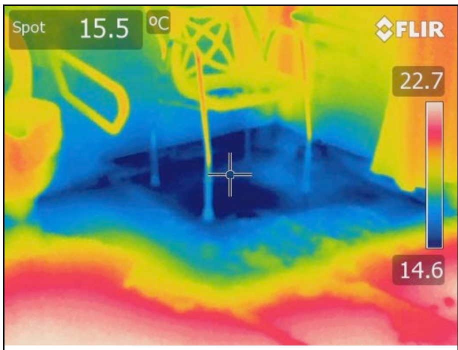
External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%

Consumer unit storage cupboard

A number of cold areas can be clearly seen on the ceiling, particularly at the junction with the partition wall and at the external wall/ceiling junction This suggests discontinuities in the insulation layer in the loft space.



IR_1999 and DC_2000

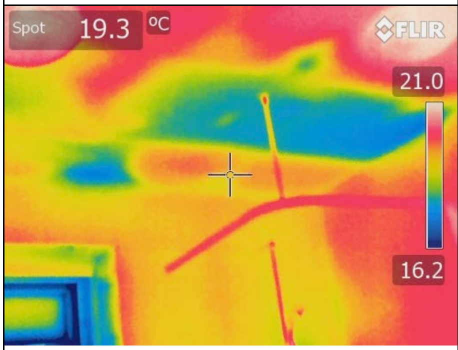
24th March 2014 10:45

Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%



IR_2001 and DC_2002

24th March 2014 10:46

Internal Temp – 21.3 °C

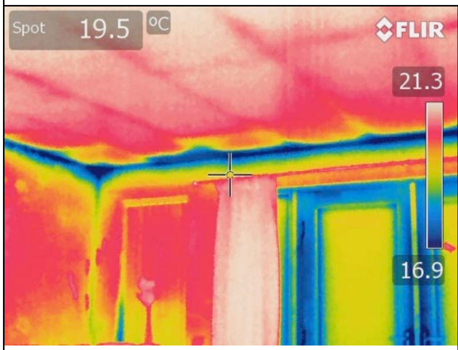
External Temp – 4.5 °C

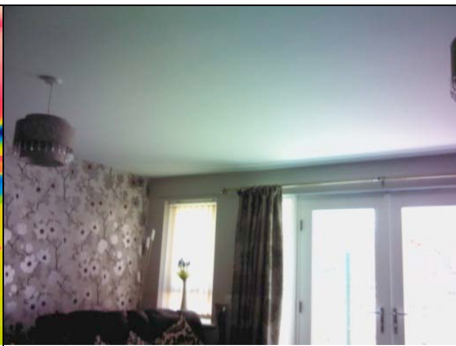
Internal RH – 44.5%

External RH – 70.7%

Bathroom 1

No underfloor heating and the lack of insulation below the sunken shower tray is evident in IR_1999. Some discontinuities in the loft insulation at the eaves and the lack of insulation below the loft access platform are also apparent in IR_2001.





IR_2005 and DC_2006

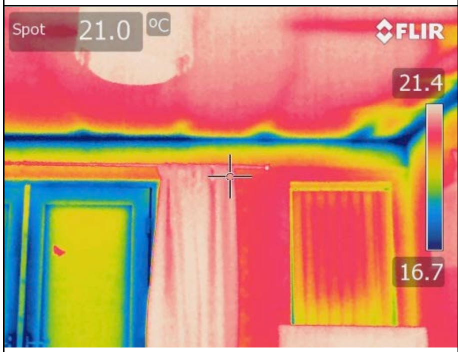
24th March 2014 10:46

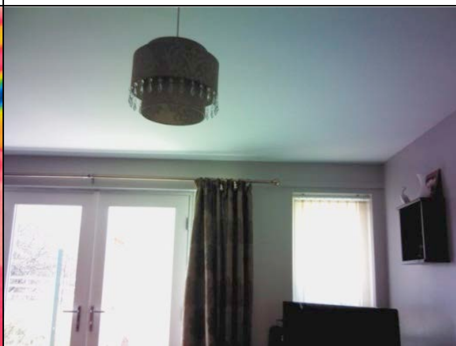
Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%





IR_2007 and DC_2008

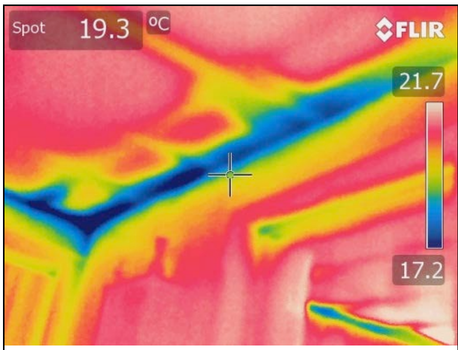
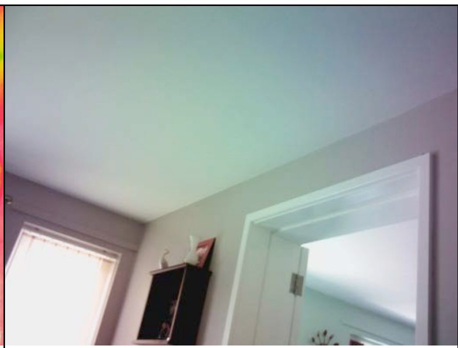
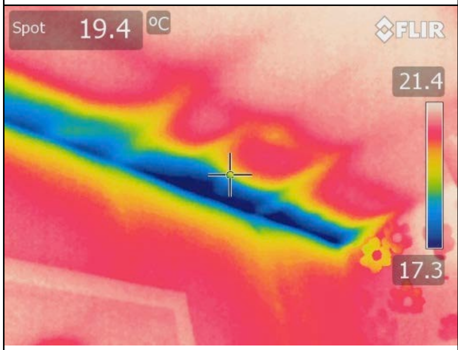
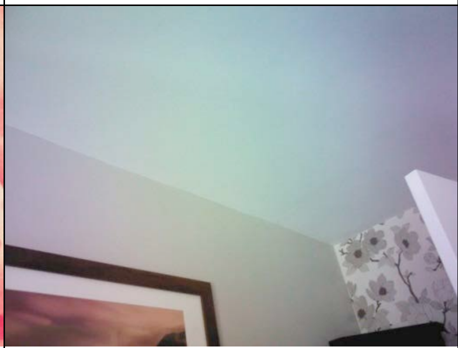
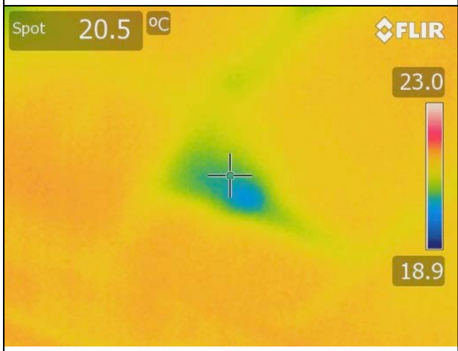
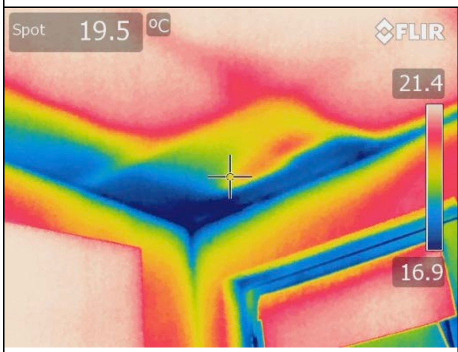
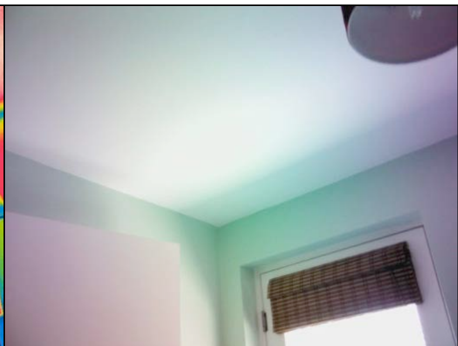
24th March 2014 10:46

Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%

		**IR_2011 and DC_2012** 24th March 2014 10:47 Internal Temp – 21.3 ^{o}C External Temp – 4.5 ^{o}C Internal RH – 44.5% External RH – 70.7%
		**IR_2013 and DC_2014** 24th March 2014 10:47 Internal Temp – 21.3 ^{o}C External Temp – 4.5 ^{o}C Internal RH – 44.5% External RH – 70.7%
		**IR_2009 and DC_2010** 24th March 2014 10:47 Internal Temp – 21.3 ^{o}C External Temp – 4.5 ^{o}C Internal RH – 44.5% External RH – 70.7%
Living area Discontinuities in the loft insulation at apparent at the eaves (IR_2005 and IR_2007) and at the potential party wall/ceiling junction (IR_2011 and IR_2013). There is also a discontinuity on the loft insulation layer on the ceiling close to the entrance to the living area from the corridor (IR_2009).		
		**IR_2019 and DC_2020** 24th March 2014 10:47 Internal Temp – 21.3 ^{o}C External Temp – 4.5 ^{o}C Internal RH – 44.5% External RH – 70.7%

<table>
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<td>
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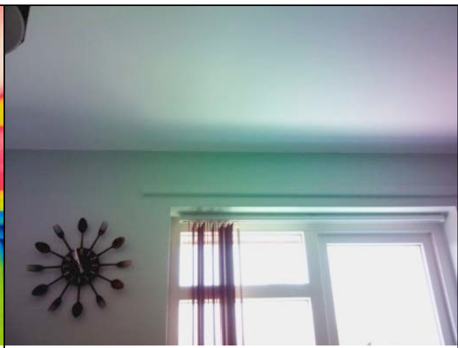
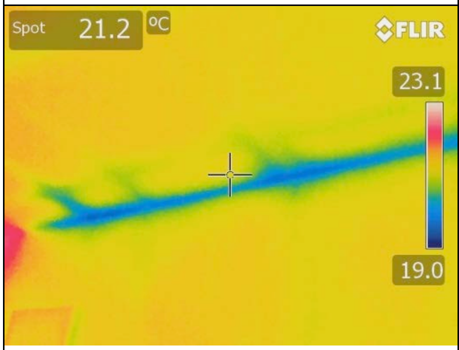
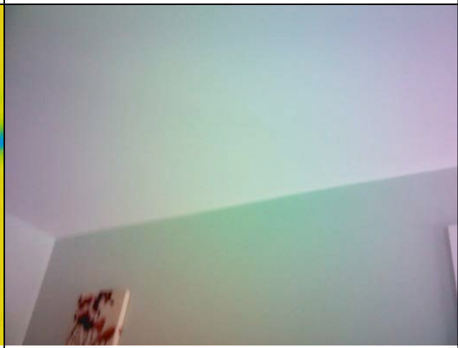
<td></td>
<td>IR_2021 and DC_2022

24th March 2014 10:48

Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

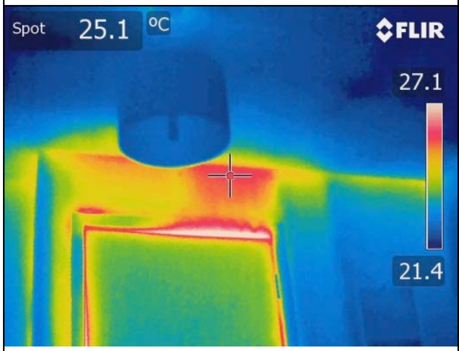
External RH – 70.7%</td>
</tr>
<tr>
<td>
</td>
<td></td>
<td>IR_2015 and DC_2016

24th March 2014 10:47

Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%</td>
</tr>
<tr>
<td>
</td>
<td></td>
<td>IR_2023 and DC_2024

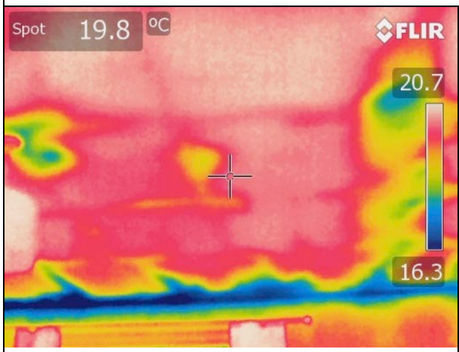
24th March 2014 10:48

Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%</td>
</tr>
<tr>
<td colspan="3">Kitchen area

Discontinuities in the loft insulation are apparent at the eaves (IR_2019 and IR_2021) and to a lesser extent at the potential party wall/ceiling junction (IR_2015). There is also some unregulated heat gain from around the frame of the central heating manifold cupboard and through the partition wall at the top of the cupboard (IR_2023).</td>
</tr>
<tr>
<td>
</td>
<td></td>
<td>IR_2031 and DC_2032

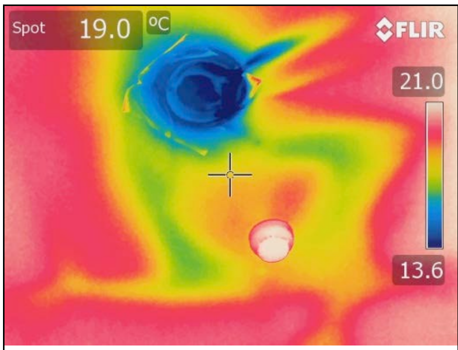
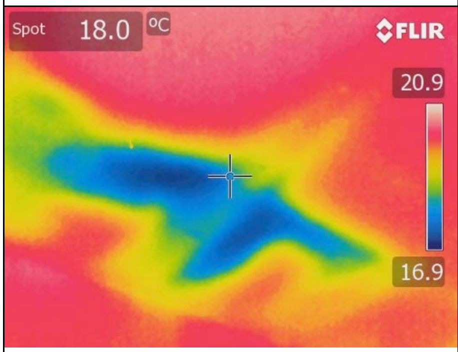
24th March 2014 10:49

