PassivHaus Bungalow

Phase 1 study
Post-construction and early occupation

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Innovate UK project number	450014 Related study: 450070 (phase 2)
Project author	Leeds Beckett University for the Gentoo Group
Report date	2013
InnovateUK Evaluator	N/A

No of dwellings	**Location**	**Type**	**Constructed**
Two 2-bedroomed terraced bungalows	Houghton-le-Spring	Terraced bungalows (one end and one mid-terrace)	2011
Area	**Construction form**	**Space heating target**	**Certification level**
66 m^2	Pre-fabricated timber-frame	N/A	CSH Level 4

Background to evaluation

The two chosen bungalows form part of a development of 28 bungalows. 25 of the bungalows were terraced units (8 end-terrace 17 mid-terrace), with the remaining 3 bungalows being detached. All 25 terraced bungalows on the development were designed to PassivHaus standards and either *Code for Sustainable Homes* (*CSH*) Level 4 or 5. Eighteen dwellings had solar thermal systems installed. In addition, five dwellings with solar thermal systems also had PV systems to enable them to achieve Level 5 of the *CSH.*

Design energy assessment	**In-use energy assessment**	**Sub-system breakdown**
No	N/A	N/A

A significant attention to detail was given to airtightness, with considerable care taken to ensure continuity of the air barrier membrane around openings, such as windows. However, gaps, some quite considerable, were observed between the sole plate and the damp-proof course. Tears were also observed in the foil-faced membrane used as an air barrier, resulting in discontinuity of the air barrier. The sills at all of the openings were not protected from the elements resulting in the mineral wool insulation used to fill these sections becoming saturated. Where services penetrated the external layer of bitroc, no attempt appeared to be being made to seal the penetration. Some of these issues were resolved before handover. The tested mean air permeability values of the two dwellings were 0.89 m^3 (m^2.h) @ 50 Pa and 1.31 m^3 (m^2.h) @ 50 Pa.

Occupant survey type	**Survey sample**	**Structured interview**
BUS domestic	21 of 27 (77.7% response rate)	N/A

Results showed that occupants found the air movement in the properties to be too still during both summer and winter, with additional concerns about air being excessively humid in summer. One possible reason for this could be incorrect use of the MVHR system, which should have provided sufficient fresh air to the dwelling. Some residents had been confused by the advice to keep windows closed to improve MVHR efficiency, and interpreted it as an instruction to not open windows. Overall, the consensus was that the dwellings were of high quality, with residents enjoying living in them and happy with their performance.

Contents

1 Introduction and overview

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

This report outlines the findings obtained from a post-construction and initial occupation study that was undertaken on two 66m^2 2 bedroomed terraced bungalows (one end- and one mid-terrace) as part of the Technology Strategy Board's Building Performance Evaluation Competition. Both bungalows were completed in November 2011 at Houghton Le Spring, Sunderland.

The two chosen bungalows, that are the subject of this study (dwellings 1 and 2), form part of a development of 28 bungalows, all of which are to be occupied by older residents. 25 of the bungalows are terraced units (8 end-terrace 17 mid-terrace), with the remaining 3 bungalows being detached units. The development is located within a large council estate in the North East of England in an area identified for renewal as part of a Citywide Renewal Plan, which aims to replace obsolete and unsustainable housing stock with around 4,000 new high quality homes. The development has been constructed on 0.98 Hectares of previously cleared land (originally housing). This land comprised a network of paths that run across a number of large sloping green public spaces (see Figure 1). The development is approximately ten to fifteen minutes' walk away from the neighbourhood retail centre and there are two bus stops adjacent to the development.

Figure 1 The site prior to development.

Two prominent Passivhaus Designers were appointed, one as the project architect and one as mechanical services engineer for the development. The dwellings were constructed by the new build housing development arm of the client, a Social Housing provider.

All 25 terraced bungalows on the development have been designed to Passivhaus standards and either Code for Sustainable Homes Level 4 or 5. The two chosen bungalows have been designed to Level 4 of the Code for Sustainable Homes. The 3 detached units have been designed specifically for mobility impaired tenants, and although they have been built to the same fabric and services standards as the terraced dwellings, due to their more challenging dwelling form, they have not been designed to be Passivhaus certified. The project is believed to be the first scheme in the UK of this scale with the intention to achieve formal PassivHaus certification.

In order to score points under the Code for Sustainable Homes, all of the bungalows, including those designed specifically for mobility impaired tenants, were equipped with cycle storage provision. Although all of the dwellings have been designed to achieve Level 4 of the Code for Sustainable Homes without the requirement for any renewable technologies, 18 of the dwellings have solar thermal systems installed on their South-facing roof slope. In addition, 5 of the dwellings with solar thermal systems also have PV systems installed on their South-facing roof slope to enable them to achieve Level 5 of the Code for Sustainable Homes.

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

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

2.1 Introduction

Dwellings 1 and 2 have been designed to Passivhaus standards and Code for Sustainable Homes Level 4. They comprise a South-facing open-plan living/kitchen area which runs the full depth of the dwelling, a North-facing master bedroom with an internal storage cupboard, a South-facing smaller bedroom with an internal storage cupboard (this cupboard also houses the main consumer unit for the dwelling), a bathroom and a mezzanine plant area. The mezzanine plant area is situated above the bathroom, corridor and both bedrooms and is only accessible via a loft hatch and ladder, as the client stated a desire that this space did not function as a loft space. Plans and elevations of the dwellings are illustrated in Figure 2 and Figure 3.

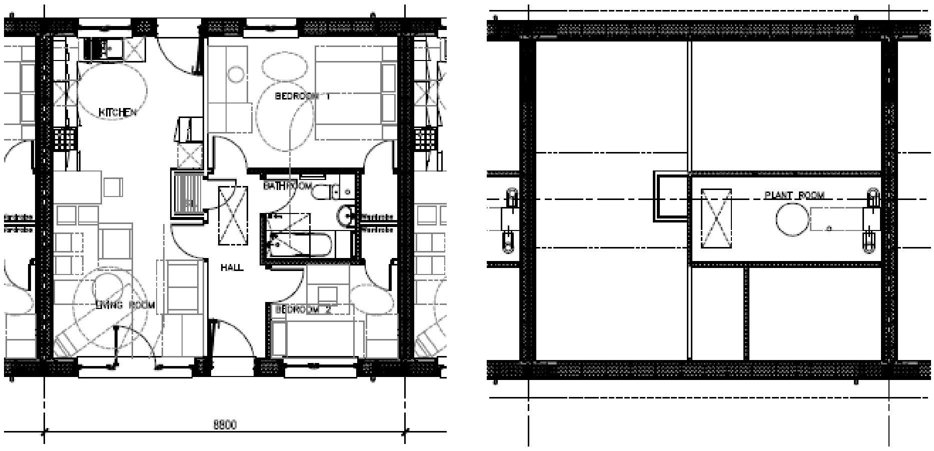

Figure 2 Ground floor and mezzanine floor plan of dwellings 1 and 2.

