Lancaster co-housing development (Forgebank)

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Innovate UK project number	450095
Project lead, authors, and client	University of Sheffield and Leeds Metropolitan University for Lancaster Co-housing Development
Report date	2013
InnovateUK Evaluator	N/A (Contact via www.bpe-specialists.org.uk)

No of dwellings	**Location**	**Type**	**Constructed**
Six	Lancaster	Detached	2012
Area	**Construction form**	**Space heating target**	**Certification level**
N/A	Full-fill masonry cavity	15 kWh/m^2 per annum	PassivHaus & CSH Level 6

Purpose of evaluation

The scope of the project was limited to the post-construction and initial occupation stage. Lancaster Co-housing development was a 41 dwelling affordable community housing project, comprising a range of dwelling types. 35 of the dwellings were within the co-housing scheme. All dwellings on the development were designed to Passivhaus standards, Lifetime Homes and Level 6 of the Code for Sustainable Homes. The project covered the post-construction and initial occupation stage and consists of a combination of physical tests alongside occupancy studies. These included co-heating tests, air-pressurisation tests, SAP check, and design and construction review, and occupant interviews and walkthroughs.

Design energy assessment	**In-use energy assessment**	**Sub-system breakdown**
Partial	No	No

The key findings from the project were that the housing construction and occupancy performance largely fulfilled the design intentions. Measured heat loss for the test dwelling of 47.1 W/K compared with a predicted heat loss coefficient of 39.0 W/K – a difference of just over 8 W/K. The dwelling tested was exceptionally airtight with a value of just less than 0.6 m^3 (m^2.h) @ 50 Pa. Design, construction, installation and commissioning procedures were all very thorough indicating that a Passivhaus helps to close the traditional performance gap that exists in housing. The occupants are exceptionally satisfied with their homes overall, although there are a number of improvements that could be made to the user handover, guidance, and usability of environmental controls

Occupant survey type	**Survey sample**	**Structured interview**
BUS survey on 6 households	36 of 36 (100 % response rate)	Yes

A Building Use Studies (BUS) survey was undertaken. 36 responses were obtained out of 36 questionnaires delivered (100%). Overall, the results produced were excellent. Residents are very positive about this development and how well it performed. Theeight summary variables covering air, comfort, design, perceived health, lighting, needs, noise and temperature are all higher or better than the UK 2011 BUS housing benchmarks.

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.

The Lancaster Co-housing development is a 41 dwelling affordable community housing project, comprising a range of dwelling types, from one bedroom apartments up to three bedroom family houses. 35 of the dwellings are within the co-housing scheme, which utilise shared community facilities. All of the dwellings on the development have been designed to Passivhaus standards, Lifetime Homes and Level 6 of the Code for Sustainable Homes. The development is intended to be the first Passivhaus certified Co-housing scheme in the UK, and it is also believed to be second largest Passivhaus development in the UK. The south facing housing is part of an ambitious re-development of a disused mill site nestling on the north bank of the river Lune just east of Lancaster. This includes a mill building converted into a business centre, a Common House, communal storage, guest rooms, childcare space, a car club, cycle storage facilities and a cycle repair workshop area, a planned mini-hydro scheme and photovoltaic array with a communal micro-grid. Further detail on the building types, form and materials is contained in Section 2.

This Technology Strategy Board Building Performance Evaluation project no. 450095 was carried out by The University of Sheffield (occupancy studies and design team interview) and Leeds Metropolitan University (construction review and physical testing) in association with Closed Loop Projects. The studies were carried out over a six month period from October 2012 to March 2013.

The scope of the project is limited to the post-construction and initial occupation stage and consists of a combination of physical tests alongside occupancy studies. These include a co-heating test to establish a firm basis of fabric performance, air-pressurisation tests, SAP check, design and construction review, thermographic survey, heat flux measurements, installation and commissioning review of systems and services, design team and occupant interviews and walkthroughs, Building User Survey questionnaire, handover and home user guidance reviews and a usability review of control interfaces.

The key findings from the project are that the housing construction and occupancy performance has largely fulfilled the design intentions. Measured heat loss for the test dwelling of 47.1 W/K compared to a predicted heat loss coefficient of 39.0 W/K – a difference of just over 8 W/K. The dwelling tested was exceptionally airtight with a value of just less than 0.6 $m^3.h^{-1}.m^{-2}$ @ 50Pa. Design, construction, installation and commissioning procedures were all very thorough indicating that a Passivhaus approach may well help to close the traditional performance gap that exists in housing. The occupants are exceptionally satisfied with their homes overall, although there are a number of improvements that could be made to the user handover, guidance, and usability of environmental controls. This demonstrates the level of satisfaction that can be achieved when there is a participatory design approach in place.

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

The test dwelling is a two bedroom two storey dwelling comprising a South-facing open-plan living/kitchen area which runs the full depth of the dwelling, an under stairs cupboard that houses the hot water cylinder and a downstairs toilet. On the first floor there is a South-facing master bedroom, a bathroom and a North-facing bedroom/study. Plans and elevations of the dwellings are illustrated in Figure 1 and Figure 2.

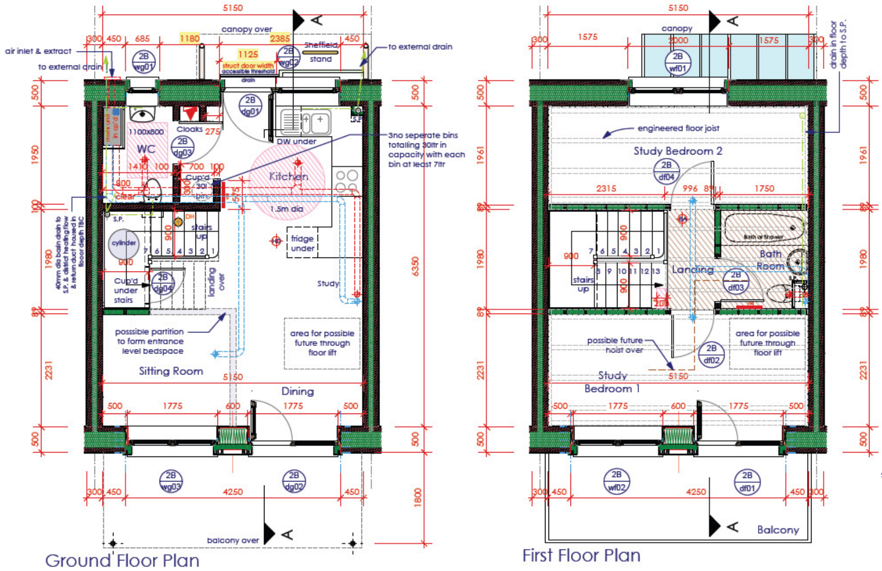

Figure 1 Ground and first floor plans of the test dwelling.