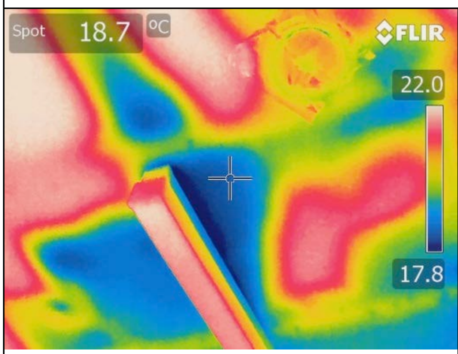
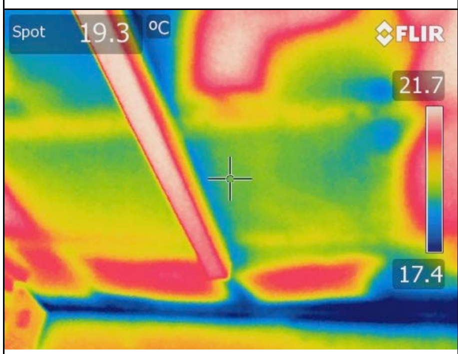
Internal Temp – 21.3 °C

External Temp – 4.5 °C

Internal RH – 44.5%

External RH – 70.7%</td>
</tr>
</table>

<table>
<tr>
<td>
</td>
<td></td>
<td>IR_2033 and DC_2034
24th March 2014 10:49
Internal Temp – 21.3 ^{0}C
External Temp – 4.5 ^{0}C
Internal RH – 44.5%
External RH – 70.7%</td>
</tr>
<tr>
<td>
</td>
<td></td>
<td>IR_2035 and DC_2036
24th March 2014 10:49
Internal Temp – 21.3 ^{0}C
External Temp – 4.5 ^{0}C
Internal RH – 44.5%
External RH – 70.7%</td>
</tr>
<tr>
<td colspan="3">Bedroom 3

Discontinuities in the loft insulation were observed at the eaves (IR_2034). In addition, discontinuities were also observed around the MVHR supply vent and smoke sensor (IR_2034) and at a section of the ceiling close to the gable wall (IR_2035).</td>
</tr>
<tr>
<td>
</td>
<td></td>
<td>IR_2037 and DC_2038
24th March 2014 10:49
Internal Temp – 21.3 ^{0}C
External Temp – 4.5 ^{0}C
Internal RH – 44.5%
External RH – 70.7%</td>
</tr>
<tr>
<td>
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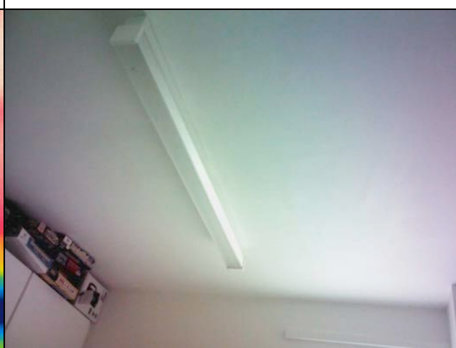
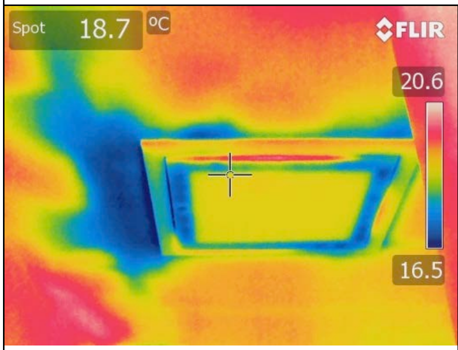
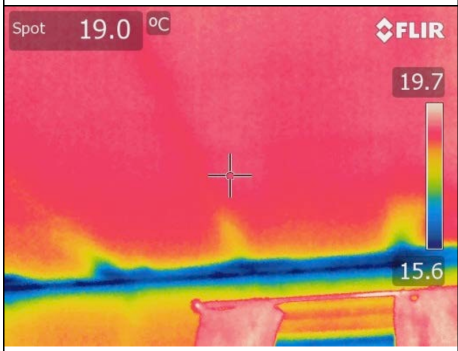
<td></td>
<td>IR_2041 and DC_2042
24th March 2014 10:49
Internal Temp – 21.3 ^{0}C
External Temp – 4.5 ^{0}C
Internal RH – 44.5%
External RH – 70.7%</td>
</tr>
<tr>
<td colspan="3">Laundry room

Significant discontinuities were observed in the loft insulation layer in the laundry room. These discontinuities</td>
</tr>
</table>

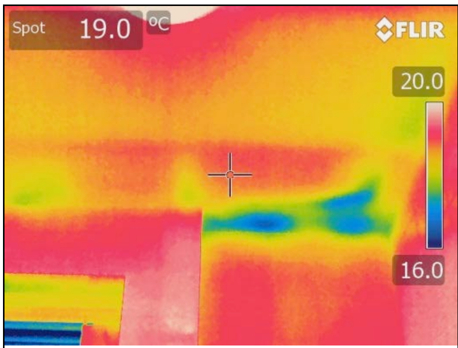
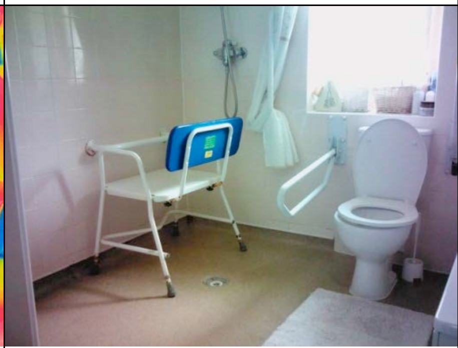
occurred at the eaves (IR_2041) and beneath the MVHR unit loft platform (IR_2039 and IR_2041).

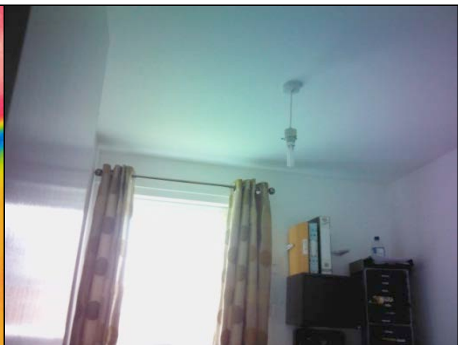
		**IR_2043 and DC_2044** 24th March 2014 10:50 Internal Temp – 21.3 ^{o}C External Temp – 4.5 ^{o}C Internal RH – 44.5% External RH – 70.7%
		**IR_2045 and DC_2046** 24th March 2014 10:50 Internal Temp – 21.3 ^{o}C External Temp – 4.5 ^{o}C Internal RH – 44.5% External RH – 70.7%
		**IR_2047 and DC_2048** 24th March 2014 10:50 Internal Temp – 21.3 ^{o}C External Temp – 4.5 ^{o}C Internal RH – 44.5% External RH – 70.7%

Bedroom 4

Colder areas are obvious around the opening portion of the loft hatch (IR_2043). There is also a discontinuity in the insulation layer around the loft hatch. Discontinuities in the loft insulation layer are also evident at the eaves (IR_2045 and IR_2047).

lack of insulation under the loft access platform that is located to the left of the loft hatch (IR_1969).

<table>
<tr><td>
</td><td></td><td>**IR_2051 and DC_2052**
24th March 2014 10:57
Internal Temp – 21.3 °C
External Temp – 4.5 °C
Internal RH – 44.5%
External RH – 70.7%</td></tr>
<tr><td>
</td><td></td><td>**IR_2049 and DC_2050**
24th March 2014 10:57
Internal Temp – 21.3 °C
External Temp – 4.5 °C
Internal RH – 44.5%
External RH – 70.7%</td></tr>
<tr><td colspan="3">Bathroom 2

Some discontinuities in the loft insulation are apparent at the eaves (IR_2051). However, these discontinuities are not as severe as those observed within other rooms in the dwelling. The lack of underfloor heating and insulation below the sunken shower tray is evident in IR_2049, which was also observed in bathroom 1 (see IR_1999).</td></tr>
<tr><td>
</td><td></td><td>**IR_2075 and DC_2076**
24th March 2014 11:02
Internal Temp – 21.3 °C
External Temp – 4.5 °C
Internal RH – 44.5%
External RH – 70.7%</td></tr>
<tr><td colspan="3">Carer's room

Discontinuities in the loft insulation were observed at the eaves.</td></tr>
</table>

In addition to undertaking the thermal imaging survey, a number of observations were undertaken in the loft in attempt to explain the images obtained from the survey. Unfortunately, due to the nature of the roof construction (a very shallow pitched roof) and the lack of access platforms, it was only possible to undertake a very little number of observations for Health and Safety reasons. These observations revealed a number of significant discontinuities associated with the loft insulation layer. These discontinuities were as follows:

- **Eaves detail** – The proprietary eaves ventilator that has been installed is too short, so does not extend far enough up the inside face of the pitched roof (see Figure 4). As a consequence, the insulation at ceiling level has being stopped short in order to ensure that there is still a ventilation gap at the eaves. By stopping the insulation short, it does not extend far enough across to cover the top of the Hemcrete® external wall, resulting in a discontinuity in the insulation and a significant thermal bridge.

- **MVHR unit platform** – A platform has been used to support the MVHR unit in the loft space immediately above the laundry room (see **Error! Reference source not found.** 5). The space beneath this platform is uninsulated, resulting in a significant thermal bridge. As the laundry room is a wet room, there will be an increased risk of surface condensation and mould growth on the ceiling of this room.
- **Services in the loft** – Electrical cables, pipework and the MVHR ductwork all run along the top of the plasterboard ceiling and up and over the ceiling joists. The loft insulation has then been applied around, but not always above, a number of these services. In addition, it appears that some of the insulation has been displaced to obtain access to some of these services. This has resulted in significant discontinuities in the insulation layer in the loft space which will result in thermal bridging and the potential for air movement (see **Error! Reference source not found.** 6).

Interestingly, all of the above bullet points were highlighted in the final report that was produced at the end of the post construction and initial occupation project. The observations above appear to suggest that these issues were never addressed. In fact, in terms of the services in the loft space, additional displacement of the loft insulation layer appears to have taken place since completion of the post construction and initial occupation project, which has exacerbated the issues.

Figure 4 Proprietary eaves ventilator.

Figure 5 Location of the MVHR unit within the loft space.

Figure 6 Discontinuities in the insulation layer in the loft space.

Further details regarding the thermal imaging survey can be found within Appendix 2.

3.4 Conclusions and key findings for this section

Dwelling 6 achieved a mean air permeability of 4.89 ($m^3/(h.m^2$ @ 50Pa), which represented only a slight decrease from tests undertaken in February 2011. This suggests that the dwelling has performed well over time, with the slight drop in airtightness most likely due to degradation of the seals around the external windows and doors.

Dwelling 4 achieved a mean air permeability of 7.00 $m^3/(h.m^2$ @ 50Pa, which suggests a slight improvement from tests undertaken in February 2011. This is thought to be due to a combination of factors, specifically the conditions of original test not being ideal and the forced closure of internal doors in the latter test due to the presence of a pet dog during testing. Despite these considerations, the two results are comparable. Under ideal conditions, the house would be expected to have behaved similarly to Dwelling 1, with a slight degradation in the level of air permeability.

The thermal imaging survey undertaken on Dwelling 6 revealed a number of significant discontinuities in the loft insulation layer. These were primarily at the external wall eaves junction, but discontinuities were also observed at the potential partition wall/ceiling junction and around a number of service penetrations in the loft. In some cases, unregulated heat gain appears to be occurring to the heated envelope from the domestic hot water pipes located in the loft space. In addition, the potential party wall appears to be acting as a thermal bypass. Although a number of these issues were identified in the earlier post construction and initial occupation project, little appears to have been done to address these issues. In fact, in some cases these issues appear to have got worse.

4 Key findings from the design and delivery team walkthrough

4.1 Introduction

No design and delivery team walkthrough has been undertaken as part of this in-use monitoring project, as it has previously been reported in an earlier Technology Strategy Board Building Performance Evaluation Competition post-construction and initial occupation study (project no. 450014).

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

5.1.1.1Introduction

The BUS seeks to inform the research team about issues from the side of the user. The information gathered highlights any issues that arise through lived in experience, and can then be cross referenced with measured data to highlight potential reasons for any poor performance.

A total of 6 BUS questionnaires were distributed to residents, of which 4 were completed and returned, representing a 66% feedback.

5.1.2 Conclusions and key findings for this section

General feedback was positive, with the majority of responses returning either 'green' or 'amber' ratings on the BUS feedback report. The areas discussed below returned negative feedback under the BUS methodology, and possible reasons for this are explored.

Utilities Cost

As can be seen in Figures 7 and 8, the cost of utilities was returned as an issue from the BUS questionnaire feedback, for both electricity and heating. Unfortunately, a significant amount of data on both gas and electricity consumption was lost due to the logging equipment being turned off over the winter period, so it is not possible for the research team to reliably evaluate if energy use was higher than would be expected for these properties over a full 12 month period.

It is anticipated that the sustainable technology integrated into the dwellings such as the MVHR and solar PV would lead to a reduction in energy use and therefore energy cost. Comments received also support the BUS scale, as can be seen in Figure 9.