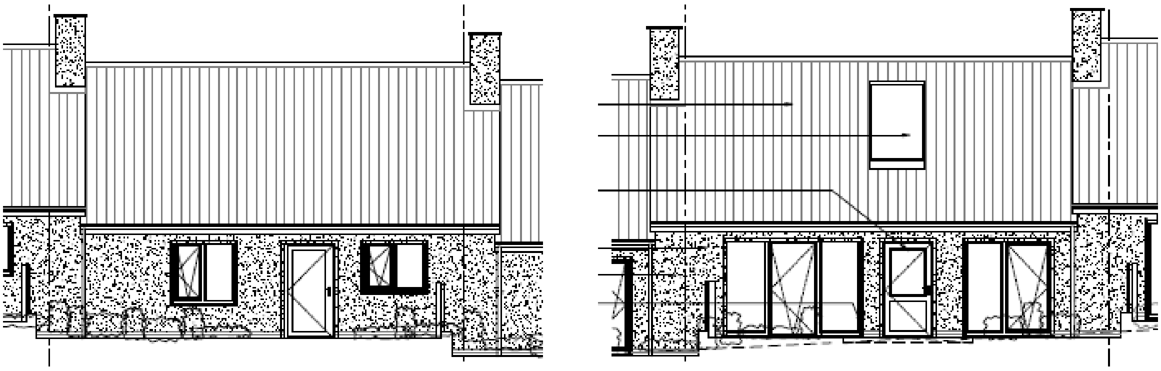

Figure 3 North and South elevation of dwelling 2. Dwelling 1 is very similar, apart from the fact that it is an end-terrace.

The external walls of the dwellings were constructed using pre-fabricated timber-frame cassettes filled with 300mm insulation and clad externally with 15mm bitroc and either brick or render. Internally, the external walls have a 47mm insulated service void which is lined with 25mm plasterboard. The ground floor comprises a reinforced concrete slab-on-ground, with 300mm insulation above the slab and 50mm screed. The roof is constructed using a 450mm insulated timber-frame cassette. The windows are triple glazed, low-e krypton filled units. A summary of the U-values for the various elements of the building fabric are contained within Table 1.These figures have been obtained from the design SAP worksheet for dwelling 1. In addition, the target design air leakage rate for the dwelling was ≤06 ac/h @ 50Pa.

Element	**U-value (W/m^{2}K)**
Ground floor	0.10
External walls	0.12
Roof	0.09
Windows	Side 0.90 Front (living area and bedroom 2) 0.90 Rear (kitchen and master bedroom) 0.90
Doors	0.90

Table 1 U-values of the main elements of dwelling 1.

2.2 Design review

A design review was undertaken on the 2 bungalows (see Appendix 1). It was found that a number of changes and challenges were encountered during the construction. These were as follows:

- Two timber-frame manufacturers went out of business during the duration of the project, as a consequence of the current economic climate.
- Additional structural timber was inserted into the timber-frame cassettes for crainage reasons, resulting in a significant increase in the timber fraction of the cassettes.
- The insulation that was inserted within the timber-frame cassettes was initially not recovering to its full thickness. This was attributed to a faulty batch of insulation.
- Two of the airtightness details were refined during construction; one adjacent to the sole plate and the other at the step in the party wall.
- Procurement issues were experienced with the doors, resulting in doors been supplied that were larger than specified.
- In order to enable the airtightness targets to be met and facilitate buildability and quality assurance measures, close co-ordination between the project architect and the contractor was required during construction.
- A number of issues resulted in significant delays occurring to the construction programme, such an unanticipated utilities below the site.
- A number of the building products used on the development were not readily available in the UK, so had to be imported, making the contractor vulnerable to currency fluctuations.

A comparison was also undertaken between the design and the as-built SAP worksheets. This revealed the following:

- As expected, some changes had been made to the fabric U-values, reflecting changes that had been made to the construction during the build process. In all cases where changes had been made, the as-built U-values were lower than the as-designed. A summary of the changes is contained within **Error! Reference source not found.** and **Error! Reference source not found.**. With respect to dwelling 2, there were also a number of anomalies associated with the window U-values contained within the as-built SAP worksheet.
- In the as-built worksheet, modelled psi values have been used to calculate the heat loss attributable to individual thermal bridges, rather than using the assumed y value of 0.03 that is contained within the design SAP worksheet. This has resulted in a significant percentage reduction in the heat loss attributable to thermal bridges in both dwellings, although only a small absolute reduction.
- The volume of the hot water cylinder has been reduced to reflect the size of the cylinder that was actually installed.

Element	Design SAP worksheet	As-built SAP worksheet
Ground floor	0.10 W/m^{2}K	0.08 W/m^{2}K
External walls	0.12 W/m^{2}K	0.10 W/m^{2}K
Roof	0.09 W/m^{2}K	0.08 W/m^{2}K
Windows	Side 0.90 W/m^{2}K Front (living area and bedroom 2) 0.90 W/m^{2}K Rear (kitchen and master bedroom) 0.90 W/m^{2}K	Side 0.80 W/m^{2}K Front (living area) 0.70 W/m2K Front (bedroom 2) 0.80 W/m^{2}K Rear (kitchen and master bedroom) 0.80 W/m^{2}K Rear door 0.78 W/m^{2}K
Doors	0.90 W/m^{2}K	0.86 W/m^{2}K

Table 2 U-values of the main elements of dwelling 1.

Element	Design SAP worksheet	As-built SAP worksheet
Ground floor	0.10 W/m²K	0.08 W/m²K
External walls	0.12 W/m²K	0.10 W/m²K
Roof	0.09 W/m²K	0.08 W/m²K
Windows	Front (living area and bedroom 2) 0.90 W/m²K Rear (kitchen and master bedroom) 0.90 W/m²K	Front (living area) 0.70 W/m2K Rear (kitchen and master bedroom) 0.90 W/m²K Rear door 0.78 W/m²K
Doors	0.90 W/m²K	0.86 W/m²K

Table 3 U-values of the main elements of dwelling 2.