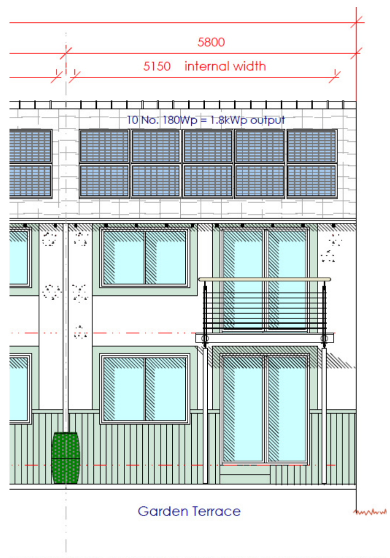

Figure 2 South-facing elevation of the test dwelling.

The majority of the external walls of the test dwelling are Full-fill masonry cavity, comprising 8-10mm render, 100mm blockwork, 300mm mineral wool, 100mm blockwork and wet plaster. On the South-façade, the in-fill panels between the windows and the patio doors comprise 12.5mm plasterboard with skim, 25mm wide service void battened out using 25 x 50mm timber battens, 9mm OSB sheathing board, 300mm mineral wool insulation between a 38 x 300mm timber frame, 9mm OSB sheathing, 100mm wood fibre insulation, 50 x 70mm timber battens and 9mm fibre cement cladding board. On the North façade, below the windows, the masonry external wall is clad with 10mm fibre cement weatherboarding on 38 x 50mm timber battens. The ground floor comprises 22mm thick tongue and grooved softwood floating floor over 150mm reinforced concrete ground bearing floor slab on 250mm of EPS insulation. The roof is a bobtail trussed rafter pitched roof construction insulated at the ceiling level with 500mm of mineral wool. The windows and doors are triple glazed low-e argon filled glazing units with 'warm edge' spacers installed within aluminium clad timber frames.

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 documentation. In addition, the target design air leakage rate for the dwelling was ≤0.6 ac/h @ 50Pa.

Element	**U-value (W/m^{2}K)**
Ground floor	0.13
External walls	0.13
Roof	0.10
Windows	< 0.80
Doors	< 0.80

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

2.2 Design review

A design review was undertaken on the test dwelling (see Appendix 1). It is evident that the transport strategy has informed the site layout. The design seeks to reduce car use and predominately locates parking to the edges of the site. The Co-housing development has implemented a car share scheme to encourage low car ownership and the design includes a large amount of cycle storage.

It was evident that significant attention was paid to airtightness during the design stage. The target air leakage rate was ≤ 0.6 ac/h @ 50 Pa. The design documentation contained a number of good practice items. Drawings indicated the location of air and wind barriers. Design review meetings were to be held between the Architect and the Contractor. The Contractor was to designate an Airtightness Champion. Air pressure tests were to be undertaken at intermediate work stages to monitor performance. Service penetrations were limited with the mains brought in through the floor and sealed for airtightness. It was acknowledged that some services, for example, the MVHR intake and exhaust, the soil vent pipe and telecommunications, had to penetrate other elements of the building fabric.

The design had paid significant attention to the limitation of thermal bridging. However, the information viewed did indicate that the thermal modelling of opening heads was not undertaken in accordance with the conventions required by Building Regulations. The thermal modelling of the opening heads included the glazing unit and frame but these should have been represented by an adiabatic boundary in accordance with the convention. This is because the thermal bridging associated to the frame is accounted for in the U-value calculations for windows and doors. In addition, the close proximity of the opening heads to other junctions meant that the adjacent thermal bridges should have been included in the thermal models of the opening heads. The information viewed indicated that two dimensional software was generally utilised for the thermal modelling of junctions but this raised a question of whether appropriate three dimensional software was used to thermally model the ground floor/separating wall junction as required by the conventions. An example of the good practice that was adopted is where the design documentation stipulated the undertaking of thermographic surveys during the construction process to confirm the continuity of insulation.

The Passivhaus Planning Package (PHPP) was used to model and verify the design for Passivhaus Certification purposes. This software package is an inherent part of the design methodology adopted but it could not be used to demonstrate regulatory compliance in the UK. Therefore, a set of SAP calculations were required as part of the Building Regulations process. The SAP calculations for the design and the as-built dwelling were compared with the following issues identified:

- The dwelling dimensions input to the calculations do not match the architectural drawings.
- The as-built calculation included a roof design that was amended during an earlier design.
- Not all construction types present were included in the calculations and those that were differed from the design requirements.
- No supporting calculations were provided for the y-value used.
- A draft lobby was included but the design did not incorporate this feature.
- The primary heat source and hot water cylinder input to the SAP calculations differed from those specified.
- There was no difference between the input and output information between the final design and as-built calculations.

The architectural information was not co-ordinated in accordance with conventions. Only the architectural information was provided in a comprehensive enough set during the design review for comments to be made.

The NEC two stage partnering contract used enabled the Contractor to input on buildability issues and gave reassurance of a guaranteed maximum price. This approach led to a change of roof design during the design process making a significant cost saving. However, it did not entirely resolve some of the detailing issues. Later changes were made to the design of the wind posts to prevent penetration of the air barriers during the construction phase but this was caught early enough to limit the impact on the works.

2.3 Construction review

Although it was only possible to undertake a limited number of site observations on the test dwelling 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. In addition, a number of areas of good practice were observed. These included: well-sealed service penetrations and wind posts, appropriate sequencing of the parging coat, effective sealing around windows using the correct airtightness tapes and the effective use of airtightness tapes a ceiling/wall junctions.

However, the observations did also 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:

- Some gaps were observed in the external insulation that was used as shuttering for the concrete floor slab and between the layers of cavity wall insulation.
- Use of a steel UB to form the lintel above the first floor patio doors. It was not observed how continuity of the insulation layer or air barrier would be achieved around this beam.
- Some gaps were observed in the party wall insulation at roof level and the bed joints in the blockwork at the head of the party wall were not fully filled.
- Discontinuity in insulation layer at the eaves.

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 2.

2.4 Conclusions and key findings

A design and construction review was undertaken on a two bedroom two storey end-terrace property that was the subject of a co-heating test. The property was designed to Passivhaus, Code for Sustainable Homes (CSH) Level 6 and Lifetime Homes Standards. It is evident from the design information made available that a substantial effort has been made to create high performance dwellings. The design standards were established early in the design phase. The method of working adopted by the Project Team and the procurement route selected facilitated the realisation of the chosen design standards. The main criticisms made concerned the inaccurate input of data to the SAP calculation and the coordination of the design documents. However, the actual design was considered to be of a very high standard.