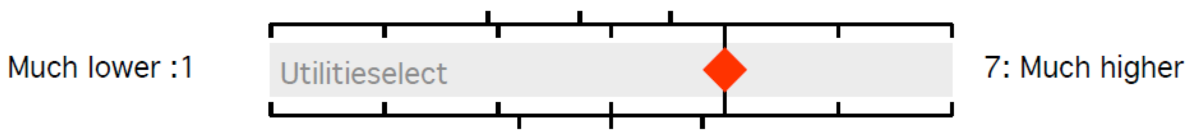


Figure 7 Cost of Electricity

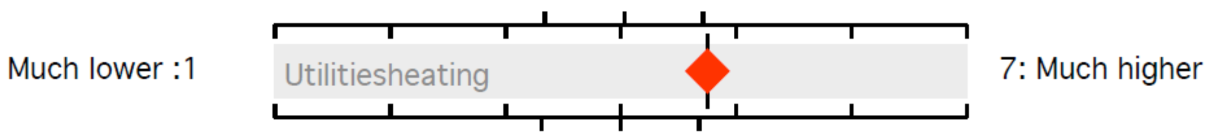


Figure 8 Cost of Heating

Other comments
For all the energy saving this house was supposed to provide my bills are so much higher. Needs fixing. Very sad as excited to live in a green house.

Figure 9 Comments on utility bills.

Ventilation system

Feedback was negative for the MVHR system in the dwellings, as can be seen in Figures 10, 11 and 12. Occupants felt that they did not have control over their ventilation system, and this had the result of providing poor quality air to the home. This may be an issue stemming from poor handover guidance, poor commissioning or a lack of familiarity with MVHR systems.

In addition to air quality issues, comments also indicated that noise was an problem with the MVHR system. This is reflected in the data and occupant feedback, with the residents of the intentively monitored house turning their MVHR system off completely due to noise complaints. Possibly as a result, high levels of CO_2 were recorded in the bedroom.

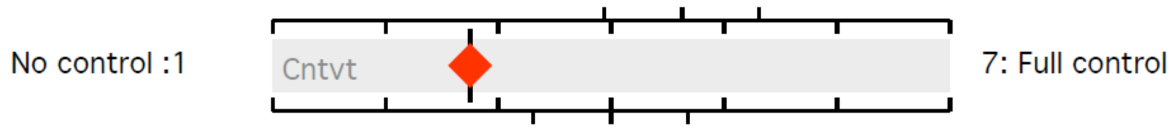


Figure 10 Ventilation Control.

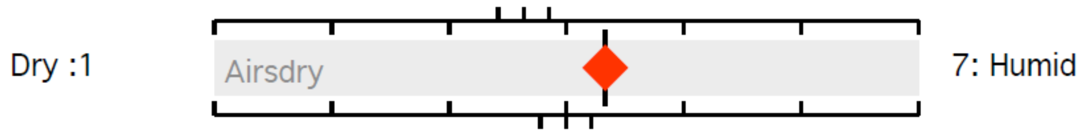


Figure 11 Summer Air.

Cooling
Ventilation system has not worked correctly either since we moved in.
Ventilation system is a joke. Far too noisy!

Figure 12 Ventilation Comments.

In addition to the points above, there were several issues in the comments received that were specifically targeted at management and engagement with the housing management. Several complaints suggested issues within the home that had been outstanding for a long period, which may indicate that residents do not feel they are having their needs met sufficiently. This may go some way to explaining the reluctance of many residents to engage with this research project, if they have had negative experiences in the past and associate the research team with the housing management staff.

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

6.1 Introduction

In the two dwellings that are participating in the in-use performance and post occupancy evaluation study, a Worcester Bosch wall mounted high efficiency gas-fired condensing combination boiler has been installed, which provides low pressure hot water to the unvented space and hot water heating system. Domestic hot water is provided via a high recovery indirect copper storage cylinder, whilst space heating is provided by a wet underfloor heating system. The space and hot water heating system is controlled by an internal 7 day programmable controller which is integral to the boiler enabling independent heating and hot water control.

Ventilation in both dwellings is provided via a Nuaire MRXBOX95-LH1 whole house MVHR system which has a SAP Appendix Q heat exchanger efficiency of 91% and a specific fan power of 0.62 W/l/s. In Dwelling 4, the MVHR unit is installed in a knee-wall cupboard on the 2nd floor. In dwelling D, the unit is installed in the loft space very close to the eaves. Boost operation of the units is provided via manually operated fan boost switches located in all of the wet rooms within the dwellings.

A PV system is installed on the roof of both dwellings. In dwelling 4, four Schuco MPE 215 PS 05 polycrystalline panels have been installed with a module efficiency of 14.4% and a rated output of 215Wp per module, giving a total output of 860Wp. On dwelling 6, three Sharp Electronics NU-185(E1) monocrystalline modules have been installed with a module efficiency of 14.1% and a nominal output of 185Wp per module, giving a total output of 555Wp.

In terms of internal lighting, the laundry room in Dwellings 1 and 6 contain a tubular fluorescent light, whilst the bathrooms and en-suite in all of the dwellings contain a low energy ceiling light. All of the remaining rooms, circulation spaces and storage areas within the dwellings are fitted with either a pendent or batten light fitting containing a low energy lamp.

6.2 Installation and commissioning checks

As this project was the subject of an earlier Technology Strategy Board Building Performance Evaluation Competition post-construction and initial occupation study, only a small number of commissioning checks have been undertaken on the monitored dwellings as part of the in-use energy and environmental monitoring study. These checks comprised a series of MVHR supply and extract duct grille flow measurements on dwelling 4 and dwelling 6. The results obtained from these measurements have been compared with those results obtained from the earlier post construction study, where applicable.

No other installation or commissioning checks been undertaken as part of this in-use monitoring project, as these checks have previously been reported in the earlier post construction and initial occupation project.

6.3 MVHR system duct flow measurements

A series of MVHR supply and extract duct grille flow measurements were undertaken on both intensively monitored dwellings (Dwellings 4 and 6) by the Leeds Met research team under both standard and boost settings. The measurements were undertaken using a Swemaflow 125D hot wire lattice anemometer.

It should be noted that in Dwelling 6, the MVHR unit is located in such a position (above the laundry room and very close to the eaves) that access to the unit is severely restricted. There is also no loft access platform from the loft hatch to the MVHR unit from the loft hatch and there is no dedicated miniature circuit breaker for the MVHR unit in the main consumer unit. Therefore, the only way to isolate power to the unit, without affecting any other circuits within the dwelling, is to use the isolation switch located next to the unit in the loft space. Consequently, it is not possible to gain safe access to the units for maintenance or to switch the units on or off. The MVHR unit in Dwelling 1 is located in the same position as the unit in dwelling 6, so suffers from the same issue identified above. All of these issues were identified in the earlier post construction and initial occupation project,

The results of the duct flow measurements that were undertaken on Dwelling 4 are detailed within Table 4.

	Standard(ls^{-1})	**Boost (ls^{-1})**
Living Area	4.75	5.53
1st Floor Rear Bedroom East	2.72	3.53
1st Floor Rear Bedroom West	2.64	3.11
1st Floor Front Bedroom	4.92	5.33
2nd Floor Bedroom	9.47	13.78
Total supply	**24.50**	**31.28**
Kitchen	3.72	3.28
WC	0.00	0.00
Bathroom	8.44	10.39
En Suite	25.17	29.36
Total extract	**37.33**	**43.03**

Table 2 Dwelling 4 MVHR supply and extract duct grille flow measurements in ls^{-1} on the 27th August 2014.

An analysis of the data contained within Table 4 indicates that the MVHR system is currently unbalanced, with insufficient supply. This may be the result of clogged filters or vents not being fully open, and will result in the system operating unproductively and with reduced efficiency. The original commissioning certificates claim that the MVHR system in the house has a trickle flow rate of 27 ls^{-1} and boost flow of 35 ls^{-1}. Measured values show a discrepancy between boost and extract flows, with supply of 24.5 ls^{-1} and boost of 31.28 ls^{-1}. Balance of the fan speeds overall is critical in terms of heat exchanger efficiency. The boost function appears to raise the overall flow of the system in a way that is comparable to the commissioning sheet, but air flow is not evenly distributed.

Very high supply and extract flow rates were recorded in the 2nd floor bedroom and adjoining En Suite, which are located next to the MVHR system. These accounted for around 70% of total air flow from the system. Closer inspection of the vents found that they were quite dirty and clogged with dust. Conversation with the residents led to the discovery that the MVHR has not been used during the majority of the tenancy, having being turned off due to the unit being too loud. Prior to being turned off, residents remarked that the kitchen extract did little to remove foul air and cooking smells. The kitchen is not fitted with an extractor cooker hood and residents had been using the MVHR boost function to remove cooking emissions. However, this was ineffective.

The results of the duct flow measurements that were undertaken on Dwelling 6 are detailed within Table 5.

	Standard(ls^{-1})	Boost (ls^{-1})
Living area	2.9	3
North West bedroom	5	4.9
North East bedroom	3.6	3.7
South West bedroom	2.9	3
South East bedroom	2.7	2.7
Office	3.7	4
Total supply	**20.8**	**21.3**
Kitchen	4.1	4.2
Bathroom 1	3.2	4
Bathroom 2	3.4	3.5
Utility room	2.3	2.3
Total extract	**13**	**14**

Table 5 Dwelling 6 MVHR supply and extract duct grille flow measurements in ls^{-1} on the 27th August 2014.

Analysis of the data contained within Table 5 indicates that the MVHR is currently unbalanced, with insufficient extract flow. This may be the result of clogged filters or vents not being fully open, and will result in the system operating unproductively and with reduced efficiency. The original commissioning certificates claimed that the MVHR system in the bungalow has a trickle flow rate of 32 ls^{-1} and boost flow of 37 ls^{-1}. Measured values show a discrepancy between boost and extract flows, with supply of 20.8 ls^{-1} and boost of 21.3 ls^{-1}. In addition to being significantly lower than the stated values on the commissioning sheet, the boost appears to have very little effect on system flow. Balance of the fan speeds overall is also critical in terms of heat exchanger efficiency. It was also noted that the flow rates from vents nearer to the MVHR unit were higher than those further from the unit, which may indicate that the existing fan is unable to provide sufficient air flow to the full system. This was most notable in the North West bedroom, which sits directly under the MVHR unit and saw flow rates of over 2ls^{-1} greater than other rooms of comparable size.

Following the grille flow measurements, all of the vents were checked for dust and opening. In general, extract vents were found to be slightly less open than supply vents, which may partially explain the lower than required extract rate. Additionally, extract vents are typically susceptible to dust build up and filter clogging which can reduce flow rates. This is a particular issue in kitchen extract vents as cooking residues may build up in the vent, ductwork and filtration equipment.

6.4 Conclusions and key findings for this section

There are a number of access issues associated with the MVHR units located in Dwellings 1 and 4. These relate to the location of the unit, the lack of a loft access platform and difficulties associated with isolating the power to the units. Although these issues were identified in the earlier post construction and initial occupation project, little appears to have been done to address these issues.

The MVHR systems installed in both dwellings appear to be unbalanced, with significant differences being measured between the total supply and extract grille flow rates. Measurements obtained for Dwelling 4 suggested issues across the full system, with over 70% of supply and extract flow coming from two vents located on the 2nd floor, closest to the MVHR unit. Additionally, some vents were seen to have no flow at all such as the extract in the ground floor WC. Flow rates also decreased the further the vent was from the MVHR unit, suggesting an imbalanced supply of fresh air to the dwelling. Vents were also observed to be clogged with dust in many cases, which is expected to have a negative impact on the system performance. Conversations with residents of this dwelling discovered an overall dissatisfaction with the kitchen extract vent, which was being used as an extractor fan to remove cooking emissions. The dwelling is not fitted with an extractor cooker hood. This use is expected to have a negative impact on the system performance. Further conversation with residents led to the discovery that the MVHR unit has been turned off for the majority of the tenancy due to high noise levels for the unit itself causing disturbance. The impact of this is explored further in the final project report.

In the case of dwelling 6, extract flow rates were lower than supply. This may be the result of extract vent openings being insufficiently open in addition to filters being clogged with dust and cooking residues. As with Dwelling 4, lower flow rates were measured from vents further away from the MVHR system, suggesting an imbalance in the supply of fresh air to the dwelling.

Overall observations found that in both dwellings, the same type of vent was used for extract and supply ventilation. It would be expected that a different shape of vent would be used for each function, to effectively disperse and collect air in the case of supply and extract air.

7 Monitoring methods and findings

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

7.1 Introduction

The research involved the extensive monitoring of 4 properties and intensive monitoring of 2 properties during a 12 month period from September 2013 to August 2014. In the interests of confidentiality, throughout this report these properties will be referred to as Extensive 1-4 (Dwellings 1, 2, 3 and 5), Intensive Bungalow (Dwelling 6) and Intensive House (Dwelling 4).

Planned equipment for installation in the Extensive and Intensive properties is detailed in Table 6. Several issues meant that some aspects of the planned monitoring could not be completed, and are detailed in subsequent sections of this report.

The in-use monitoring project suffered from multiple issues throughout the 12 month monitoring period which have been detailed in the quarterly project progress reports to this point. These issues have unfortunately had a negative effect on the overall success of the monitoring, and are described in more detail in Section 7.2.