2.3 Construction review

Although it was only possible to undertake a limited number of site observations on dwellings1 and 2 during the construction phase, the observations revealed that substantial effort was being made by the construction team to build very high performance dwellings. For instance, significant attention to detail was given to airtightness, with considerable care taken to ensure continuity of the air barrier membrane around openings, such as windows. However, the observations did highlight a small number of issues that had the potential to have an adverse effect on the as-built performance of the dwellings. These were as follows:

- A number of gaps, some quite considerable, were observed between the sole plate and the DPC. Grout was subsequently applied from the inside of the dwelling to seal these gaps but it is not known how effective this would be.
- A number of tears were observed in the foil faced membrane used as an air barrier, resulting in discontinuity of the air barrier. On later visits, it was evident that considerable care had been taken to repair any tears. It is not known whether all of the tears were adequately repaired.
- The sills at all of the openings were not protected from the elements resulting in the mineral wool insulation used to fill these sections becoming saturated. In addition, construction debris was also observed in the open sill sections.
- At the front door, the air barrier membrane had begun to detach from the sill.
- Where services penetrated the external layer of bitroc, no attempt appeared to be being made to seal the penetration. Also in the kitchen, one of the seals around a pipe had been compromised by pushing the pipe further through the sealed hole at a later date
- Both dwellings were constructed during the particularly severe winter of 2010/11 resulting in the structure becoming saturated.

It should be noted that the above observations only illustrate what was observed at a particular snapshot in time. Consequently, they may not be representative of what was finally built in-practice, particularly if a particular element was only partially constructed when the observation took place.

Further details relating to the construction observations can be found within Appendix 1.

2.4 Conclusions and key findings

It is clear from the design review that a number of changes were made to the design during the construction. These included changes to the timber-frame cassettes and refinement of some of the airtightness details. The design and construction team also experienced a number of significant challenges during the construction process, the majority of which were completely out of their control.

For instance, two timber-frame manufacturers ceased trading during the project, as a result of the economic climate, and unanticipated utilities were discovered below the site. Both of these challenges resulted in significant delays to the construction programme. In addition, difficulties were also experienced sourcing a number of the building products, as they were not readily available in the UK, or obtaining sufficient information from the suppliers, as was the case with the external doors. Despite these changes and challenges, the dwellings were constructed pretty much as intended. In fact, the as-built U-values for all of the elements of the building fabric were lower than those that were used to inform the original design. Given this, the design and construction team should be commended.

The construction observations revealed that overall, the dwellings were being built to a very high standard with considerable attention given to the detail, such as airtightness. However, the observations did highlight a very small number of issues that, if not adequately addressed, did have the potential to have an adverse effect on the measured performance of the dwellings.

3 Fabric testing (methodology approach)

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

3.1 Introduction

Fabric testing was undertaken over the period 8th November to the 22nd December 2011. It comprised:

- Pressurisation testing and leakage detection.
- Coheating test.
- Heat flux measurements.
- Thermographic survey.

3.2 Pressurisation testing and leakage detection

As the two bungalows were designed to Passivhaus standards, the air leakage target for the dwellings was ≤ 0.6 h^{-1} @ 50Pa. Both dwellings were pressure tested immediately prior to and after the coheating test. The results of the tests are detailed within Table 4.

Dwelling	Date	Depressurisation only	Pressurisation only	Mean Air Permeability	Comment
		$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	
Dwelling 1	08/11/11	0.83	0.94	0.89	Pre coheating test
	21/12/11	0.86	0.91	0.89	Post coheating test
Dwelling 2	09/11/11	1.30	1.33	1.31	Pre coheating test
	22/12/11	1.30	1.33	1.31	Post coheating test

Table 4 Pressure test results.

The results revealed that both dwellings are very airtight by UK standards and that that there has been effectively no deterioration in airtightness as a result of the elevated temperatures experienced during the coheating test.

Leakage identification was undertaken on both dwellings during the pre-coheating test. In both cases, only very small amounts of air leakage were identified. The areas identified were as follows:

- Around the communal heat pipes located in the loft space of both dwellings as they penetrated through the party wall.
- Via holes observed in the plasterboard dry-lining in the loft space of both dwellings.
- At the threshold corners of the external doors and French doors in dwelling 2.
- Around the trunking that supplies the cable to the occupant alarm system in dwelling 2.
- Around the bracket support for the pipe hangers in the loft space of dwelling 2.
- Via the telephone cable entry point in the external wall of dwelling 2.

A series of pressure equalisation tests were also undertaken on dwellings 1 and 2 to determine whether there was any inter-dwelling air leakage between dwellings 1 and 2 and dwellings 2 and 3 (mid-terrace). The results revealed small amounts of leakage between dwellings 1 and 2 and from dwelling 2 to dwellings 1 and 3. This is likely to be caused by the inadequate sealing of the communal services located in the loft space as they pass through the party walls of each dwelling.

A comparison was all made between the LeedsMet test and those undertaken by an external contractor for Building Regulations compliance purposes. This revealed that the LeedsMet results were considerably higher. This was partly due to the much higher internal envelope area used by the external contractor, but also due to the fact that the tests were undertaken almost two weeks after the external contractor tests, and during this time, a number of holes had been made in the plasterboard lining to enable access to be gained to cables located within the service void.

Further details relating to the pressurisation tests can be found within Appendix 2.

3.3 Coheating tests

The coheating tests were undertaken on one end-terraced (dwelling 1) and the adjacent mid-terraced (dwelling 2) bungalow between the 11th November and the 21st December 2011. An additional bungalow (dwelling 3), adjacent to dwelling 2, was used as an access dwelling.

It should be noted that in dwelling 1, the temperatures in the South-facing bedroom peaked at over 28°C on a number of occasions. These peaks in temperature correlated with periods of high solar insolation. This highlights the difficulties associated with undertaking coheating tests in very highly insulated and airtight dwellings that have small South-facing rooms in which a large proportion of the external envelope is glazed. In addition, it was not possible to control access or obtain a mean elevated internal temperature of 25°C within dwelling 3 over the period of the coheating test. Consequently, the heat loss coefficient figure obtained for dwelling 2 has to be treated with a degree of caution, as there is likely to have been some heat gain from the adjacent dwelling 3.