The construction observations revealed that overall the dwellings were being built to a very high standard with considerable attention given to the detail. A number of areas of good practice were observed. These included: well-sealed service penetrations and wind posts, appropriate sequencing of the parging coat, effective sealing around windows using the correct airtightness tapes and the effective use of airtightness tapes a ceiling/wall junctions. 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 to the 29th January 2013 inclusive. It comprised:

- A series of pressurisation tests and leakage detection.
- A coheating test.
- A series of heat flux measurements.
- A number of thermographic surveys.

3.2 Pressurisation testing and leakage detection

As the test dwelling was designed to Passivhaus standards, the air leakage target for the dwelling was $\leq 0.6\ h^{-1}$ @ 50Pa. In order to achieve this target, a well though through, properly designed and communicated primary air barrier was incorporated within the dwelling along with an appropriate airtightness testing strategy.

A total of 4 pressurisation tests were undertaken on the dwelling; one a few weeks after practical completion, one immediately prior to and immediately after the coheating test and a spot 50Pa pressure equalisation test. The tests revealed that the test dwelling is very airtight by UK standards ($<0.6\ m^3.h^{-1}.m^{-2}$ @ 50Pa) and that there was no measureable air leakage between the test dwelling and the adjacent mid-terraced dwelling. As to be expected with a dwelling with such high levels of airtightness, very few leakage points were identified within the dwelling, with only small amounts of leakage being observed at the patio door in the master bedroom and around service penetrations under the kitchen sink. In addition, a spot 50Pa pressure equalisation test indicated that there was no measurable air leakage between the test dwelling and the adjacent mid-terrace dwelling.

The pressurisation tests also revealed that the dwelling did become very slightly leakier following completion of the coheating test. Thermal images revealed that this was likely to be attributable to additional air leakage making its way through the mitred joints on the fixed window lights, which had opened up slightly as a result of the shrinkage/drying out that had occurred during the coheating test.

A comparison of the tests undertaken by LeedsMet and the external contractor was also undertaken. Even when differences in methodological approach were taken into consideration, significant differences in the results were obtained. Closer analysis revealed that this was attributable to error in the areas and volumes used by the external contractor. The figures used by the external contractor were much greater, as they related to a 3 bedroom property, rather than a 2 bedroom property.

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

3.3 Coheating tests

The coheating test was undertaken on the test dwelling between the 8th and the 29th January 2013. Unfortunately, it was not possible to control access or heat input to the adjacent mid-terraced dwelling throughout the coheating test period, as this dwelling was occupied. However, it was possible to place a number of temperature/humidity sensors in this dwelling during the duration of the test.

For the majority of the test period it was possible to maintain all of the rooms at the mean elevated temperature of 25°C. However, on a number of occasions, the temperature in the South-facing living area and bedroom rose to over 28°C and almost 30°C, respectively, for a short period of time. These peaks in temperature correlate with periods of high solar insolation. The peaks in temperature measured during the coheating test highlight the difficulties of 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.

The test results revealed a difference in the heat loss coefficient, with the measured heat loss coefficient being greater than that predicted. Whilst an analysis of the data revealed that in overall percentage terms the difference between measured and predicted appeared to be large, at just over 20%, in absolute terms the difference in heat loss coefficient was in fact very small – measured heat loss of 47.1 W/K compared to a predicted heat loss coefficient of 39.6 W/K – a difference of 7.5 W/K. If this result is compared to the results of some 22 other new build coheating tests undertaken by LeedsMet, it is clear that the dwelling is one of the best performing dwellings in the sample.

Further details relating to the coheating test can be found within Appendix 4.

3.4 Heat flux measurements

During a two-week period in the coheating test, 20 heat flux plates were strategically positioned at various locations on the test dwelling's thermal elements. These plates measured the heat flux density at one minute intervals through each location; measurement of the air temperature on either side of the thermal element was also recorded. Measured values for heat flux density and air temperature were used to calculate in-situ effective U-values for the majority of the dwelling's thermal elements. It must be noted heat flux measurements were obtained from only a small proportion of the total thermal element surface area during a limited period following building completion, and that heat flux plate positioning was hampered due to the form and orientation of the test dwelling; therefore effective U-values presented may not be representative of each thermal element as a whole.

Measurements obtained on the masonry section of external wall, at the location least influenced by thermal bridging, resulted in a calculated mean effective U-value of 0.18 W/m^2K, with a standard deviation of 0.004 W/m^2K. Effective U-values at this location ranged between 0.16 W/m^2K to 0.19 W/m^2K. This value represents a discrepancy of 0.05 W/m^2K from the specified design value of 0.13W/m^2K. The discrepancy is outside the range of error associated with the test procedure, the reason for its magnitude could not be established using construction observations and non-destructive testing methods available to the research team. It is entirely feasible that had it been practical to undertake heat flux density measurements on the larger and unbroken expanse of masonry external wall on East façade, a lower effective U-value might have ensued. Measurement of heat flux density was not undertaken on the timber in-fill panel section of external wall on the South façade due to the effects of direct solar radiation.

The mean effective U-value calculated from heat flux density measurements obtained at two locations on the roof was 0.09 W/m^{2}K, with a standard deviation of 0.001 W/m^{2}K. Effective U-values ranged between 0.09 W/m^{2}K to 0.10 W/m^{2}K. The calculated U-value compares favourably with the specified design value of 0.10 W/m^{2}K.

The mean effective U-value calculated from heat flux density measurements obtained at two locations on the ground floor, in the period after the slab reached thermal capacity, was 0.14 W/m^{2}K, with a standard deviation of 0.005 W/m^{2}K. Effective U-values ranged between 0.13 W/m^{2}K to 0.15 W/m^{2}K. The calculated effective U-value suggests that the ground floor performs favourably with the specified design U-value of 0.13 W/m^{2}K.

The mean calculated centre pane effective U-value for the door on the North façade was 0.63 W/m^{2}K, with a standard deviation of 0.010 W/m^{2}K. Daily effective U-values ranged between 0.61 W/m^{2}K to 0.64 W/m^{2}K. The mean calculated centre pane effective U-value for the kitchen window was 0.66 W/m^{2}K, with a standard deviation of 0.011 W/m^{2}K. Daily effective U-values ranged between 0.64 W/m^{2}K to 0.67 W/m^{2}K. Both measurements suggest thermal performance close to the design specification of <0.60 W/m^{2}K.

It was not possible to perform measurements of heat flux on either side of the party wall; therefore the effective U-value of the party wall could not be ascertained with any degree of confidence. Heat flux density measurements undertaken on the party wall within the test dwelling combined with temperature readings from the test and adjacent dwellings during the test period; suggest that the party wall was not acting as a significant heat loss mechanism to the external environment, performing close to the design value of 0 W/m^{2}K.