Sensor	Intensive Bungalow	Intensive House	Extensive 1	Extensive 2	Extensive 3	Extensive 4
Living Room Temperature	Yes	Yes	No	No	No	No
Living Room Humidity	Yes	Yes	No	No	No	No
Living Room CO_2	Yes	Yes	No	No	No	No
Bedroom Temperature	Yes	Yes	No	No	No	No
Bedroom Humidity	Yes	Yes	No	No	No	No
Bedroom CO_2	Yes	Yes	No	No	No	No
Bathroom Temperature	Yes	Yes	No	No	No	No
Bathroom Humidity	Yes	Yes	No	No	No	No
Total Water	Yes	Yes	Yes	Yes	Yes	Yes
Gas	Yes	Yes	Yes	Yes	Yes	Yes
Total Electric	Yes	Yes	Yes	Yes	Yes	Yes
Sub Metered Electric A	Yes	Yes	No	No	No	No
Sub Metered Electric B	Yes	Yes	No	No	No	No
Space Heating	Yes	Yes	No	No	No	No
Water Heating	Yes	Yes	No	No	No	No

Table 5 Planned monitoring equipment for each dwelling.

7.2 Monitoring Issues

7.2.1 Equipment

Weather Station

In order to determine how dwellings react to different environmental conditions, it is essential to monitor local weather data. A weather station was located at the nearby Joseph Rowntree Tanners Yard site for this purpose (less than 200 metres away from the development). This location was deemed to be close enough to the monitored dwellings to give appropriate weather data, but had the advantage that it did not require the weather station mast to be attached to the gable end of one of the dwellings. The weather station unit was located on the gable end of a storage building, with logging equipment sited inside the main JRHT offices. So that an external power source was not needed, the weather station was equipped with a photovoltaic (PV) panel to allow the internal battery to charge during daylight hours.

Early in the monitoring period it was discovered that the PV panel was not supplying enough electricity to the weather station to charge the internal battery. As a result, after 2/3 days of data collection the weather station ceased transmitting data to the logger due to a flat battery. The location of the weather station necessitated the use of scaffolding in order to undertake remedial work, which had to be arranged in advance and limited opportunities to fix the issues. Several attempts were made to fix the weather station, including the trial of replacement batteries, replacement PV panels and rewiring the existing PV panel. Following each action, the weather station operated for a short period before ceasing to transmit. The time delay between issue identification and an opportunity to attempt a fix, led to large portions of environmental data being lost, and as such meant that this data was not captured during the monitoring project.

For future projects, the recommendation would be to locate the weather station such that issues can be resolved more quickly. In this case, the weather station appeared to be functioning following each attempted fix, prompting the research team to leave it installed, only to fail after several days when the battery ran out of charge. Had access been easier, the several attempts to fix the system could have occurred in a short period with a longer term solution sought quickly. With the location in a busy yard and action requiring scaffolding, each attempted fix took several weeks to action, leading to significant data loss.

Heat Meters

Heat meters and the associated pulsed head units were installed in both extensively monitored properties so that energy use for domestic hot water and central heating could be recorded. These meters and head units were passed on directly to the team at JRHT, and following installation it was discovered that the head units were configured for one pulse per kWh, despite being ordered with a pulse resolution of 1 pulse per Wh (Figure 13). Unfortunately, it is not possible to check the pulse resolution of the heat meter head unit until the device is powered and each head unit is calibrated to a particular heat meter, so it is not possible to simply replace the head unit. The pulse resolution that was supplied with the heat meters does not give a good indication of energy use in a domestic setting as energy use is too low. As a result, the heat meters and the associated head units had to be removed and sent back to the supplier for reconfiguration.

During this process, two of the heat meters and head units were misplaced and had to be replaced which led to further delays. Once the heat meters and head units were returned, there were further delays due to access issues to the properties to allow reinstallation. The heat meter head units are equipped with a pulse output that is connected to an Eltek GC62 pulse transmitter which sends data to the external logger. When the heat meters and head units were reinstalled, they were not reconnected to the Eltek transmitter, resulting in data only being recorded on the heat meter unit and making interpretation impossible. There were then further delays whilst the correct transmitters were located and reconnected. The result was that no usable data was collected by the heat meters in either property.

The issue with pulse resolution was unavoidable from the perspective of the research team, as the correct equipment was originally ordered and the fault was with the supplier. A system which allows pulse resolution to be checked prior to installation may have avoided the issue. Delays due to misplaced equipment and access were also out of the control of the research team.

Figure 13 Installed Heat meters in MWh resolution

Electric meter water ingress

In order to monitor total electrical consumption, dwellings were fitted with pulse enabled kWh meters. These were located in the external meter boxes and connected to Eltek GC62 pulse transmitters. Although understood to be weatherproof, the external electricity meter boxes housing the electricity meters allowed severe water ingress, causing the transmitters to become water damaged as can be seen in Figure 14 below. This led to significant data loss in addition to several hundred pounds worth of equipment damage. In order to continue monitoring, equipment had to be replaced with Leeds Metropolitan University inventory. Transmitters must be synchronised with a logger in order to record data and loggers were located within the Extensive house. Access issues to allow this led to further data loss.

This issue was not foreseen by the research team as the external housing was thought to be weather proof. In future projects, the research team will use weatherproofing systems that are known to be sufficiently robust.

Figure 14 Water damage to pulse transmitters.

Data loss from logging equipment

During monitoring there were two periods of data loss. The first occurred between the 4th and 11th November 2013. This was due to a systems upgrade at Leeds Metropolitan University which led to the downloaded data files becoming corrupted. It was unfortunately not possible to recover this data.

The second incidence was significantly damaging to the monitoring project. Between the 5th January and 17th February monitoring loggers located in the Extensive House (Dwelling 4) recorded no data. The reason for this was discovered following conversations with residents, and was found to be the result of the loggers being unplugged during the movement of furniture. The loggers were originally located on the top floor landing, but were removed to accommodate a vivarium and were not subsequently reconnected to the power supply. As a result, the loggers could only record data for a short period of time before the internal batteries within the logger discharged. Although this was noticed in the first week of failed data downloads, it was not possible to gain access until 17th February resulting in the large period of data loss.

Residents were asked to keep equipment powered, with efforts made to locate the logging equipment in a convenient location. Ideally, loggers should be located out of sight, with the best location being in the loft space with a dedicated socket.

Sub-meter labelling

All circuits in the extensively monitored properties were sub-metered to allow disaggregation of electrical data and determine how energy was used in the dwelling. When this was originally installed in the dwelling, the trailing wires for the pulse outputs on the sub-meters were not labelled, making it impossible to determine which trailing wire was attributable to each circuit (Figure 15). This required the JRHT electrician to return to the property to label each of the trailing wires and resulted in data loss.

Figure 15 Unlabelled wiring

Internal conditions data loss

Internal conditions monitoring suffered data loss in both dwellings during the monitoring period. In addition to the data loss due to loggers being unplugged, the following issues were encountered:

- **Sensor unplugged –** The combined temperature/humidity/CO_2 sensors require a power supply to operate. These were unplugged on several occasions in both dwellings, leading to data loss. The issue with these sensors is that they occupy a plug socket in a lived-in space, meaning residents are more likely to unplug them. This is unfortunately unavoidable, as there is no reliable battery powered alternative compatible with the existing monitoring equipment. Despite residents being asked to leave the equipment plugged in and reminders being given when issues are noticed, there is still a risk that the equipment will be unplugged accidentally.
- **Broken sensor –** The combined temperature/humidity/CO_2 sensor installed in the intensive bungalow (Dwelling 6) was found to have been accidentally damaged shortly after installation, so was not recording temperature or relative humidity data. Unfortunately, there was no available replacement in the Leeds Metropolitan University inventory, leading to a delay in data collection whilst a replacement sensor was sourced and installed.
- **Sensors moved –** During the monitoring period, the layout of the living room in the Intensive Bungalow (Dwelling 6) was changed, which led to the movement of the combined temperature/humidity/CO_2 sensor.

Water meter issues

Several issues were experienced with water metering equipment, which led to loss of data for both extensive and intensive dwellings. Efforts were made to fix these issues with limited success. Replacement of meters would require significant disruption for residents with no guarantee of success, so the decision was taken to continue with the data available.

Tables 6-15 detail the status of the monitoring equipment throughout the in-use monitoring period.

	Gas	Electric	Water
Extensive 1	Yes	Yes	Yes
Extensive 2	No	No	Yes
Extensive 3	Yes	No	No
Extensive 4	No	No	No

Table 6 September 2013.

	Gas	Electric	Water
Extensive 1	Yes	Yes	Yes
Extensive 2	Yes	Yes	Yes
Extensive 3	Yes	Yes	Yes
Extensive 4	Yes	Yes	Yes

Table 7 December 2013.

	Gas	Electric	Water
Extensive 1	Yes	Yes	Yes
Extensive 2	Yes	Yes	No
Extensive 3	Yes	Yes	Yes
Extensive 4	Yes	No	Yes

Table 8 March 2014.

	Gas	Electric	Water
Extensive 1	Yes	Yes	Yes
Extensive 2	Yes	Yes	No
Extensive 3	Yes	Yes	Yes
Extensive 4	Yes	No	Yes

Table 9 June 2014.

Sensor	Status
Living Room Conditions	OK
Bedroom Conditions	OK
Bathroom Conditions	OK
Total Water	OK
Gas	No readings
Total Electric	OK
Sub metered Electric A	OK
Sub Metered Electric B	OK
Space Heating	No Readings
Water Heating	No Readings

Table 10 Intensive House (Dwelling 4) December 2013.

Sensor	Status
Living Room Conditions	OK
Bedroom Conditions	No readings
Bathroom Conditions	OK
Total Water	OK
Gas	No readings
Total Electric	OK
Sub metered Electric A	OK
Sub Metered Electric B	OK
Space Heating	No Readings
Water Heating	No Readings

Table 11 Intensive House (Dwelling 4) March 2014.

Sensor	Status
Living Room Conditions	OK
Bedroom Conditions	OK
Bathroom Conditions	OK
Total Water	OK
Gas	No readings
Total Electric	OK
Sub metered Electric A	OK
Sub Metered Electric B	OK
Space Heating	No Readings
Water Heating	No Readings

Table 12 Intensive House (Dwelling 4) June 2014.

Sensor	Status
Living Room Conditions	Broken sensor
Bedroom Conditions	OK
Bathroom Conditions	OK
Total Water	No readings
Gas	OK
Total Electric	OK
Sub metered Electric A	No readings
Sub Metered Electric B	OK
Space Heating	No Readings
Water Heating	No Readings

Table 13 Intensive bungalow (Dwelling 6) December 2013.

Sensor	Status
Living Room Conditions	OK
Bedroom Conditions	OK
Bathroom Conditions	OK
Total Water	No readings
Gas	OK
Total Electric	Damaged Equipment
Sub Metered Electric A	OK
Sub Metered Electric B	OK
Space Heating	No Readings
Water Heating	No Readings

Table 14 Intensive bungalow (Dwelling 6) March 2014.

Sensor	Status
Living Room Conditions	OK
Bedroom Conditions	OK
Bathroom Conditions	No Readings
Total Water	No readings
Gas	OK
Total Electric	Damaged Equipment
Sub Metered Electric A	OK
Sub Metered Electric B	OK
Space Heating	No Readings
Water Heating	No Readings

Table 15 Intensive bungalow (Dwelling 6) June 2014.

7.3 Occupancy and access

Access to properties was a significant barrier to the successful monitoring of the Dormary Court dwellings. Equipment issues were exacerbated by the difficulty in gaining access to properties so that problems could be resolved. Although all residents gave consent to participate in the research, willingness to engage with the research team to resolve issues was rarely forthcoming. This resulted in lengthy delays when trying to resolve issues with equipment.

In addition to access issues, several actions of residents had a significant impact on data gathering. One example was the decision of residents to move logging equipment resulting in data loss. Although residents were reminded of the data gathering and had previously signified their willingness to participate, there is little that can be done by the research team with regards to resident activity in the home.

7.4 Data Analysis

7.4.1 Extensively monitored properties

The graphs below show the data collected to date for each of the extensively monitored properties. The gaps in the data represent the various issues encountered with monitoring equipment. Unlike testing a vacant property, it is often difficult to resolve technical problems due to access issues. Consequently, the gap between issue identification and resolution can be considerable.

Total electricity use across all properties is displayed in Figure 16, and whilst being erratic over short periods, was largely consistent for each property. Extensive 1 has the highest occupancy of all monitored properties, being both a larger dwelling and functioning as a home for adults with disabilities. This results in 24 hour occupancy, and this is reflected in the higher amount of electricity use from all of the monitored properties. In contrast, Extensive 2 is occupied by one adult and one child, and the smaller occupancy can be seen in the lower total electricity use data.

The higher occupancy in Extensive 1 is also apparent in the total water use data presented in Figure 17. As with monitored electricity data, the overall pattern of use for properties is consistent despite data being erratic over shorter time periods. There are several high peaks of water use, most noticeably on 20th May in Extensive 1 and 4th June in Extensive 3. Although the reason for this short term increase is unknown, it is common for residents to use large amounts of water in a short period in the summer months, as warmer weather encourages the watering of gardens and washing of cars.

Total gas use for all properties is displayed in Figure 18. Higher usage is shown in the two bungalows, suggesting that these buildings with their larger size and floor area require more heating that the 4 multi-storey terraced houses. Gas use is seen to increase during the winter months, as would be expected due to the additional requirement for space heating as external temperature decreases. The consistency of water use over 12 months suggests that the additional gas use is for space heating, as there is no noticeable rise in total water use that would be observed if domestic hot water consumption were responsible for the increased gas consumption.