Despite the above issues, the results of the coheating tests demonstrated a very high level of correlation between the measured and the predicted performance. The measured and predicted heat loss coefficient for dwelling 1 was 46.7 W/K and 43.4 W/K, respectively and for dwelling 2 it was 38.1W/K and 36.6W/K, respectively.

Further details relating to the coheating tests can be found within Appendix 3.

3.4 Heat flux measurements

A number of heat flux plates were strategically located throughout dwelling 1 and 2 to obtain in-situ measurements of the effective U-values of various elements of the building fabric. In total 30 heat flux plates were installed, 20 in dwelling 1 and 10 in dwelling 2, with measurements being undertaken at one minute intervals throughout the coheating test. It is important to realise that the figures obtained from the heat flux plates are based upon a small number of measurements that were undertaken on a small area of each of the building elements, so are only indicative. Consequently, they may not necessarily be representative of the building element as a whole.

The heat flux measurements revealed that the effective U-values for the external walls ranged from 0.08 to 0.23 W/m²K, with a mean of 0.12 W/m²K. This is close to the nominal design value of 0.10 W/m²K. For the ground floor, the effective U-values ranged from 0.07 to 0.18 W/m²K, with a mean of 0.10 W/m²K, which is in agreement with the nominal design value of 0.10 W/m²K. For the ceiling, the effective U-values ranged from 0.09 to 0.20 W/m²K, with a mean of 0.13 W/m²K which is slightly greater than the nominal design value of 0.09 W/m²K. The reason for the discrepancy in the ceiling U-value is thought to be the fact that 2 out of the 3 sensors were positioned close to the thermal bridge at the wall/roof junction, resulting in a slightly higher than anticipated U-value.

The effective U-value of the centre-pane of the window and the window reveal was also measured. The effective U-value for the centre-pane of the window ranged from 0.56 to 0.78 W/m²K, with a mean of 0.68 W/m²K. This is slightly lower than the nominal design whole window value of 0.87 W/m²K. The effective U-value for the window reveal ranged from 0.17 to 0.36 W/m²K, with a mean of 0.23 W/m²K).

A series of heat flux plates were also installed on both sides of the party wall between dwellings 1 and 2 to determine whether the party wall was acting as a heat loss mechanism. The results indicated that very small amounts of positive heat flux were measured from both sides of the wall, with a mean effective U-value of 0.02 W/m²K from each side of the wall. In addition, negative heat flux was measured through the party wall from both dwellings on a few occasions. This suggests that the party wall is acting as a complex heat transfer mechanism, with small amounts of heat flowing both into and out of it during the measurement period.

Measurements were also undertaken for the external wall and ceiling at the eaves/wall junction, resulting in a mean U-value of 0.21 W/m²K and 0.18 W/m²K, respectively.

Further details relating to the heat flux measurements can be found within Appendix 4.

3.5 Thermographic survey

A series of Infra-red thermographic surveys were undertaken on the dwellings on a number of different days under various different weather conditions. Overall, the surveys revealed that the dwellings performed very well, with no significant areas of unexpected heat loss. The only areas where a small amount of unexpected heat loss was observed was at the jambs of the West-facing window in dwelling 1 (both internally and externally), at the jamb of the window in the rear bedroom of dwelling 1 (internally only), at the external door handles (condensation was also observed) and at the external door thresholds.

Further details relating to the thermographic survey can be found within Appendix 5.

3.6 Conclusions and key findings for this section

A series of fabric tests have been undertaken on dwellings 1 and 2. These tests have revealed that both dwellings are very airtight by UK standards, the measured effective U-values were close to the nominal design U-values for each of the building elements in the majority of cases, and no significant areas of unexpected heat loss were identified. Most importantly, the results of the coheating tests revealed that very little difference existed between the measured and the predicted heat loss coefficient of both dwellings, with any difference observed being well within the range of the measurement error associated with the test. This suggests that the dwellings are performing pretty much as designed.

The results also appear to suggest that careful design coupled with the implementation of appropriate quality control systems, such as those required to attain Passivhaus Certification, may be conducive to delivering dwellings that *'bridge the gap'* between measured and predicted fabric performance.

The coheating test also revealed some of the difficulties involved in undertaking such tests in dwellings that are very highly insulated and airtight and have small South-facing rooms in which a large proportion of the external envelope is glazed.

4 Key findings from the design and delivery team walkthrough

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

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

4.1 Introduction

The design and delivery team walkthrough is based upon numerous discussions that have taken place with one of the Passivhaus Designers of the development (the Project Architect) and a walkthrough that was undertaken with the client in November 2012 on a different mid-terraced dwelling that has the same plan form and specification as the test dwellings.

4.2 Design intent compared to as-built

As previously stated in section 1, dwellings 1 and 2 have been designed to Passivhaus standards and Code for Sustainable Homes Level 4. Despite a number of issues were encountered during the construction process, some of which were significant, the design team felt that the original design intentions have been met as both dwellings have achieved Passivhaus Certification and Code for Sustainable Homes Level 4. Dwelling form, layout and space planning was all as intended.

4.3 Replicability of the design

The Project Architect gave a mixed response with respect to replicability of the design. Issues identified by the Project Architect in favour of repeating the design were as follows:

- The client is understood to have a tenant base that appreciates bungalows and the accessibility that this house type offers. The bungalows serve to meet this demand.
- The master planning of the site is agreeable and the spaces between homes are convivial.

Issues identified by the Project Architect that they would not replicate were as follows:

- The form factor of the dwellings (a bungalow) is disadvantageous in terms of Passivhaus design, due to the high surface area to volume ratio. Utilising such a disadvantageous form factor results in additional heat losses that have to be compensated for by increased performance specifications. Utilisation of a more efficient form factor, such as a two or three storey dwelling, can result in lower performance specifications and consequently a reduction in capital costs.
- Space planning restrictions imposed by the client resulting in the plant space (MVHR and solar thermal systems) being located on the mezzanine floor. This is not the preferred option in terms of building maintenance, for instance, changing filters, etc.
- Given that the dwellings were designed to be occupied by elderly residents, the Project Architect understands that homes with stair cases offer the opportunity for greater exercise and can help to reduce the incidence of osteoporosis thus greater health and well-being.