Heat flux density measurements undertaken on the test dwelling revealed that all the thermal elements measured, with the exception of the masonry external wall, performed very close to their specified design U-values and all of the elements performed to a level expected of a dwelling designed and constructed to Passivhaus standards.

Further details relating to the heat flux measurements can be found within Appendix 5.

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. However, there were a number of areas where unexpected heat loss had been identified. The most significant area was at the external wall/eaves junction (both internally and externally) where the insulation had not been installed correctly. A temporary loft hatch was made in the test dwelling and remedial works were undertaken to rectify the insulation. Despite the remedial work, subsequent surveys still identified some unexpected heat loss at this junction, although to a much lesser degree. Other areas of unexpected heat loss included: two spots above the utility area at intermediate floor height, at lintel edges (particularly on the gable wall), at the MVHR system exhaust and supply grilles(externally) at the soil pipe (externally), at the eaves junction with the North façade, at the external door handles (internally) and around the temporary loft hatch (internally). In addition, hot spots were also identified on the path on the North elevation of the terrace. The reasons for these are unknown and require further investigation

Further details relating to the thermographic survey can be found within Appendix 6.

3.6 Conclusions and key findings for this section

A series of fabric tests have been undertaken on the test dwelling. These tests have revealed that the test dwelling is very airtight by UK standards and that the measured effective U-values tended to be close to the specified design U-values for each of the building elements, with the exception of the masonry external wall. The reasons for this are unknown and require further investigation. In addition, some significant areas of unexpected heat loss were identified during the thermal imaging surveys, most notably at the external wall/eaves junction. Although remedial works were undertaken to rectify this issue, thermal imaging has revealed that additional heat loss is still occurring through this junction, but to a lesser extent.

The coheating test did reveal a small difference in the heat loss coefficient (7.5 W/K), with the measured heat loss coefficient being slightly greater than that predicted (47.1 W/K as opposed to 39.6 W/K). If this result is compared to the results of some 22 other new build coheating tests undertaken by LeedsMet, it is clear that the dwelling is one of the best performing dwellings in the sample.

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 begin to *'bridge the gap'* between measured and predicted fabric performance.

The coheating test also 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 pressurisation testing work has revealed a number of lesson/messages that would be of benefit to the wider industry. These lessons are as follows:

a) It is possible to construct very airtight cavity masonry dwellings in the UK. However, this is likely to require:
    - A well thought through, properly designed and properly executed primary air barrier.
    - Adoption of a formal well communicated airtightness target.
    - Plans and details annotated to include information on airtightness
    - Inclusion of an airtightness testing strategy into the construction programme that enabled the dwelling to be pressure tested at various different stages of construction.
    - Well communicated construction strategy and training programme for on-site personnel.

b) It is imperative that the correct areas and volumes are used when calculating the air permeability and air leakage rates, particularly if a very high level of airtightness has been specified. Even if an airtightness testing regime has been incorporated into the construction programme, if the wrong figures have been used, then there is a risk that construction could progress on the assumption that the dwelling is within the specified airtightness target, when in reality it may not be. This may result in the dwelling failing the post completion test. Undertaken airtightness remedial work at post completion stage is practically difficult and expensive.

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 Interview was conducted as a Teleconference on 26th November 2012 for one hour because it was impossible for all members of the team to find a mutually convenient date within the programme time frame allocated to attend the site. The consultant had previously walked through the entire site, a typical home and the unfinished Common House building with the Client Project Manager in order to familiarise herself with all aspects of construction prior to the interview.

The interview included the Client Project Manager, the Project Architect, the Mechanical and Electrical Engineer (referred to as the 'M&E Engineer') and the Civil/Structural Engineer. The Contractor was invited to attend but did not respond, due to the site still being developed and at a critical stage at the time of the interview.

The interview consisted of 11 semi-structured questions with additional prompts under each question to obtain a wide range of views on the design intention and performance of the development (see Appendix 7 for the Interview Guide). The questions were deliberately designed to capture information concerning the difference between co-housing and ordinary housing developments.

This section describes the basic procurement process together with original design intentions. It then sets out key changes identified by the Design Team and Client that occurred during the design and construction phases with the reasons for these and highlights key lessons as well as recommendations for future projects of this kind. It also highlights conflicts between current regulatory requirements and sustainable housing design standards that have been used on this development.

There are many differences between this co-housing development and any other mainstream developer; the participatory design process, company make up, cooperative values, partnering procurement process and tight budget. The suggestions and recommendations put forward here are to help refine the procurement, design and construction process whilst also providing feedback to the design team and client management group.

Please note that at the time of interview, the development was not complete with a further phase of terraced housing and ancillary buildings to be completed along with ground works due to a significant delay in the construction programme, as such comments relating to maintenance and aftercare are relatively limited.

4.2 Design intentions and delivery

This is a highly unusual development and it has followed an unusual delivery path, with exceptional and beneficial involvement from the prospective residents both in terms of procuring the development as a group and in co-designing the development with the Architect.

The design intentions have been extremely high with this development being the first co-housing development to try to tackle Code for Sustainable Homes (CSH) level 6, Lifetime Homes and PassivHaus standards all at once. There were numerous conflicts between these standards that had to be resolved.

The design team have always taken a holistic view in relation to the required standards set out, rather than treating them as a 'tick box' exercise. The unusual nature of the project has involved planning relaxations and overcoming significant hurdles in the building regulations, neither of which are designed to cope with co-housing requirements.

The extensive value engineering carried out on this project post tender resulted in numerous changes to the original design, including lowered ceiling heights, (leading to alterations to MVHR ductwork routing and thermal bridging details as a consequence) reduced number of windows, a repositioning of windpost bracing and reduced painting specification.

The process for resolving any changes during the development of the design and subsequent construction on site has involved the M&E Engineer working very closely with the Architect and Civil/Structural Engineer to resolve clashes between any structural requirements, fabric detailing and services. This has generally worked well and has been helped through the use of an NEC Partnering contract with the contractor.

The district heating infrastructure required for this project, the desire for a car-free site without roads and the elongated nature of the site with poor access, have all contributed to make this a difficult project to deliver during the construction stage.

The intention not to remove any material from site was impossible to deliver on, due to the shape of the site and poor access, as well as the difficulty of re-using material efficiently and to a budget.

The final delivery mechanism needed more time and resulted in a degree of 'messiness' when finishing the development off. The phased handover put everyone under a lot of time pressure, particularly due to the difficulties with banks and finance.

MVHR fan filters were often blocked up due to other site operations and there appeared to be no site procedure for checking when one task was finished, handing over to the next task and ensuring that items had been adequately cleaned before and after each task.