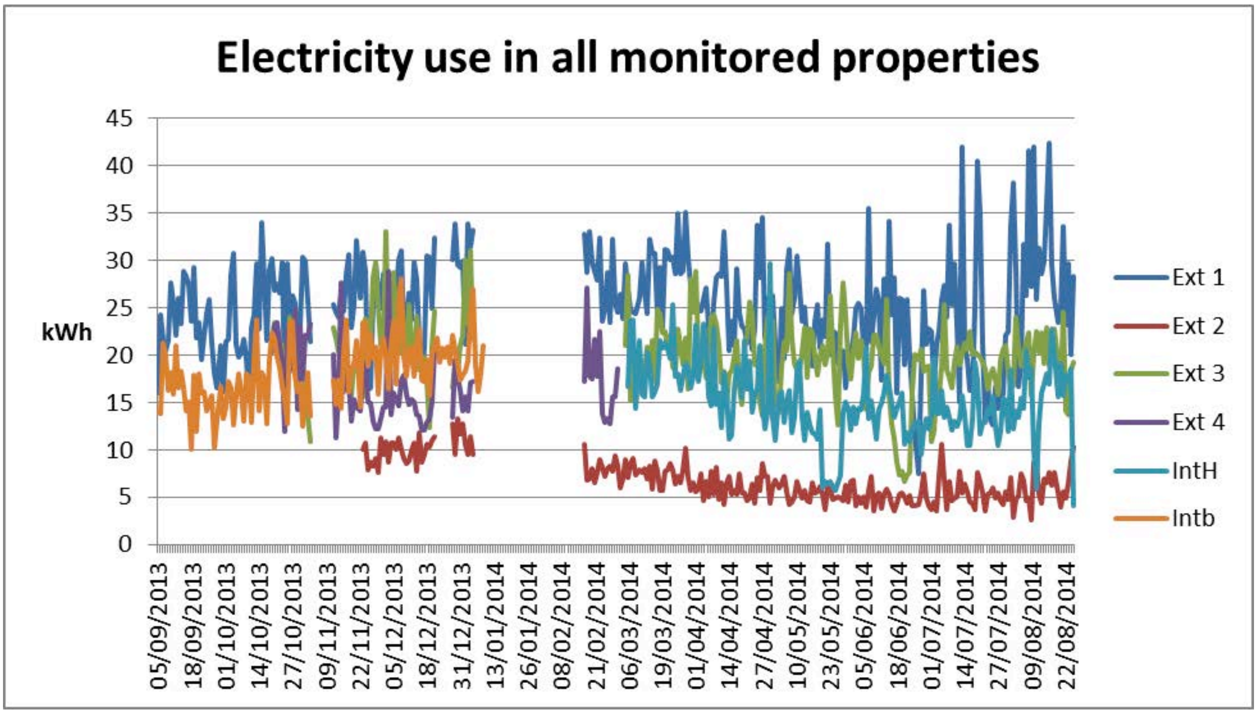


Figure 15 Electricity use in all monitored properties

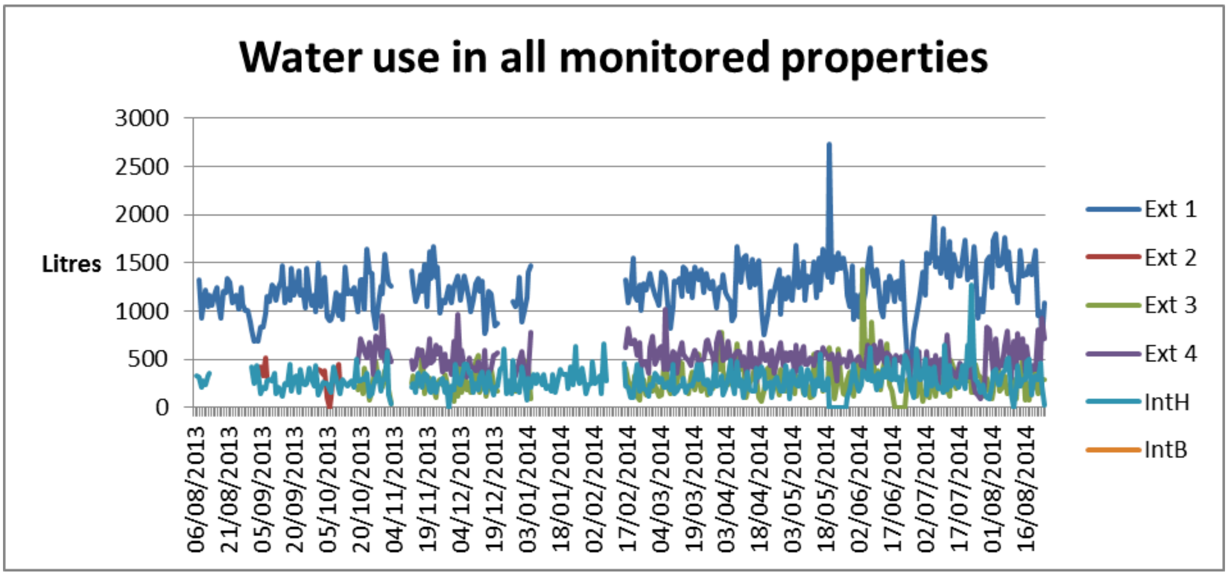


Figure 16 Water use in all monitored properties

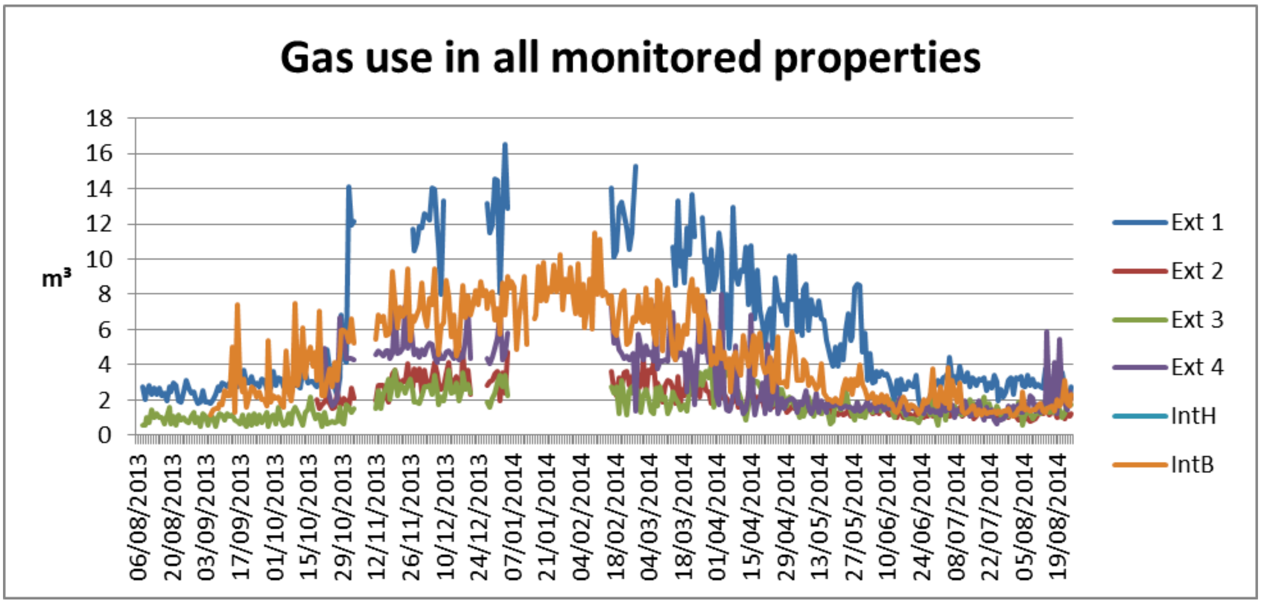


Figure 17 Gas use in all monitored properties

Additional monitoring equipment in the intensively monitored properties (Dwelling 4 and 6) allows for further analysis of environmental conditions and energy use within the dwelling. Each of the intensive properties has equipment installed to monitor the internal conditions in the living spaces. Each property has the temperature and relative humidity measured in the living room, bedroom and bathroom. In addition to this, CO_2 levels are measured in the living room and bedroom. Measurement of these conditions allows for indoor comfort and an indication of internal air quality to be assessed.

Internal temperature data for the intensive house (Dwelling 4) is displayed in Figure 18. Internal temperature appears quite erratic on a daily basis, although consistently within a range of 19-23°C across the full monitoring period. The exception to this is during winter, when the living room temperature appears to drop significantly. This may suggest that the dwelling heating system is unable to heat this space effectively. It has already been determined through occupant questioning that the MVHR system in the home is not in operation, having been turned off due to noise complaints, and this may provide an explanation for the lower temperature in the living room. Despite the various peaks and troughs, the intensive house does display the ability to maintain an internal temperature. The data shows comfortable living conditions, with only brief overheating periods (over 23^{0}C in bedrooms, over 26^{0}C living room) which appear to be the result of short term factors, such as increased occupancy.

Internal relative humidity displayed in Figure 19 fluctuates between 40-65% for the majority of the testing period, with only short periods of time outside this range. It is interesting to observe the reduction in internal humidity during winter months, which may be the result of reduced window opening during colder weather and a consequent decrease in the introduction of moist external air to the dwelling.

Internal CO_2 provides an indication of internal air quality, and is particularly relevant when monitoring relatively airtight dwellings such as those at Dormary Court who are equipped with MVHR systems. Figure 20 displays daily CO_2 average measurements with additional data on the maximum and minimum recorded level for each day. Whilst the living room appears to have a normal CO_2 concentration, fluctuating around 600ppm, the bedroom appears to be noticeably higher, with a CO_2 level fluctuating around 800ppm with high daytime peaks.

Figures 21 and 22 give an indication of the total time that CO_2 levels were above 1500ppm and 1000ppm during the entire monitoring period. The CO_2 level is recorded as being above 1000ppm for 23% of the time, and the majority of this is during the night when the room is occupied. It is possible that this high concentration of CO_2 is the result of the MVHR system being turned off, leading to fresh air not being supplied to the bedroom. Residents should be advised of the purpose of the MVHR system, and the impact of not using it.

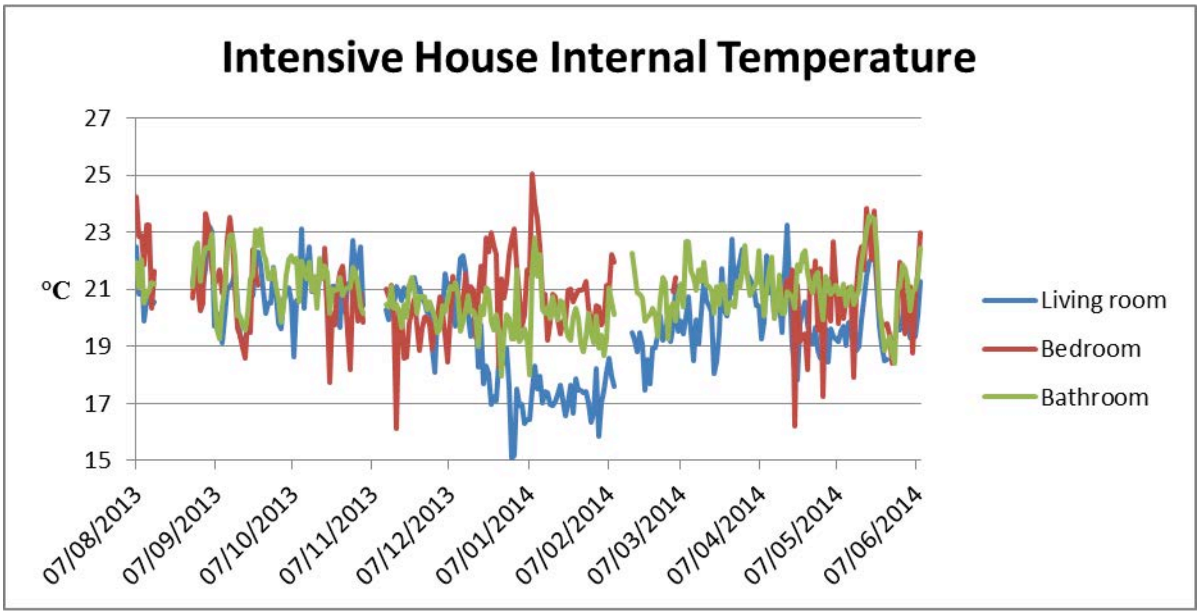


Figure 18 Intensive house (Dwelling 4) internal temperature.

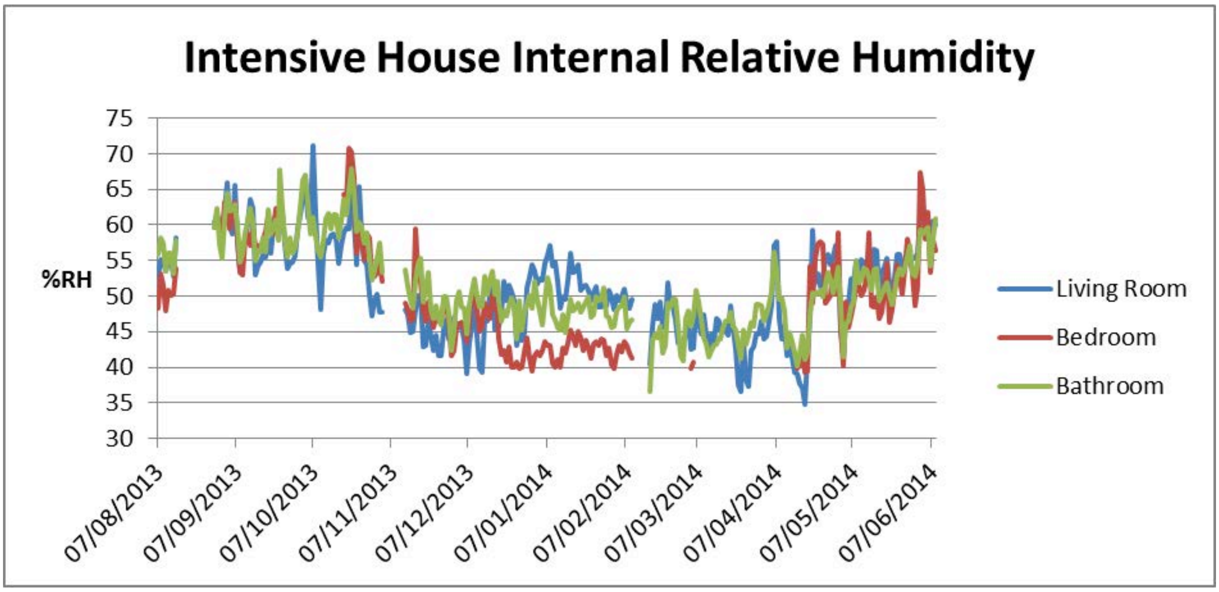


Figure 19 Intensive house (Dwelling 4) internal relative humidity.