The Project Architect was also asked to identify anything that they would do differently, if they had the opportunity to do so. In addition to the changes highlighted in the previous bullet points (different form factor, not locating plant on mezzanine floor and the use of stairs), the project Architect stated that they would have used some of the improved Passivhaus Certified MVHR units that are now on the market. These units offer higher heat recovery efficiencies and also incorporate an automated rather than manually operated summer bypass. This would improve control during the summer months and reduce the likely risk of overheating. In addition, they would have also used OSB as the primary air barrier, rather than a membrane, as this would have reduced the risk of damage occurring to the primary air barrier as a result of other construction activities.

4.4 Comfort and Control

Feedback from the client indicates that there has been some overheating reported within the dwellings on the development, particularly during the summer. Some of the tenants have attempted to reduce the degree of overheating by opening all of the windows, however, this is not reducing the internal temperatures sufficiently. In warm still days where the external temperature is close to the internal temperature, opening windows will have little effect in reducing overheating, as there will be no wind effect and due to the form of the dwellings having very little stack effect.

The Project Architect has responded to the client by identifying a wide range of measures that can be taken to reduce the risk of overheating. These range from utilising the summer bypass mode on the MVHR systems, changing window opening behaviour and degree of opening, using curtains on South-facing windows to reduce solar gains in summer and switching off non-essential appliances to reduce incidental internal gains.

4.5 Best and worst aspects of the development

The Project Architect was asked to identify the best and worst aspects of the development. The best aspects identified were reduced energy bills and environmental impact, improved comfort in winter and appropriate comfort in summer as long as the dwellings are ventilated correctly.

The worst aspect was deemed to relate to the additional inclusion of solar thermal and photovoltaic systems (these are only installed in certain dwellings within the development). Some concerns were also raised by the Project Architect regarding the usability of the heating system and the controls. The concerns related to the use of all-air-heating and whether the building occupants were able to comprehend the inter-relationship that exists between the space heating and the ventilation system. For instance, if you reduce the amount of ventilation to address relative humidity issues, you will also reduce the indoor temperature that can be achieved. In terms of improving usability, splitting heating and ventilation is, as far as the Project Architect is concerned, considered to be better practice. The concern regarding controls related to an underlying issue that exists in many homes and was not specific to this project.

4.6 Conclusions and key findings for this section

Discussions with the Project Architect and the client have revealed that the finished dwellings have been constructed as intended, despite significant difficulties being encountered during the construction phase. A number of positive aspects of the development were also identified. These included reduced energy bills and environmental impact, improved comfort in winter and appropriate comfort in summer as long as the dwellings are ventilated correctly. Despite this, a number of aspects of the design were identified by the Project Architect that, given the opportunity, would not be replicated in future designs. These related to the use of a disadvantageous form factor of the dwellings (a bungalow) and the placement of the ventilation, heating and hot water services on the mezzanine floor, as this is not ideal for maintenance purposes. In addition, it was also felt that the services were rather complex for tenants and there were concerns associated with the long-term maintenance of the systems.

Feedback from the client and tenants has identified some overheating within the dwellings. A range of measures have been identified by the Project Architect to address this.

5 Evaluation of guidance offered to the occupants and the physical handover process

Technology Strategy Board guidance on section requirements:	It is essential that this section provide a critical evaluation of any guidance provided, therefore there should be an explicit review and critique of the materials used for the handover. The evaluation of the written documentation is a separate exercise from the walkthrough and needs to tackle clarity, comprehensiveness, layout, longevity, ease of access and relevance (i.e. are some aspects season specific). What was the main source of material? Were these written or visual, bespoke or generic? Does the guidance use good English with a comprehensive and user-friendly layout? In addition to the comprehensive handover literature / guidance evaluation, the section should cover the occupier handover process, initial aftercare process, post completion building operation, and initial maintenance and management – particularly in relation to energy efficiency, reliability, building operation and the approach to maintenance i.e. proactive or reactive. The evaluation must cover the use of training and operating manuals, aftercare and any interviews and discussions. The aim is to compare how well the demonstrator uses and communicates the written guidance provided by the developer to the occupant and how well they demonstrate the home. Special attention should be given to how interactive the tour is, and whether the occupant allowed to try things out for themselves or not. It is imperative that the observer does not intervene in the proceedings at any point, but is simply a 'silent witness'. Any conflicting advice given in relation to the functioning of the home or the written guidance provided should be noted with the reason why this has occurred where possible. This will help to improve training of demonstrators where needed or pick up on changes needed to procedures, documentation etc. Was the demonstrator clear on what aftercare entails? How were the handover processes carried out? Were the handover materials (i.e. user manual) used and referred to constantly throughout the handover. How were occupiers trained to use equipment and do they demonstrate the right competences? Was there a proper handover and a system put in place to log problems, and did this help resolve teething issues? If any handover processes were not completed, please detail why. Comment on key findings, conclusions, and lessons learned and investigate recommendations on what would be done differently next time. This walkthrough should be compared and contrasted with the delivery and design team walkthrough (see previous section) with comments on whether the design intent was desired, delivered and valued by the occupant and where and how differences between intent and expectation have arisen. If action was taken to remedy misunderstandings, improve support or feed occupant preferences into future design cycles this should be explained. Ideally the observer should tape the proceedings and analyse a transcript. The occupiers' permission must be sought to do this. If

	recording is not possible, then notes should be taken using the document *TSB BPE Domestic - Guidance on handover and walkthroughs.doc* (available on `_connect') as a guide to establish whether the home demonstrator has communicated all relevant aspects in relation to the written home user guidance provided and manuals.

5.1 Introduction

The materials given to occupants when they moved into the properties were critically evaluated as part of this study, as were the processes by which they were inducted to their new home. This evaluation was then compared to the original aspirations of the design team, and also the initial usage of the property.

Full analysis and evaluation of the handover process can be found within Appendix 6.

4.2 Handover Materials

The main document used to inform the occupant is the 10 page "A Quick Guide to your PassivHaus Home", which was supplied with every dwelling. This offers concise information on PassivHaus, in particular how they differ from more traditional buildings, and the advantages of this. The booklet also gave detail on services that may be unfamiliar to the occupier (e.g. MVHR), with images to familiarise users with the control systems.

Several "door hangers" were placed within the dwelling, on the handles of rooms containing potentially unfamiliar control units. These are short guides with a description and picture of the control unit which offer information at the point of use. These are seen as a novel example of good practice. Occupants were also supplied with an Occupant Pack. This contains all essential information pertaining to the dwelling's services and appliances, including manuals, certification and guarantees. Emergency contact details were also contained within the Occupant Pack.