The Contractor was not particularly experienced in dealing with either large scale civil engineering works required or the size of the development. As a result, the project got off to a slow start with significant delays due to stabilisation requirements which then had to be carried out in poor weather conditions.

There were a number of supply chain issues due to the exacting requirements of the PassivHaus standards in relation to products. In particular, the windows ended up coming from abroad and this caused numerous issues in terms of delivery, timing and storage and the choice of MVHR systems was very limited also.

Although the MVHR systems appear to be working well, there was some difficulty in ensuring the airtightness of the fabric, partly due to the difficulty of drying out the masonry work and the consequential difficulty of securing tape seals to wet surfaces.

PH has a very critical cut off point of 15kWh/m^2.yr, and last minute changes to the design specification which do not appear major at the time can be an issue further down the line.

A more detailed report on the Design and delivery team interview can be found within Appendix 7.

4.3 Conclusions and key findings for this section

The close relationship between the design team and the client group has ensured that design expectations have generally been met, or where they have not been met the client and design team have been in agreement with the changes made.

This development offers an approach to the development of low carbon housing communities which is exemplary in terms of its social and environmental aspirations. The level of participatory design is highly commended in terms of ensuring that the client gets what they want. There are number of recommendations which will help to promote better procurement:

- A co-housing model needs to be developed in the UK to help residents with the design input, without having to keep reinventing the wheel. This should encompass legal structures and procurement.
- It is essential for co-housing developments to have a strong project manager who will champion the development from start to finish alongside the residents.
- New financial procurement models are needed to ensure that developments with phased handovers are not unduly affected by financial pressure from lenders.
- A review is required of CSH and current building regulations in relation to the PH standard as there are numerous contradictory requirements between the various standards.
- The use of a domestic ‘Soft Landings’ process to ensure that adequate time and care is taken with handing over housing is particularly important when new technologies such as MVHR and PVs are being installed.
- The use of an enabling contract on housing sites with difficult ground conditions, employing contractors who are more experienced in this type of civil engineering work, can help with the selection of an appropriate contractor for building the housing to a high level of construction and finish. It is unrealistic to expect medium size contractors to be skilled in all departments.
- In order to ensure that all site operatives can communicate and thus organise the construction process well, it is important to have good site facilities situated in the centre of the site.
- It is particular important with the PH standard, that there are no design changes after the PH calculations, as these can cause major issues further down the line. There should be a ‘design freeze’, including any value engineering, before the PH calculations are carried out.
- Site procedures need to be developed by contractors to ensure that one task is finished before another is started and that all affected elements are properly checked and cleaned where necessary. This is particularly important in relation to MVHR filters on low-energy developments.
- If alternative mechanical jointing details could be developed by designers in future these would help avoid the use of tape sealing for airtightness.
- An ‘air tightness champion’ should always be appointed to ensure this requirement is comprehensively dealt with across all site activities.

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 guidance evaluation process comprised:

- A review of the electronic home user guide
- Observing a live demonstration of the heating and ventilation system given to residents on 25 January 2013.

5.2 Home user guide review

The Forgebank and Heron Bank Home user guide 121023 is a practical and straight forward document containing links to all instruction manuals and general guidance for maintaining systems in the home. It is laid out in two main parts; a Quick Start Guide and Section 2. Section 2 is broken down into a further two parts, covering operational issues and the site and its surroundings.

The cooperative relationship at Forgebank means there is closer and more informal contact than usually found between developer and resident, suggesting a user guide may not be considered essential. This unique relationship has the advantage of an intimate and flexible approach to management queries but the informality may be problematic if it leaves no audit trail for future reference. Therefore, providing a user guide is a positive way to address this. It also benefits new residents who move into the development in the future as they will not have been involved in the construction process or be familiar with their new home's systems. The developer has prioritised face-to-face contact targeted at addressing specific issues over optimising the user guide.

A link to the user guide is sent to residents in an email prior to handover. After moving in, demonstrations of the ventilation and heating systems are given by members of the Building Services Team. No hard copy is given. The review was carried out in November 2012.

The review suggested that, whilst the guide was thorough and well written, it lacked images, so making it hard in some instances to understand what was being described. Some images of the elements were included in the manuals but presented in isolation and not in context. Showing images of all components of a particular system and how they related to each other in addition to the text was suggested as a way to add clarity. It was recommended that making more complex systems housetype specific would help improve usability.

The house plans included in the user guide were useful but overly complicated and would have been better if simplified. Too much information had been included; not all of it relevant. For the most complex systems, i.e. the MVHR and heating, a suggested way to reinforce instructions given in the user guide at the source, was to include laminated sheets of annotated photographs and guidance to the inside of the cupboard doors housing the equipment. Aspects relating to building envelope air tightness and waste recycling were considered of paramount importance, and were very well written with considerable detail.

A key consideration here was that the close relationship between the community's Building Services Team and residents may have meant that any system problems were resolved almost immediately: an invaluable resource for residents but one to be used sparingly. As residents themselves, there was thought to be a risk of them solving system problems all day, every day even when off duty. Therefore, a suggestion put forward was that the user guide needed to be the first and easiest point of reference for minor queries. If consulting the user guide did not solve the problem, then the Team may have been able to help. The demonstrations given were clear and extremely helpful; capturing these on video and storing them online for residents to access in their own time was considered beneficial and a way of providing assistance without taking up the Team's time. However, the electronic only format may have made things difficult for some residents as they may not have had an Internet connection when moving in.

The structure of the user guide seemed logical to ensure all CSH requirements were met but instances of duplication made it difficult to reference. Whist it was essential for the CSH assessor to identify where requirements had been met, the user guide was felt to be ultimately for residents' benefit. Therefore, it needed condensing and restructuring accordingly with essential contact information at the front.

In places, the language used in the guide had a technical emphasis to it, therefore adding a glossary was suggested to help non-technical residents understand these terms. In addition to this, the high number of hyperlinks meant labelling was critical and required improving to ensure readers knew what each link was for.

And finally, one aspect not emphasised enough was how the development was very unique to other schemes, with exceptional features. However these were barely referenced. It was recommended that the excitement and passion behind residents that live here came through more in the text, along with reminders about what a great achievement this development is.

Further information on the guidance review can be found in Appendix 8.

5.3 Handover and system demonstrations

A formal handover was not observed as part of this study. Live demonstrations given to a group of residents on 25 January 2013 were observed instead. This was for the heating, hot water and the MVHR systems.

Both demonstrations were given by members of the Building Services Team who also residents and took place in a three bed two-storey house in Terrace A. Each demonstration lasted approximately 15 minutes. Around half a dozen residents were present; the majority female.