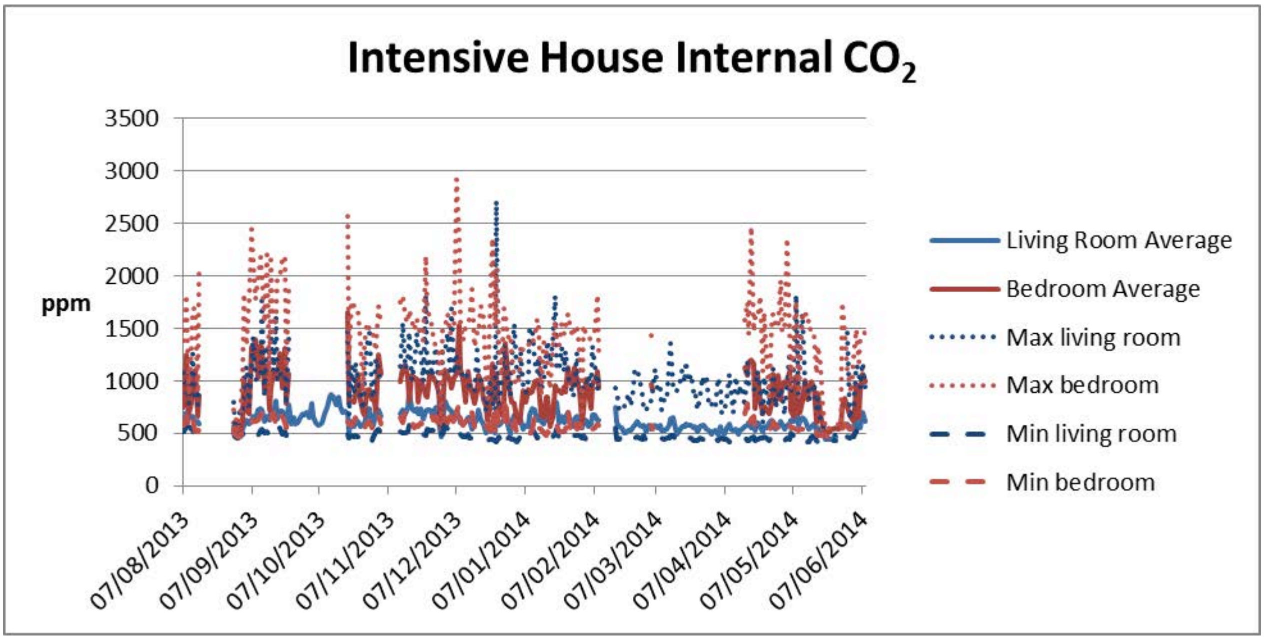


Figure 20 Intensive house (Dwelling 4) internal CO_2.

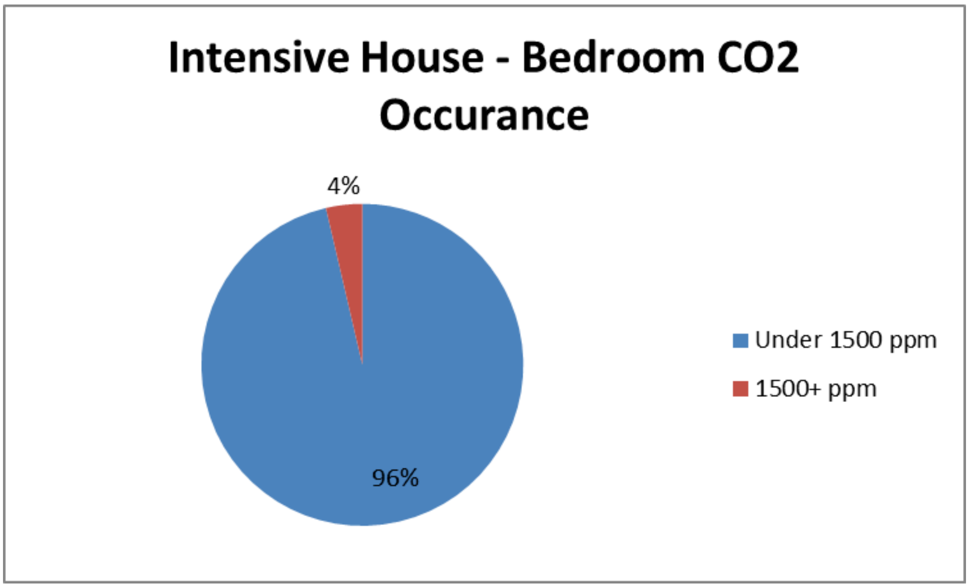


Figure 21 Intensive house (Dwelling 4) bedroom CO_2.

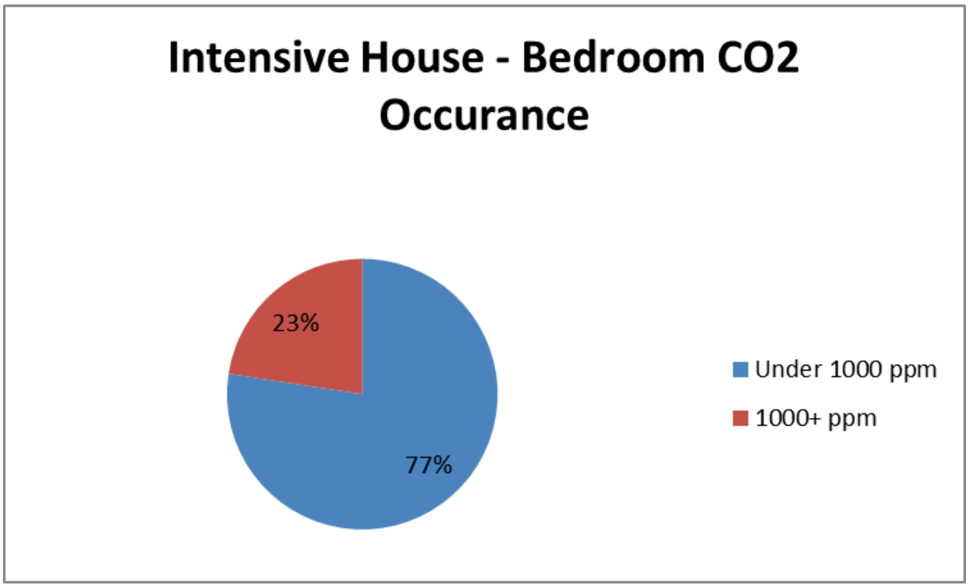


Figure 22 Intensive house (Dwelling 4) bedroom CO_2.

Internal temperature for the intensive bungalow (Dwelling 6) is displayed in Figure 23. Temperature is seen to be consistent at what would be perceived as a comfortable temperature during winter, suggesting that the dwelling heating system is able to sufficiently heat the home. There is a noticeable increase in internal temperature during summer, however, with average temperatures rising to a peak of 27°C on the 25th July. Although the temperature in the living room does not spend a significant time above the comfort threshold of 26°C, the bedroom temperature appears to be above the comfort threshold of 23°C during summer.

Figures 24 and 25 explore overheating in more detail, with a focus on the period from May-August where temperatures rose. It was noted that the bedroom temperature was exceeding the comfort threshold of 23°C for 62% of the time (1739 hours) during this period and exceeding the overheating threshold of 25°C for 13% (374 hours). Following the high average temperature peak in July, internal temperatures are observed to decline rapidly to a more comfortable level. It is unknown what prompted the rapid decline, although it may be due to a change in external conditions. The presented temperature data suggests that the intensive bungalow is becoming excessively warm during summer, which may be the result of occupants not opening windows to expel hot internal air.

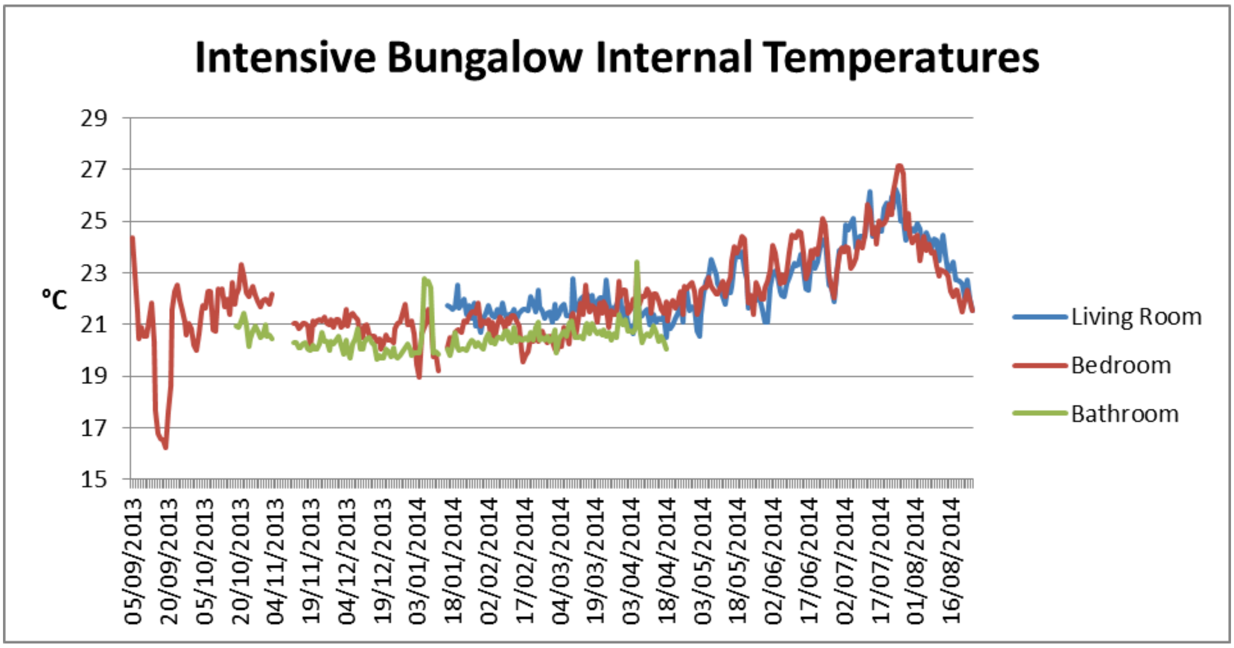


Figure 23 Intensive bungalow (Dwelling 6) internal temperature.

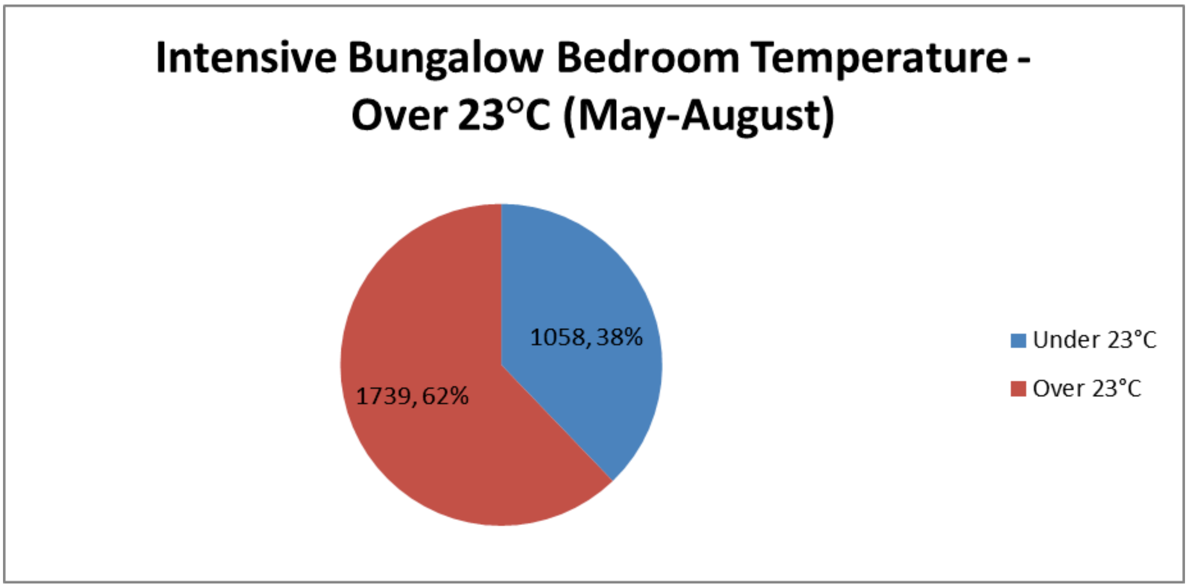


Figure 24 Intensive bungalow (Dwelling 6) – time exceeding comfort threshold (hours and total percentage)