The "A Quick Guide to your PassivHaus Home" booklet provides a concise and logical introduction to both the occupant's property and the concept and goals of PassivHaus in general. It is very informative without being overbearing, and for the most part uses language and presentation that is accessible to a non-technical audience. Due to the nature of the housing development, this is regarded as very positive. For the occasions when technical language is unavoidable, a glossary may be helpful.

The booklet goes to good lengths to describe the novel features that are present in PassivHaus design, providing helpful illustrations throughout to aid conceptualisation. There is also advice and instruction running throughout the booklet, giving helpful reminders and guidance. One error in the booklet was the misrepresentation of a control unit. In the guide, reference was made to a Honeywell ST6100A timer, when in fact the properties are equipped with Honeywell ST9400A control systems. Although the correct unit was shown in a subsequent section, this may cause confusion. The booklet also does not indicate that other formats are available until page 10. This option should be given on the first page.

The door hangers are a useful reminder, and are a nice addition to the homes, particularly for users unfamiliar with sustainable technology.

The Occupant Pack is not particularly well presented, but it is an essential feature of the home, containing all of the necessary manuals and certificates. The occupant pack would greatly benefit from some form of ordering and contents identification to assist the user in finding information if it is needed.

4.3 Handover process and walkthrough

The physical handover is the process by which new occupants are walked around the dwelling by a member of the buildings team and introduced to the various systems and services contained within. The handover process provides an opportunity for occupants to ask questions and have issues resolved by the buildings team. Following the handover, occupants have ready access to Gentoo should they experience any issues or have any further questions. The process does not represent an end of relationship.

It should be noted that it was not possible to observe an actual handover, so the process was demonstrated to a Leeds Met research in a role play format.

The walkthrough process on the whole was excellent. The information given was thorough and accurate, with demonstrations given of equipment and occupants encouraged to familiarise themselves with equipment. It followed a logical route through the property in order to ensure every room was covered in detail. Care was also taken to make sure that the occupant was happy with all of the services demonstrated, and contact details were given should any issues arise.

The occupant was also informed about maintenance and management of the various services. For example, it is the responsibility of the occupant to maintain air filters for the MVHR system, and that Gentoo will maintain the communal boiler.

4.4 Initial occupant use and design aspirations

It was observed that, during post completion operation, occupants were not opening their windows which led to overheating. This was traced back to earlier advice given to the occupants asking them to avoid opening their windows, as this would reduce the effectiveness of the MVHR heat recovery. This advice is repeated in the booklet. Care should be taken to ensure that the occupants are aware of the reasons why it may be advantageous to leave windows closed (i.e. to enable the recovery of heat from within the dwelling and to prevent over ventilation). However, it should also be pointed out that they do have the freedom to open windows as they please, and may need to do so, particularly in the summer months. It should be pointed out that intermittent opening of windows should not have an adverse impact on the operation of the MVHR system, unless the windows are left open for an extended period of time.

Overall, occupants appeared to be happy with the novel systems installed in their homes. The development offers excellent support, so any questions or issues could be quickly addressed.

5.2 Conclusions and key findings for this section

The materials and walkthrough process given were found to be of a high standard, providing sufficient guidance to allow occupants to understand and enjoy their homes. Of particular note were the good presentation of the guide booklet, and the use of 'door hangers' on novel equipment to quickly familiarise the occupants. The only real issue with the printed materials was that of the incorrect image for a temperature control unit. This is an error that can be quickly remedied, and was not envisaged to have had any lasting negative impact.

The walkthrough process was thorough and helpful, providing occupants with a good opportunity to have any questions answered. This was reinforced by providing contact details in case any further questions should arise at a later date.

There was an issue of overheating in some homes as a result of keeping windows closed during summer, which was traced back to guidance concerning the MVHR unit given to occupants. This has since been remedied, but should be taken into consideration for future projects.

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

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

6.1 Introduction

A total of 27 BUS questionnaires were distributed to residents, of which 21 were completed and returned. 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.

6.2 Key findings from BUS questionnaires

On the whole, occupants displayed satisfaction with their properties, with the majority of question categories returning positive feedback. There were some exceptions, however, which are highlighted below with possible explanations for their occurrence.

- **Air quality –** Results show that occupants found the air quality in the properties to be too still during both summer and winter, with additional concerns about air being excessively humid in summer. One possible reason for this could be incorrect use of the MVHR system, which should have provided sufficient fresh air to the dwelling. It is likely, however, that this is due to a combination of the residents in question and incorrect window use. It was noted during occupant feedback that some residents had been confused by the advice to keep windows closed to improve MVHR efficiency, and interpreted it as an instruction to not open windows. As many residents are aged slightly older, they may perceive the air to be still and stuffy as they have not opened windows for fresh air – not realising that their needs were being met by the MVHR system.
- **Temperature –** Many residents have said that they find the temperature in the dwelling too hot, both in summer and winter. This may be due to a combination of several factors, incorrect MVHR operation, the influence of a large South-facing glazed façade, leaving windows closed and thermostats not set at an appropriate level or not functioning correctly. As was mentioned, many residents did not open their windows because they were concerned about security issues while leaving their windows open. Therefore, they did not purge the dwelling, which could have led to the overheating issues. It is also not known of the thermostats were operating correctly or were set at an appropriate level – this should be investigated. These issues are certainly something to be aware of and address in future projects of a similar nature.
- **Noise levels –** Feedback indicated that many residents found noise levels to be too quiet. It is assumed that this is a direct result of the dwelling being away from roads and made of materials with superior soundproofing to the occupant's previous property. It should also be noted that this is not a negative aspect of the dwellings – feedback indicated that residents liked this feature of their homes.
- **Light levels –** Both natural and artificial light levels were thought to be slightly higher than the benchmark in the dwellings. This is assumed to be a result of the large, South-facing glazed surface that lights the main living area. Again, this is a feature that is largely subjective, with some residents enjoying the light, airy feeling of the open plan space. This issue is easily resolved with shading for the windows. Overall, the majority of the residents felt that lighting was satisfactory. Despite this, some residents commented that the large bedroom can get too dark and that the low energy pendant light bulbs were too dim.
- **Heating bills** – Some tenants have highlighted electrical bills which are larger than would be expected this is likely due to the increase of electricity tariffs throughout the UK. The tenants have not received a gas bill for the property for their heating requirements; however this is likely to be greater than what was first expected due to the increase in gas prices.