For the heating and hot water demonstration, a one-page handout was given to each resident attending, which described the system concisely and how it should be set up. The demonstrator showed how the controller under the stairs should be on the "all day" setting and how to change the thermostat in the kitchen. Questions from residents focused on the speed at which their homes heat up and cool down and what to do if they go away for a long period of time. The demonstrator also clarified that the radiator downstairs should not be turned off as it works in tandem with the system but that the temperature of towel rail in the bathroom could be altered to help heat the house if required. When discussing hot water, the demonstrator emphasised that the thermal store should be set at 60°C ideally, and no lower than 55° C. It was also noted that hot water was best set to "all day".

The ventilation demonstration was given by a different resident and was naturally more difficult to observe given the location of the unit is in the downstairs WC. The demonstrator explained that the system should be always on and that if the power goes out, the air just gets stuffy, there is no risk of suffocation. Residents were instructed that under no circumstances should they adjust the inner portion of the diffusers, as they have been very carefully set. Instructions were given about how to remove the outer casing for maintenance and decoration.

It was noted that the MVHR units are plumbed in to the mains drainage to remove condensation and that extractor fans should be used for cooking as the MVHR units cannot remove fat. The demonstrator showed how to take off the front panel of the unit and the black polystyrene front panel of the frost protection unit to change the filters. It was also explained that the Team will help residents initially to change the filters. It was made clear that all three filters would be changed at the same time and that residents, as a group, will be bulk buying them. When looking at the controller, descriptions were given as to what each setting does and when is best to use it, plus what the boost does. Questions raised from residents asked whether the MVHR unit dehydrates people, the response was that they don't as they do not go below 40% humidity.

In summary, both demonstrations were extremely useful. Residents seemed engaged, interested and able to see what was going on. The one-page sheet given for the heating and hot water was accepted gratefully by residents. It appeared difficult for all residents to see filters being changed given the confined nature of where the MVHR unit is. But most people gathered round to have a look. There is an opportunity to see more than one demonstration to help reinforce the message if required, although that was not stated explicitly.

An observation worth raising here is that whilst both demonstrators were very technically minded and clearly knew their subject inside and out, the heating and hot water session was given in very general terms and appeared easier to understand than the ventilation one. There could be a number of reasons for this; for example the demonstrator for the heating and hot water session was a lady and giving advice to a mostly female audience could help her empathise more and relate better. The male demonstrator for the ventilation system was extremely thorough, although the speed at which he went through the subject and some of the language used could possibly be a little technical for some residents to understand if being heard for the first time.

Further information on the review of the demonstration process can be found in Appendix 9.

5.4 Conclusions and key findings for this section

Residents at Forgebank are given a user guide in electronic format before moving in and technical demonstrations for the heating, hot water and MVHR systems once they have moved in.

The home user guide is a reasonably comprehensive document although there is scope to improve the structure, readability and accessibility of it. It relates well to the design intentions. With this type of development, there is the risk that residents will not refer to their user guide in the first instance, and prefer to ask someone instead. At the moment, this may be acceptable but in the fullness of time, may become a drain on resources. Further work is required to develop the home user guide to make sure this does not happen. Part of this could be making sure resources are available in video format, or even as a hard copy, to clearly show how to maintain each system.

There is no formal handover procedure at present. Instead, residents rely on a technical team to explain key environmental technologies.

Key recommendations of ways to enhance the home user guidance and handover are as follows:

- Understanding can be improved by adding images or photographs to emphasise the points being made.
- Laminated sheets of annotated photographs and guidance should be added to the inside face of every MVHR and heating system cupboard door across the development, to offer instant assistance with the two most complicated systems.
- Using video to get a message across is familiar territory that the team can use to their advantage. It is a cost effective way to inform users and goes with the development's digital ethos.
- Including housetype floor plans is extremely effective and a good reference for residents. The set currently being used could be considered overly complicated and would benefit from being much simpler.

- Condense sections which have been covered two or three times.
- To ensure residents can find essential information quickly during an emergency, it may be better to gather it all up and put it at the front for ease of reference.
- For the most complicated systems (MVHR, heating and hot water) each individual configuration across the development should be explained in detail, using images and videos to clarify.
- The complex building systems included at Forgebank means the language used in the guide has a technical emphasis to it. Adding a glossary to explain technical phrases may be helpful. If this is not possible, an effort should be made to describe technical references more clearly in the text.
- Hyperlinks should explain what they are about to help the resident navigate the home user guide.
- Throughout the guide there are brief references to exceptional features that are barely mentioned, however. Consider reminding residents what a great achievement this development is.
- The live demonstrations are extremely effective and well given and again relate well to the design intentions. It may be worthwhile considering additional ways to address audiences to ensure better understanding.
- A more formal handover procedure should be developed for future occupants.

Further detailed recommendations on home user guidance are highlighted in Appendix 8.

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 comfortable 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

The occupant evaluation process comprised:

- A BUS survey for all adults at Forgebank
- Interviewing six households from four housetypes
- A usability review of all control interfaces

6.2 BUS questionnaire

A Building Use Studies (BUS) survey was undertaken between 28 January and 13 February 2013. 36 responses were obtained out of 36 questionnaires delivered (100%). Therefore every adult living at Forgebank at that time completed a questionnaire. This helps give a complete and comprehensive picture of the development.

Overall, the results produced are excellent. Residents are very positive about this development and how well it performs. The eight summary variables covering air, comfort, design, perceived health, lighting, needs, noise and temperature are all higher or better than the UK 2011 Housing benchmark. Comparisons against the dataset show that five of the summary variables for Forgebank are either the highest or second highest performers when compared against other studies. This is an exceptional achievement.

In addition to the eight summary variables above, the questionnaire asks for information about an additional twenty variables, thus exploring in more detail what it is like to live at Forgebank. Against these, this study has ten variables that are higher or better than the UK housing benchmark (green), six that are no different from the benchmark (amber) and four that are lower than the benchmark (red). From the summary variables, it is possible to establish a Comfort, Satisfaction and Summary Index for each study in the dataset. Here, all three are the highest across the dataset; the Comfort Index in particular is quite remarkable. A calculation for “Forgiveness” is also produced. This study has the highest Forgiveness Index of the dataset.

General aspects of the design which are positive include: the beautiful setting, the development’s appearance, the open plan living space, the general comfort and warmth, the effective ventilation system, the communal facilities, effective use of space and high levels of natural light.

Looking in detail, the houses are found to meet user needs well; this is more than likely due to the high level of resident input into the design. Also, as residents are delivering the houses being both contractor and client, there appears to be a particularly high degree of forgiveness. The internal environment contributes positively to temperature and air quality. As a consequence, comfort and perceived health are also felt to be very good. Natural daylight levels are considered good although this does reduce levels of privacy.