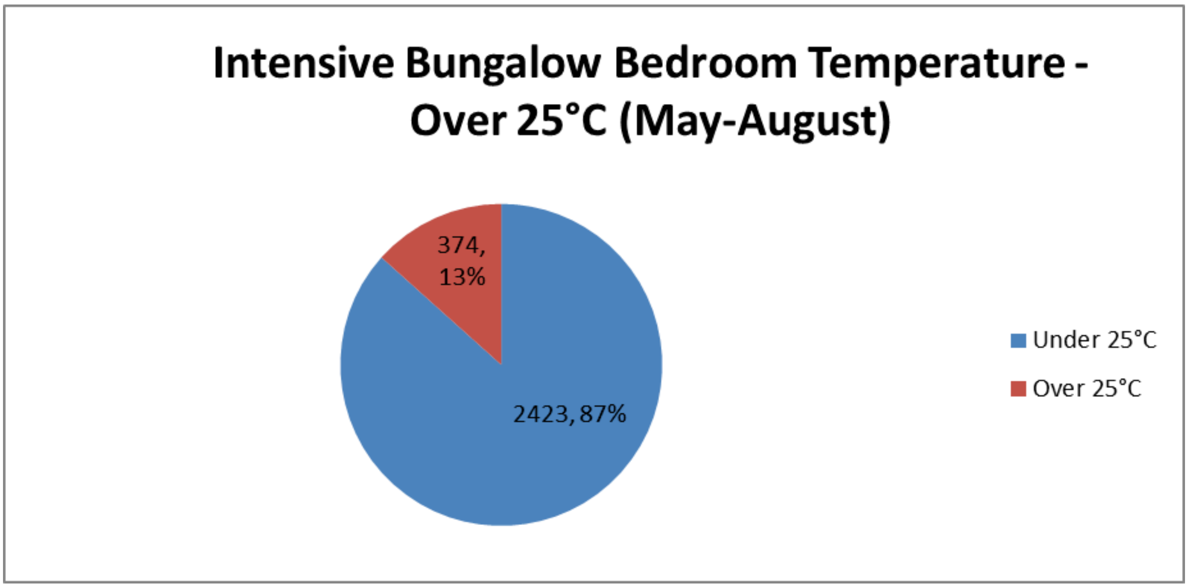


Figure 25 Intensive bungalow (Dwelling 6) – time exceeding overheating threshold (hours and total percentage).

Internal relative humidity data is presented in Figure 26 and shows a fluctuation between 40-65% for the majority of the monitoring period, with isolated periods outside this range. As with the intensive house (Dwelling 4), relative humidity appears to decrease during winter, with the most probable cause being a reduction of moist external air entering the dwelling as windows are closed during cold weather.

Monitored CO_2 levels in the intensive bungalow are displayed in Figure 27. Due to a single high reading on 1st April, they are displayed on a reduced scale in Figure 28 for better clarity. The period of high reading is explored in Figure 29, and can be seen to be the result of a short term event, and not representative of normal activity. Average level of CO_2 in both zones is very similar, suggesting that air is mixing well within the dwelling. CO_2 concentration is consistently around 750ppm which is slightly higher than may be expected, and may be a result of higher occupancy or a lack of air extraction from the MVHR system.

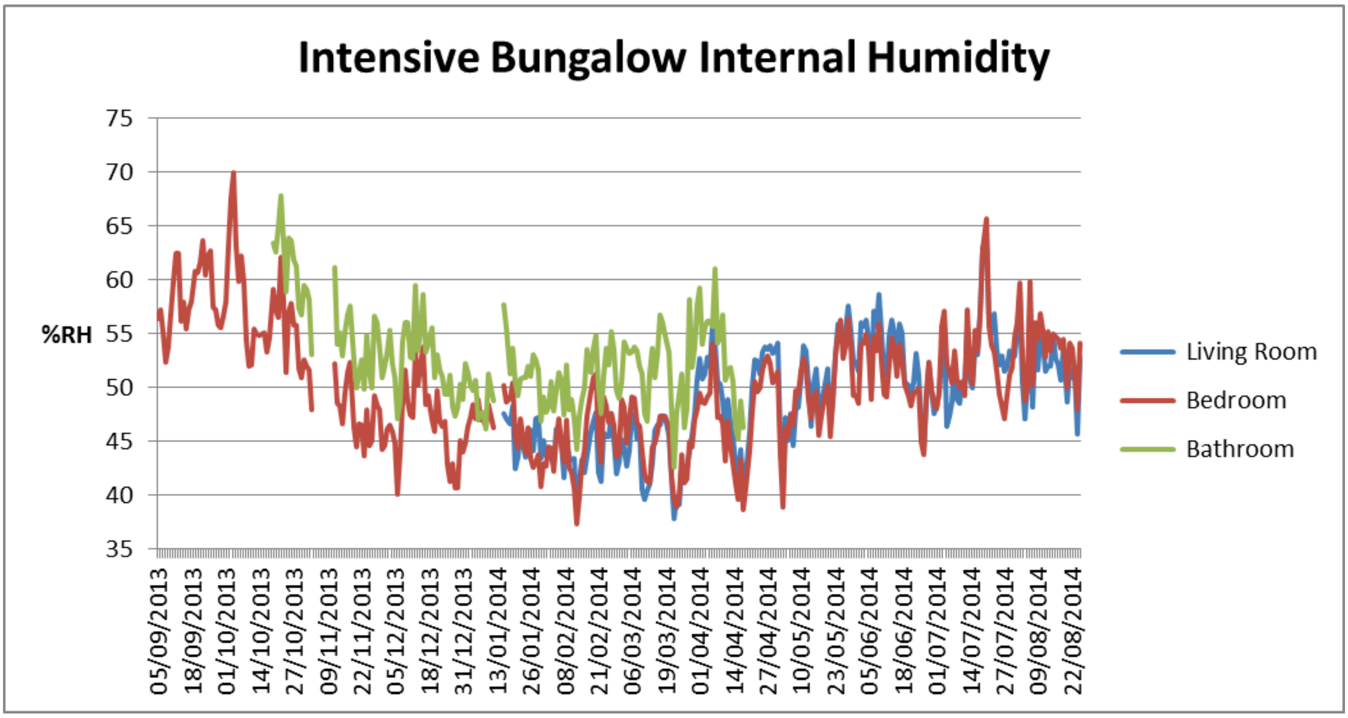


Figure 26 Intensive bungalow (Dwelling 6) internal relative humidity.

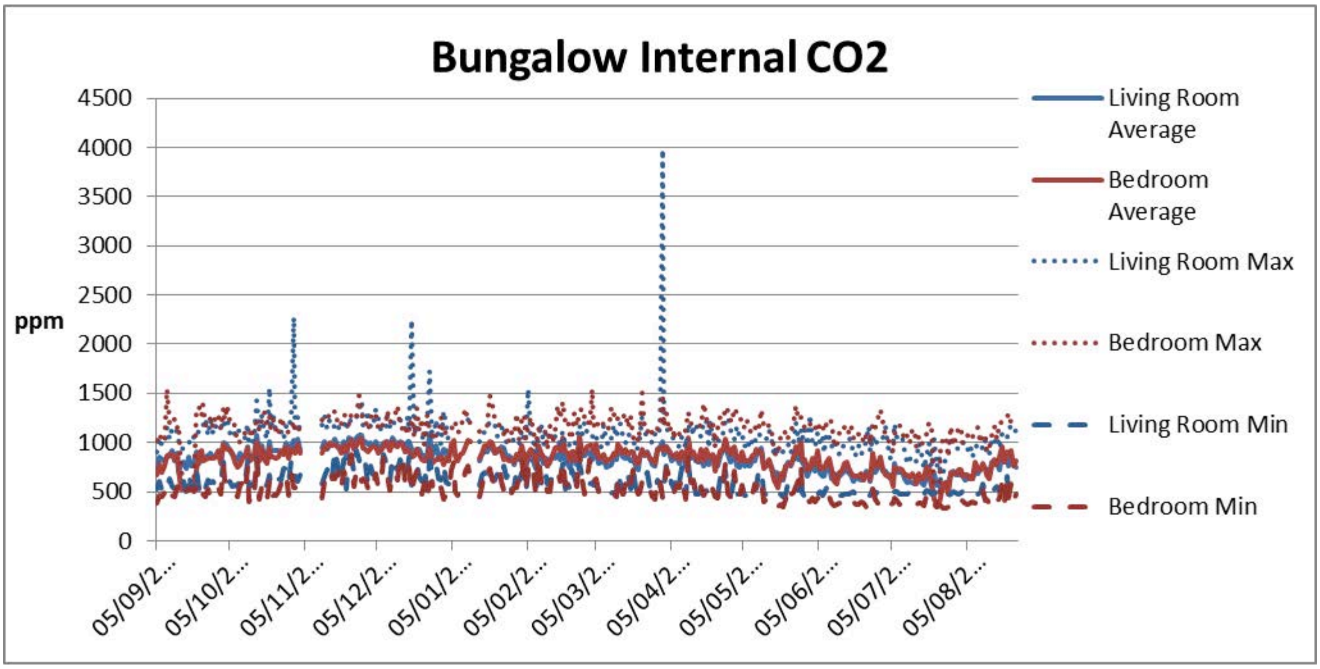


Figure 27 Intensive bungalow (Dwelling 6) internal CO_2.

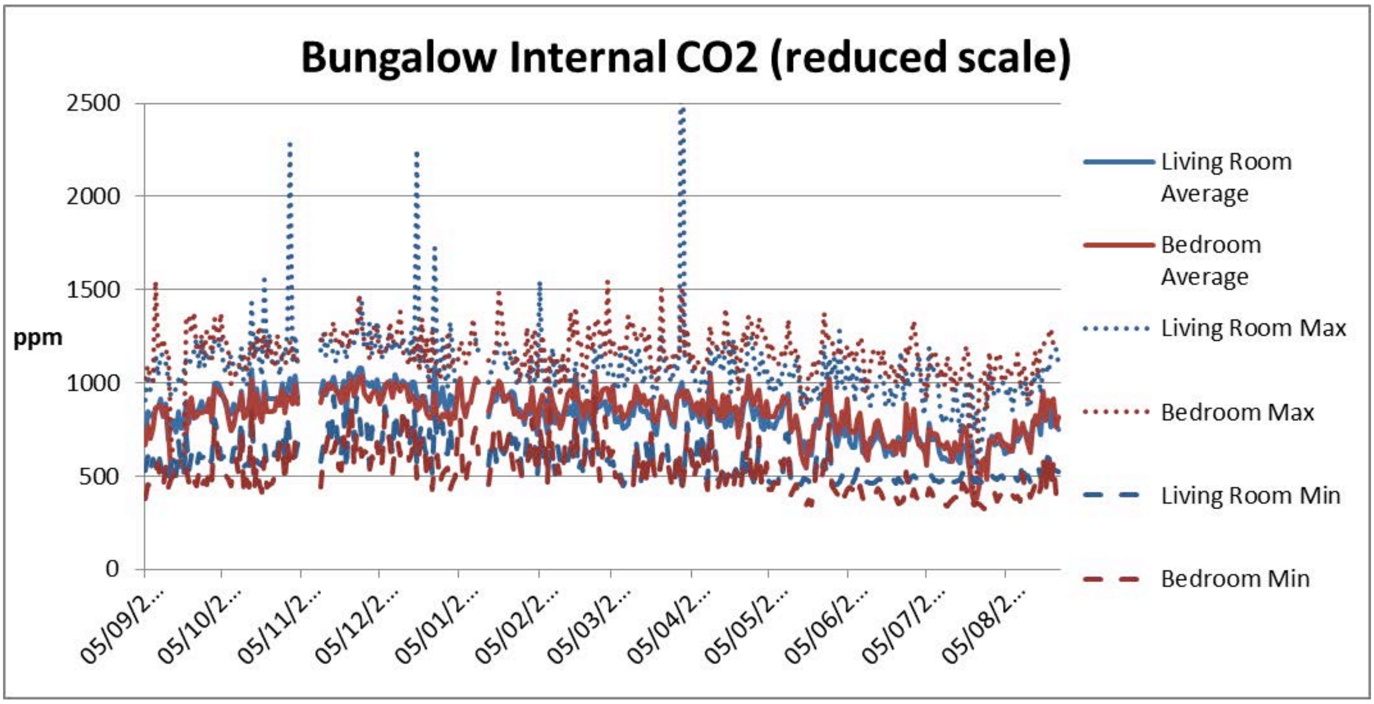


Figure 28 Intensive bungalow (Dwelling 6) internal CO_2.