6.3 Conclusions and key findings for this section

Of the feedback received, the overall consensus was that the dwellings were of high quality, with residents enjoying living in them and happy with their performance. In terms of negative aspects, the key area of concern is that of overheating, which hopefully will be lessened now that residents have been properly instructed on the use of their windows, and the ability to purge the dwellings.

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

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

7.1 Introduction

As both dwellings are built to Passivhaus standards, the space heating energy demand is very low, so a conventional wet central heating system is not required. Instead, space heating is provided via a small low temperature hot water heater battery installed in the MVHR ductwork, which heats the fresh air supplied to the dwelling from the MVHR system. In addition to the heater battery, a heated towel radiator is provided in the bathroom, along with a small radiator in the drying cupboard. Hot water to the heater battery, towel radiator and small drying cupboard radiator are supplied from a communal boiler, a 38kW Valiant Ecotec plus 438 gas-fired wall-hung boiler, which is located in a small boiler room on the East end of the terrace. The communal boiler supplies hot water to all seven of the dwellings in the terrace via a communal heat main.

Control of the heater battery is provided via a thermostat located in the living room and a 24 hour programmer (this also controls the water heating) located in the drying cupboard. The heating has been pre-programmed to run continuously throughout the day. Although this is not the most accessible location for the programmer, it has been intentionally located in this position to avoid the occupant altering the time control of the heating. The small radiator located in the drying cupboard is controlled via a touchstat in the drying cupboard, which is operated manually and incorporates a boost setting. The towel radiator is controlled both by the room thermostat in parallel with the duct heater, and also via a manually operated boost switch located in the hall, enabling the towel radiator to be activated for a 30 minute, 1 hour or 2 hour period when heating is not otherwise needed.

The communal heat main also supplies hot water to a 200 litre unvented POWERflow 2000 indirect hot water cylinder, located in the mezzanine loft space in both dwellings. This cylinder has a twin coil, with input from the communal heat main and a Viridian V260 solar hot water system, which has a 3m^2 single roof-mounted collector on the South-facing roof slope. A normal cylinder thermostat and heating programmer is used to control boiler input into the cylinder.

Ventilation is provided via a Paul Atmos 175 DC whole house MVHR system which incorporates a frost protection heater. This is installed in the mezzanine loft space of both dwellings. Boost operation of the unit is provided via a manually operated fan boost switch located in the hall or in the kitchen. A remote control keypad, used to control and program the operation of the MVHR unit, is located on the wall inside the drying cupboard

In terms of internal lighting, pendant or batton lamp holders have been installed in the living area, kitchen and bedrooms of both dwellings, In addition, an IP X4 luminaire has been installed in the bathroom.

7.2 Installation and commissioning checks

Commissioning data was provided for the space and hot water heating system and the MVHR system. The information provided for each service varied considerably and comprised a checklist for the space heating system, a site inspection record for the solar hot water heating system and a series of duct flow measurements for the MVHR system. An analysis of this data revealed that a number of issues had been identified when commissioning the hot water heating system and that these had been rectified. No issues were identified with the space heating system or the MVHR system.

Observations were also undertaken on the space and hot water heating system, the MVHR system and the lighting system. These revealed that the space and hot water heating system had been installed to a very high standard and the vast majority of the exposed pipes in the loft space were very well insulated. However, there were one or two locations where the insulation had been cut slightly short, the insulation was not generally continuous over fittings and at supports and there was a small section of pipework near the base of the hot water cylinder that was uninsulated.

In terms of the MVHR system, it was clear that all visible ductwork had been installed to a very high standard, considerable care had been undertaken to insulate the ductwork where required and supply grilles had been individually adjusted to meet individual room requirements.

With regards to the lighting system, the wall-mounted luminaires that were originally identified within the electrical services specification for the living area, kitchen and bedrooms have been replaced with pendant or batton lampholders. The reasons for the change in luminaires was due to a change in the electrical engineer for the project, coupled with the fact that the client decided that the pendants and battons would be easier to maintain and more cost effective than wall-mounted luminaires. An IP X4 luminaire has been installed in the bathroom.

Further details relating to the installation and commissioning checks can be found within Appendix 7.

7.3 MVHR duct flow measurements

A series of MVHR supply and extract duct grille flow measurements were also undertaken on dwellings 1 and 2.These revealed that in both dwellings, the whole house supply and extract rates were balanced and both units satisfied the ventilation requirements contained within Part F of the Building Regulations. However, the measurements also highlighted that the total supply and extract flow rates were higher than the design flow rates, in some cases by almost 50%. The reason for this was felt to be attributed to the manufacturer supplying fans with a higher minimum flow rate than originally intended. In addition, some small differences in grille measurements were observed between those undertaken by the LeedsMet team and those undertaken by the external contractor. These differences were felt to be attributable to differences in the equipment used to undertake the measurements, particularly relating to those air flow grills that exploit the ‘coanda’ effect.

Further details regarding to the MVHR duct flow measurements can be found within Appendix 7.

7.4 Conclusions and key findings for this section

The commissioning data along with the observations and MVHR duct flow measurements suggest that overall, the services within both dwellings have been installed and commissioned correctly. An analysis of the commissioning data revealed that the amount of data provided for each service varied considerably and there does not appear to be any standardised method of commissioning particular services. The development of a standardised method would be useful and would enable comparability between dwellings.

Observations of the services indicate that considerable care has been taken when installing the services and they have all been installed to a very high standard. In addition, the vast majority of the exposed hot water pipework located within the mezzanine plant area is very well insulated with only a few small areas of pipework where the insulation is discontinuous – this generally occurs over fittings and supports. However, it is common for these areas of pipework to be uninsulated in new dwellings.

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.

8.1 Observations during coheating test

During the coheating tests, it was observed that large quantities of water had accumulated in the frost protection units of the MVHR systems. The reason for this was thought to be attributable to warm, moisture laden air from within the dwellings entering the MVHR system ductwork, either through gaps in the (as yet uninsulated) ductwork or around the temporary sealing of the supply air valves. This air was then being driven through the unit to the outside, and at some point between the supply air duct intake from outside and the frost protection unit, the moisture laden air was being reduced below its dew point temperature, resulting in water droplets forming within the ductwork. These droplets were then flowing down the inside face of the ductwork and accumulating in the base of the frost protection unit.