General challenges to address in the development include: dry air in the houses which may be due to the MVHR system although it is unclear whether the dryness is perceived positively or negatively, the narrow baths; bedroom shape and size to accommodate furniture; lack of individual internal and external storage space within homes; noise transfer within the homes and between flats; the balcony railings and perforated flooring and one way balcony door handles (this has subsequently been addressed); lack of area to the front of homes to store wet or muddy items; the poor floor finish; excessive artificial lighting provision, poor light switch location and wiring; and complex controls of the heating and ventilation systems.

Looking in detail, room dimensions limit options for flexible furniture layouts, requiring innovative or bespoke solutions. Internal and external storage provisions is less than satisfactory meaning residents are thinking creatively and looking to the Mill for future use. Noise is reported as troublesome between rooms within the dwelling and between flats, as well as a feeling of no control over noise; although resident expectation, previous experience and noise hypersensitivity may play a part.

Low thresholds cannot accommodate carpet underneath doors, reducing resident flexibility and choice of furnishings. The material used on the balcony floor whilst letting light through is uncomfortable to walk on, prompting residents to adapt them (the Architect is in the process of proposing alternative solutions for residents). The air is reported as dry and still, suggesting a need to check settings, although the humidity levels need to be checked first. System controls are not as intuitive as they could be, leading to a potential loss in energy and water efficiency. The artificial lighting provision is felt to be excessive and wired illogically; meaning residents learn through trial and error how to use the lighting. The baths are thought by most to be uncomfortable, although some enjoy the bath type and WC flush is counter intuitive. The building fabric's slow response to temperature changes may lead residents to consider energy intensive rapid solutions to discomfort.

The issues raised here however, should not detract from the many successes this co-housing development has achieved. It is hoped that positive attributes present here, designed in with thought and care can be used to inform others in future.

Further detailed information on the BUS survey review can be found in Appendix 10.

Recommendations for immediate performance enhancement:

- Consider compiling storage options being used across the development and share this knowledge to give all residents an idea of what they could accommodate where.
- Examine ways to screen external storage spaces, for example using planting etc., to improve tidiness.
- Feedback comments to Lancaster Co-housing to relevant resident workgroups to see how each item listed for improvement can be addressed retrospectively.
- Check whether each housetype is wired the same way and reflect this in the user guide in a bespoke manner if necessary.
- Review potential adjustments to heating systems to avoid overheating at night.
- For those homes where a temperature differential between downstairs and the bedrooms is perceived as problematic, consider ways to provide supplementary heat upstairs if required.
- Ensure demonstrations explain in detail how the fabric of the house behaves and why.
- Check the humidity maintained in the houses and review use and settings of MVHR if too low.
- Double check to make sure all MVHR systems are commissioned correctly.
- Check for additional noise transfer paths between rooms and between flats e.g. missing insulation or attenuation.
- Consider how to improve internet speed to ensure effective home working.
- Review heating, energy and water use in six months' and a years' time to assess whether utility costs are lower or higher than anticipated and check for any trends relating to use or commissioning which might help to improve performance if necessary.
- Consider introducing an Energy and Water club for benchmarking purposes and to help encourage residents to lower their bills through mutual learning.
- Remind residents of the option to apply translucent film internally to windows and doors to address privacy issues if necessary.
- Circulate the Architect's suggestions for balcony improvements before residents make changes, to prevent loss of incoming room daylight below them.
- Provide simple instructions immediately next to complex systems
- Examine whether the lights in each housetype are wired the same way and review how the lights could be wired in a more logical way.

- Whilst compliance for building regulations and Lifetime Homes requires a level door threshold, there is scope to take this up to 15 mm which has the potential, depending upon the product, to accommodate carpet.

Design recommendations for future projects:

- Review bedroom size and layout to ensure flexibility i.e. able to fit a bed lengthways or comfortably accommodate a king-size bed, wardrobe and sufficient space for people to move around.
- Review size of internal and external storage provision at an early point in the process.
- Review options for creating an area (internally or externally) to provide a place to leave muddy or wet items, that is easy to clean and helps prevent the spread of dirt into the house from outside.
- Analyse each positive aspect and see how they can be incorporated into future projects.
- Check at the design stage that there is scope to accommodate carpet and that this is checked during construction.
- Encourage designers and contractors to look at ways of improving construction build up and detailing for noise transmission in future projects.
- Given the construction method complies with the Building Regulations, and noise conditions between some flats are perceived as unsatisfactory, this suggests the standards set may not yet sufficient and need addressing.
- Avoid over specifying fittings and unnecessary complexity in lighting layouts.
- Review lighting layout to improve both switch location and gang size.
- Consider specifying more LEDs where possible and practical to reduce energy use and maintenance requirements.
- Retain a good daylight provision but ensure control of glare is possible by other means (blinds or curtains). Consider how to achieve control when tall (or large) windows are provided.
- Review control for all elements and services related to comfort; including design, specification, settings, usability and installation procedures. Ensure sufficient training is provided to occupant at hand over giving clear instruction and hands-on experience of service interfaces.
- Consider ways to make controls and interfaces more self-explanatory and intuitive.
- It may be worthwhile for mainstream developers to examine ways of engaging residents to participate and contribute more in the design process, thus improving the forgiveness factor for their developments.
- Add additional tolerance to ensure the minimum possible length delivered by the contractor still meets the desired room dimension.
- Review ways to reduce noise hypersensitivity in new buildings, to help increase tolerance towards internal noise or noise between dwellings.
- Consider the usability of eco-baths, Also, specify intuitive and visibly dual flush WCs, for example, one with buttons.
- Anticipate how the houses will be used and check that the radiator(s) are in the places where people are likely to spend the most time. Therefore, they can benefit from the radiant heat even if the air temperature is slow to respond.

More detailed recommendations from the BUS survey review can be found in Appendix 10.

6.3 Occupant interviews and walkthroughs

The six households interviewed in January 2013 were extremely satisfied overall with both their house and the community aspects of the Forgebank cohousing development. The interviews carried out spoke to residents from four of six house types at Forgebank. The residents had been living in their houses for a maximum of five months before the interview; most less. The heating systems had been on for a maximum of three months prior to the interviews, and were either on a timed setting or on all day.

The best aspects of the houses were thought to be; the warmth, the views and being close to community facilities. The worst aspects were felt to be the storage provision followed by the balcony design and the poor flooring that cannot be carpeted over easily.

The best aspects of the community were; knowing your neighbours, sharing facilities and the support offered. The worst aspects were thought to be the feeling of exhaustion associated with all the work involved with delivering the project. Also people that had not become neighbours yet but were instead still committee members.

All residents interviewed participated in community activities and had various communal responsibilities. Female residents appeared to be involved in social aspects and men the technical aspects. Male members were also more familiar with low energy systems prior to moving in. Both community and environmental aspects were a major draw for residents now living here.