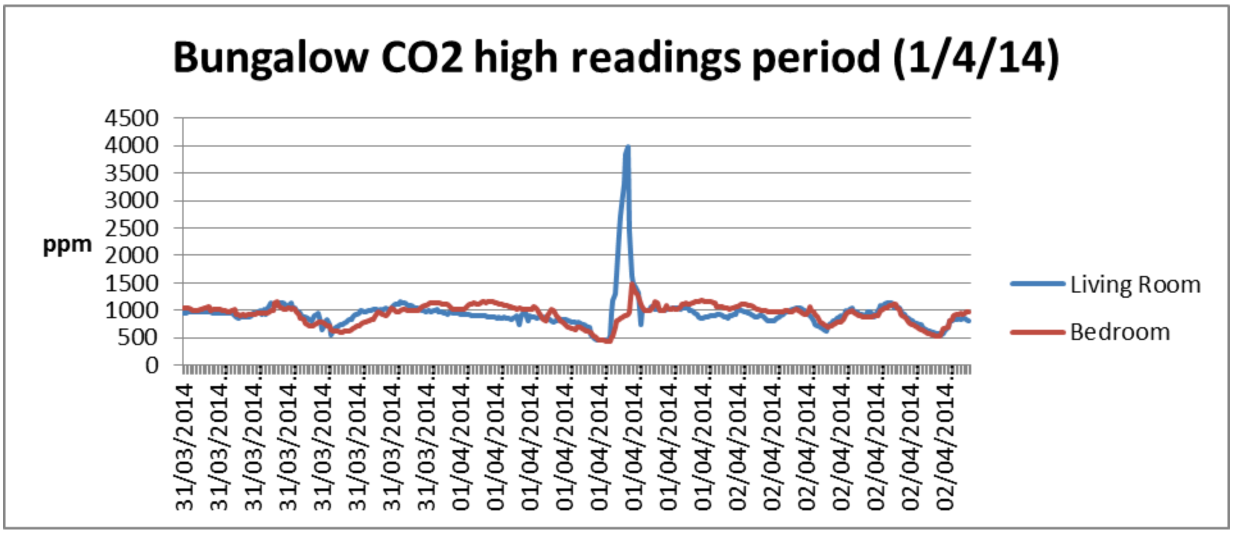


Figure 29 Intensive bungalow (Dwelling 6) internal CO_2.

7.5 Conclusions and key findings for this section

Due to monitoring issues, data is incomplete in many areas, limiting the ability of the research team to draw confident conclusions with regard to the internal environmental conditions and the energy use. This section of the final report details the various issues encountered throughout monitoring, and offers solutions where possible. Unfortunately, many issues encountered were beyond the control of the research team. The most significant issue was the inability to gain access to the monitored properties when issues arose. Not being able to quickly resolve issues meant that large amounts of data were lost. Future projects should involve communicating the need for access to resolve issues, and engage with residents to ensure co-operation.

Equipment failure was also an issue, with unforeseen issues including damaged transmitters and incorrect configuration of meters. Whilst in this instance it was not possible to mitigate against the majority of equipment issues, the problems encountered will provide guidance for future projects. For example, although the external box containing the transmitters for electrical consumption claimed to be weatherproof, in future the research team will use additional waterproofing measures to ensure damage does not occur.

Internal conditions in both intensively monitored dwellings suggested possible areas for further investigation. In the intensive house, CO_2 levels were noticeably high in the bedroom, which it is suspected is a result of turning off the MVHR system. In the intensive bungalow, the bedroom appeared to experience some summer overheating, suggesting that residents are not opening windows sufficiently.

8 Other technical issues

Technology Strategy Board guidance on section requirements:	This section should review the underlying issues relating to the performance of the building and its systems that have not been adequately captured elsewhere in this report. These could be technical issues detected through through testing, building use data and occupant issues etc. What technical issues have been discovered which could be leading to comfort or energy problems? Are the automated or manual controls being used effectively by the occupants or are they still becoming familiar with their operation? Did the commissioning process actually setup the systems correctly and, if not, what is this leading to? Are there design related technical issues, which are already becoming apparent and need to be highlighted for a future Phase 2 BPE study? Are there challenges being created through the dwelling usage or operation patterns? Summarise with conclusions and key findings.

No other technical issues were identified other than those previously discussed in Sections 2 to 7.

9 Key messages for the client, owner and occupier

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

9.1 Introduction

This section summarises the key messages obtained from undertaking the in-use energy and environmental monitoring study. These messages are detailed within the relevant sections below.

9.2 Physical fabric testing

As this project was the subject of an earlier Technology Strategy Board Building Performance Evaluation Competition post-construction and initial occupation study (project no. 450013), only a very limited number of building fabric tests and surveys have been undertaken on the monitored dwellings as part of the in-use energy and environmental monitoring study. The main findings from the physical fabric testing reports (Pressurisation Testing Report and Thermal Imaging Report) were as follows:

- Taking into account the non-ideal test conditions experienced when testing Dwelling 6, the pressurisation tests undertaken by the LeedsMet research team revealed that the air permeability of the two intensively monitored dwellings (Dwellings 4 and 6) has only changed very slightly since they were previously tested in February 2011 as part of the earlier Technology Strategy Board Building Performance Evaluation Competition post-construction and initial occupation study. The slight drop in airtightness measured in Dwelling 4, is most likely due to degradation of the seals around the external windows and doors. This degradation is common in new build housing. It is advised that the air permeability of all of the dwellings on the development is monitored by the client to ensure that the air permeability does not deteriorate any further.
- Although the air permeability of both intensively monitored dwellings has only changed very slightly, suggesting that the method used to construction the dwellings is relatively robust in terms of airtightness, the air permeability of both dwellings does exceed the suggested air permeability of 3 $m^3/(h.m^2)$ @ 50Pa that is commonly recommended for properties with MVHR systems. Consequently, there will be an energy penalty associated with using the MVHR unit in these dwellings. It is advised that the client undertakes remedial airtightness measures on both dwellings to reduce this energy penalty.
- The thermal imaging survey undertaken on Dwelling 6 revealed a number of significant discontinuities in the loft insulation layer. Despite the majority of these issues being identified in the earlier post construction and initial occupation project, little appears to have been done to address these issues. In fact, in some cases, the issues identified have been exacerbated. For instance, additional displacement of the loft insulation layer appears to have taken place since completion of the post construction and initial occupation project. These discontinuities in the loft insulation layer are likely to have a detrimental effect on the thermal performance of Dwelling 6. There may also be a risk of degradation of the building fabric in the medium to long term due to the formation of condensation on those areas where there is a thermal bridge. It is advised that the client addresses the discontinuity issues as a matter of urgency, and that additional surveys are undertaken on the other dwellings on the development to determine if these areas of heat loss are particular to the test dwellings or are much more widespread throughout the development.

9.3 BUS survey

Due to the small sample size and low return rate of the BUS questionnaire on the development, the research team do not feel that conclusive evidence of issues can be presented based on the BUS results alone. With this in mind, the main findings from the BUS survey were as follows:

- General feedback from the development was positive, with the majority of responses returning either 'green' or 'amber' ratings on the BUS feedback report.
- High energy costs (both heating and electricity) were identified as an issue. Unfortunately, as a significant amount of utility data on both gas and electricity consumption was lost due to equipment issues it is not possible for the research team to reliably evaluate if energy use was higher than would be expected for these properties over a full 12 month period. It is advised that the client
- Feedback on the MVHR system was negative, with occupants feeling that they had a lack of control over their ventilation system, resulting in poor indoor air quality. In addition to air quality issues, comments also indicated that noise was a problem with the MVHR system. This is reflected in the data and occupant feedback, with the residents of the intensively monitored house turning their MVHR system off completely due to noise complaints. The lack of indoor air quality is reinforced by the results of the duct flow measurements which indicate that there are significant issues with the MVHR systems installed within Dwellings 4 and 6. It is advised that the client re-commissions the MVJR units as soon as possible to address these issues. It is also advised that additional guidance and training is given to the occupants regarding the operation of the MVHR systems as soon as is possible.
- Several comments were received indicating that a number of the issues identified within the home that had been outstanding for a long period. It is advised that these issues are investigated and addressed by the client as soon as possible.

9.4 Duct flow measurements

The main findings from MVHR duct flow measurements undertaken on the two intensively monitored dwellings (Dwellings 4 and 6) were as follows:

- The MVHR systems in both dwellings are unbalanced, with total supply and extract measurements being significantly different. In the case of Dwelling 6, extract flow rates were lower than supply. This may be the result of extract vent openings being insufficiently open in addition to filters being clogged with dust and cooking residues. Dwelling 6 also displayed weaker flow rates from vents further away from the MVHR system, suggesting an imbalance in the supply of fresh air to the dwelling. Measurements for Dwelling 4 suggested issues across the full system, with over 70% of supply and extract flow coming from two vents located on the 2nd floor, closest to the MVHR unit. Additionally, some vents were seen to have no flow at all, such as the extract in the ground floor WC. As with Dwelling 6, flow rates decreased the further the vent was from the MVHR unit, suggesting an imbalanced supply of fresh air to the dwelling. The results suggest that the MVHR units installed in these dwellings may not have been commissioned correctly in the first instance. This has important implications for the performance of the MVHR units and indoor air quality. It is likely that further visits and commissioning checks will need to be undertaken on all of the MVHR systems installed on this development to ensure that the units are appropriately balanced and are operating correctly.

9.5 In-use energy and environmental monitoring

A number of significant issues were encountered undertaking the in-use energy and environmental monitoring on this development, the majority of which were beyond the control of the research team. These issues have meant that in-use monitored data is incomplete in many areas, limiting the ability of the research team to draw confident conclusions with regard to the internal environmental conditions and the energy use. The issues experienced during the course of this study are summarised as follows:

- The most significant issue encountered was the inability to gain access to the monitored properties when issues arose. Not being able to quickly resolve issues meant that large amounts of data were lost. It is advised that in any future projects, the need for access to residents homes to resolve issues, if they arise, should be clearly communicated to the residents. It is also important that residents actively engage with the in-use monitoring to ensure co-operation.
- A number of items of in-use monitoring equipment failed throughout the in-use monitoring period. For instance, the pulse transmitters used to monitor the total electricity consumption of the dwellings filed due to water ingress into the external electricity meter consumer units. Although these enclosures should be weatherproof, in this instance they clearly were not. It is advised that in future projects this issue is mitigated against in the future by ensuring that the pulse transmitters are installed in an additional weatherproof enclosure.
- The heat meters used for this study were incorrectly configured by the manufacturer, resulting in an inappropriate resolution for the pulsed output. This is despite the fact that clear instructions were provided to the manufacturer regarding the pulse resolution that was required. This issue was compounded by the fact that it was not possible to check the pulse resolution of the heat meters until they were installed. In future projects, it is advised that an alternative heat meter is purchased that enables a check to be made on the pulse resolution prior to installation.
- A number of replacement heat meters for those that were incorrectly configured were accidentally misplaced by the client. This required additional heat meters to be purchased, which introduced a significant delay. It is difficult to know how this particular issue could be mitigated against in any future projects.

In those instances where it was possible to monitor the internal conditions, a number of areas were identified that required further investigation. In Dwelling 4, CO_2 levels were noticeably high in the bedroom, which it is suspected is a direct result of turning off the MVHR system. In Dwelling 6, the bedroom appeared to experience some summer overheating, suggesting that residents are not opening windows sufficiently.

10 Wider Lessons

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

10.1 Wider lessons

This project has revealed a number of lesson/messages that would be of benefit to the wider industry. These lessons are summarised below under the appropriate headings.

10.2 Lessons for installation and commissioning of MVHR systems

To try and mitigate against the duct flow issues that were experienced in dwellings 4 and 6, the following is proposed:

- A standardised commissioning process is be developed for all MVHR systems to ensure that the MVHR system has been commissioned correctly in the first instance,
- Indicator lights are provided on MVHR systems to alert the occupants when the systems become unbalanced or when the flow rates reduce below a pre-set level.
- A series of annual duct flow measurements are required to be undertaken on all MVHR system to ensure that the units are operating correctly.

10.3 Lessons for in-use monitoring

This project has highlighted a number of the difficulties that can be associated with undertaking in-use energy and environmental monitoring studies. These relate to gaining appropriate access to equipment in a timely manner, equipment failure and the supply of incorrect equipment. Although many of these issues encountered are often beyond the control of the research team, there are a number of lessons that can be learnt for future research projects. These are as follows:

- The domestic in-use energy monitoring industry is still a relatively new market and there are a limited number of products available for in-use monitoring. This creates some difficulties in measuring certain parameters, such as being able to disaggregate energy consumption into the main end-uses categories within the home, namely: space heating, water heating, lights, appliances, cooking and ventilation. In addition, a number of the products that are available for measuring various parameters appear to suffer from reliability issues. The market for such products need to be stimulated to ensure that reliable products are available and can be easily installed to enable energy use within the home be disaggregated down to the main end-use categories.

- Considerable care should be taken when siting equipment to avoid any potential access issues if the equipment were to malfunction. Ideally, equipment should be sited in such a location that access to the home is not required. It is understood that this is not always practical. In such instances, the potential need for access to the in-use monitoring equipment should be clearly communicated to the residents. It is also important that residents actively engage with the in-use monitoring to ensure co-operation.

- Ensure that any equipment that has a risk of exposure to the elements is located within a suitable protective enclosure.

- Where possible, check the configuration of any meters prior to installation to ensure that they produce the required pulsed output.

10.4 Dissemination

Feedback on the findings from this study have been fed back to the Client (JRHT) of the development.

The duct flow measurements obtained from this study have been incorporated into a number of PowerPoint slides which the co-author of this report has presented to a range of undergraduate students studying various courses at Leeds Metropolitan University. Courses include: BSc (Hons) Building Surveying, BSc (Hons) Architectural Technology, HND Building Studies and BSc (Hons) Construction Management.

The authors of this study are also involved in a wide array of housing performance studies. Consequently, the findings from this study have been compared to other developments where in-use energy and environmental monitoring studies have been undertaken.

11 Appendices

There are numerous appendices associated with this report which are available as separate documents. These are as follows:

1. FLETCHER, M. GLEW, D. and JOHNSTON, D. (2014) In-use Monitoring and Post Occupancy Evaluation Study, Dormary Court, York – Air Pressure Testing and MVHR Duct Flow Measurements. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. August 2014. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.

2. JOHNSTON, D. and FLETCHER, M. (2014) In-use Monitoring and Post Occupancy Evaluation Study, Dormary Court, York – Thermal Imaging Survey. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. March 2014. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.

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