8.2 Conclusions and key findings for this section

The accumulation of significant quantities of water in the frost protection unit of the sealed MVHR units has a number of important implications regarding undertaking coheating tests in dwellings that have high internal humidity, are airtight and have an MVHR system installed. In these instances, it may be more appropriate to seal the MVHR system at the intake and exhaust connections to the main unit, rather than at the individual supply and extract grilles to the individual rooms, when undertaking such tests.

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 Key findings

The main findings from this report are as follows;

- It is clear from the design review that a number of changes were made to the design during the construction. In addition, the design and construction team also experienced a number of significant challenges during the construction process, the majority of which were completely out of their control. Despite these changes and challenges, the dwellings were constructed pretty much as intended. In fact, the as-built U-values for all of the elements of the building fabric were lower than those that were used to inform the original design. Given this, the design and construction team should be commended.
- The construction observations highlighted a number of issues that had the potential to have an adverse effect on the measured performance of the test dwellings, if not adequately addressed. An analysis of the pressurisation test results and the coheating data indicates that both dwellings have been built to a very high standard with considerable attention given to the detail. Both dwellings not only achieved very high levels of airtightness (0.49 and 0.50 h^{-1} @ 50Pa for dwellings 1 and 2 respectively), but also achieved a measured heat loss coefficient that is in very close agreement with the predicted heal loss coefficient (measured value of 46.7 and 43.4 W/K, respectively as opposed to a predicted value of 38.1 and 36.6W/K, respectively), with the difference in heat loss being well within the range of the measurement error associated with the test. In addition, the measured effective U-values were close to the nominal design U-values for each of the building elements in the majority of cases, and no significant areas of unexpected heat loss were identified. This suggests that the issues highlighted during construction were either rectified at a later stage during the construction phase, or had little effect on the eventual airtightness and thermal performance of the dwellings.
- The commissioning data along with the observations have revealed that overall, the type of services that were originally designed and specified to be installed within the dwelling, have actually been installed, and have been installed in accordance with the original design. An analysis of the data also revealed that the amount of data provided for each service varied considerably and there does not appear to be any standardised method of commissioning particular services.
- Observations of the installed services revealed that considerable care had been taken when installing the services and that they had all been installed to a very high standard. Despite this, there are a few small areas of pipework where the insulation is discontinuous – this generally occurs over fittings and supports. However, it is common for these areas of pipework to be uninsulated in new dwellings. These areas of uninsulated pipework are likely to result in increased heat loss. In the summer months, the unintentional increase in incidental gains from this pipework may contribute to overheating within the dwelling. This will need to be closely monitored to ensure that this is not the case.
- A number of positive aspects of the development have been identified. These have included reduced energy bills and environmental impact, improved comfort in winter and appropriate comfort in summer as long as the dwellings are ventilated correctly.

- A number of aspects of the design were identified by the Project Architect that, given the opportunity, would not be replicated in future designs. These related to the use of a disadvantageous form factor of the dwellings (a bungalow) and the placement of the ventilation, heating and hot water services on the mezzanine floor, as this is not ideal for maintenance purposes. In addition, it was also felt that the services were rather complex for tenants and there were concerns associated with the long-term maintenance of the systems.
- The materials and walkthrough process were found to be of a high standard, providing sufficient guidance to allow occupants to understand and enjoy their homes. Of particular note were the good presentation of the guide booklet, and the use of ‘door hangers’ on novel equipment to quickly familiarise the occupants.
- The walkthrough process was thorough and helpful, providing occupants with a good opportunity to have any questions answered. This was reinforced by providing contact details in case any further questions should arise at a later date.
- Of the feedback received, the overall consensus was that the dwellings were of high quality, with residents enjoying living in them and happy with their performance. In terms of negative aspects, the key area of concern is that of overheating in some of the dwellings. Part of the reason for this relates to the occupants keeping windows closed during summer, which was traced back to the guidance given concerning the MVHR unit. A range of measures have been identified by the Project Architect to address this.

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 as follows:

- A number of areas of good construction practice were observed which should be dissemination to the wider industry. For instance, significant attention to detail was given to airtightness, with considerable care taken to ensure continuity of the air barrier membrane around openings, such as windows.

- The coheating test highlighted some of the difficulties involved in undertaking such tests in dwellings that are very highly insulated and airtight and have small South-facing rooms in which a large proportion of the external envelope is glazed. These difficulties need to be considered when undertaking coheating tests on such dwellings.

- The results of the various fabric tests appear to suggest that careful design coupled with the implementation of appropriate quality control systems, such as those required to attain Passivhaus Certification, may be conducive to delivering dwellings that begin to *'bridge the gap'* between measured and predicted fabric performance.

- The accumulation of significant quantities of water in the frost protection unit of the sealed MVHR units during the coheating tests has a number of important implications regarding undertaking coheating tests in dwellings that have high internal humidity, are airtight and have an MVHR system installed. In these instances, it may be more appropriate to seal the MVHR system at the intake and exhaust connections to the main unit, rather than at the individual supply and extract grilles to the individual rooms, when undertaking such tests.

- There does not appear to be any standardised method of commissioning particular services. The development of a standardised method would be useful and would enable comparability between dwellings.

11 References

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

1. JOHNSTON, D. MILES-SHENTON, D. and SIDDALL, M. (2012) Post Construction and Early Occupation Study, Sunderland – Design and Construction Review. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. July 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
2. JOHNSTON, D. MILES-SHENTON, D. WINGFIELD, J. and FARMER, D. (2012) Post Construction and Early Occupation Study, Sunderland – Pressurisation Test Report. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. July 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
3. JOHNSTON, D. MILES-SHENTON, D. FARMER, D. and WINGFIELD, J. (2012) Post Construction and Early Occupation Study, Sunderland – Coheating Test Report. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. July 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
4. JOHNSTON, D. FARMER, D. MILES-SHENTON, D. and WINGFIELD, J. (2012) Post Construction and Early Occupation Study, Sunderland – Heat Flux Measurement Report. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. July 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
5. FARMER, D, JOHNSTON, D. and MILES-SHENTON, D. (2011) Post Construction and Early Occupation Study, Sunderland – Thermography Report. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. November 2011. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
6. JOHNSTON, D. and FLETCHER, M. (2012) Post Construction and Early Occupation Study, Sunderland – Evaluation of guidance offered to the occupants and the physical handover process. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. December 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
7. JOHNSTON, D. and MILES-SHENTON, D. (2012) Post Construction and Early Occupation Study, Sunderland – Installation and Commissioning Report. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. July 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.