Changes in behaviour from having shared facilities were noted. For example, using a shared laundry; eating meals together; cycling or driving more; using the common house for socialising; parents using the children's room; storing bikes and outdoor equipment; using the co-op food store; using the car club on a regular basis; using the guest rooms on an occasional basis; holding community events; sharing outdoor space. Beneficial aspects identified were: socialising, looking after children and sharing resources.

In terms of handover, it was felt that there was room for improvement. It would have been helpful to have had more information about how the houses worked and demonstrations soon after moving in. Some issues of snagging affected handovers which was less than ideal and in some instances houses were not cleaned before residents moved in. Regardless of this, all those interviewed understood that Lancaster cohousing is not a commercial developer and made allowances for this.

On the whole, the user guide had not been read. Some had forgotten they had it, others couldn't access it, a few found it difficult to read as there is a lack of imagery, one or two felt it would have been useful to have a hard copy and in one instance the quick start section was not helpful.

Clarifying resident responsibilities was not yet fully resolved and this included what to do to report a problem and what problems to report to whom. Male residents appeared to have more of a detailed technical understanding than the women interviewed; with the ladies participating mainly with the community responsibilities. It also seemed that some of the women interviewed were not sure whether they wanted to have a detailed understanding of the technical systems; others wanted to know more.

The MVHR system was praised. There were some comments relating to the dryness of air, however. Residents found the controls usable but were quite surprised as to how much storage space the equipment occupied. There is also a clash between the front panel of the MVHR unit and fixed lower panel of the cupboard it sits in within the houses. A point was raised in the flats about an inconvenient location for a MVHR on/off switch in the cupboard below the unit, as it kept being knocked. It was reported that traffic fumes had been brought into houses via the MVHR system by cars parking on Mill Lane. One resident identified that as a result of the comfortable and draft free environment in their house, they were starting to develop a hypersensitivity to draughty environments elsewhere.

The heating system was reported as good; however, residents had adjust to the time lag in temperature change due to the thermal mass in the homes. This has meant fan heaters being used in the short-term in one instance, which is undesirable in terms of additional energy use. Residents commented on the perception of relatively high temperatures at night. In terms of usability, some found the thermostat confusing; no one had used the green button on their thermostat to save energy. Most felt that the heating and hot water controls were satisfactory but not particularly easy to use. Half the households interviewed commented that their front door was not closing and sealing properly, and a number wondered why the cupboard under the stairs was so warm.

Residents felt that the high level of daylighting was very positive and it is that this was due to the amount of glazing. However, there appear to be privacy issues associated with the level of glazing. A problem was initially reported with the balcony doors as they could not be closed from the outside and that the locks are too easy to operate accidentally from inside (the manufacturers are rectifying this). In terms of plumbing and sanitary ware, most found the baths too small, the tap flow in the bathrooms mean and the WC flush counterintuitive. In addition, some problems were identified with WCs blocking and that pipework under kitchen sinks consumed too much storage space.

When exploring issues relating to the WC flush with the project team, it was explained that the aim was to use leak-free siphons rather than drop valves, as it was found that leaks due to drop valve types outweighed any water saving benefits of a dual flush. The siphons require a lever for operation rather than buttons. The counter-intuitive press and hold for a short flush was driven by regulation but the mode of operation as installed can be changed.

When discussing noise, interviewees said that there was very little noise from outside but that it travelled internally. No residents identified it as an issue and felt that it was only likely to be problematic between flats. Attitudes towards it may be both previous experience and expectation.

Residents felt that there were too many light fittings in their homes, cluttering up the space. Many reported the wiring as illogical, and that the light fitting in the three story house loft space was likely to get damaged.

In terms of design, residents felt that the open plan layout, induction hobs, downstairs WC, view from the balcony, second bedroom for children, stairs for drying clothes and the very pleasant external space very positive aspects of the development. Conversely, the quality of the worktops and floors, low thresholds, main bedroom size, balcony flooring material, small dark bathrooms, small baths, balcony door locks and handles were all highlighted as less satisfactory elements of the design. Some felt that the short distance between the party wall and window reveal hindered possible options for furniture locations. In the three storey houses, the fire door, access to the community and lack of level access from the back door to external steps were all elements that could be improved.

All residents felt that their homes accommodated both themselves and their possessions well and that they would be easy to adapt in future to meet their needs. The exception to this was the three storey house if a third bedroom was required on the middle floor instead of the basement.

The room sizes were what residents expected or slightly smaller. Some people struggled to accommodate the necessary furniture and people in the main bedrooms. Downsizing was felt to be easier for single people or couples living in two or three bedroom houses; not so much so for families.

The general consensus was that there was insufficient internal and external storage; however, the loft storage space in the three storey house was praised. Residents were looking at innovative ways to improve this.

More detailed findings from the occupant interviews can be found in Appendix 11.

Recommendations for immediate performance enhancement

- The heating system is designed to be on all day, as a constant rather than varying load for the biomass boiler. It appears a number of residents have set their programmers for various times throughout the day. It may be beneficial to ensure residents have their heating set correctly.
- Given the small footprint and large amount of glazing, heat gains may be excessive in summer. It may be beneficial to purge the houses of this excess heat by opening the windows, particularly at night. A suggestion is to add a note about this in the user guide.
- Future residents would benefit from a more formal and informative handover.
- There may also be merit in handing over homes at a point when builders no longer have access to the property, therefore giving residents a greater sense of ownership.
- If for any reason the house has not been professionally cleaned, it may be helpful to communicate why not and the proposed resolution.
- The user guide could be made more accessible, user-friendly and clear.
- Hold training or demonstrations as quickly after moving in to avoid bad energy habits developing.
- Ensure new residents are aware of snagging procedures and clarify their responsibilities in terms of maintenance.
- Add a light to three-storey house cylinder cupboard to improve visibility when accessing controls.
- Fit a doorbell to the back door of the three storey houses, given that these have become the main entrances by default.
- Arrange a means for checking residents' ventilation and heating settings.
- Review and address balcony door ironmongery and balcony flooring (this has happened already).
- Distribute to residents the Architect's options for adapting balconies to inform now before residents make changes.
- Improve insulation to hot water pipework and any equipment giving off heat. This will ensure that heat gains are more controlled and in line with modelled predictions.
- Work with residents to adjust their heating settings in relation to the thermal lag induced by thermal mass to help reduce temperatures at night.
- Work with residents to check and improve temperatures in bedrooms where it is considered problematic.

Design recommendations for future projects

- Review MVHR switch locations in kit cupboards in the flats to avoid the system being turned off accidentally.
- Ensure that the MVHR system air intake point from outside is not adjacent to any potential air pollution sources e.g. cars, outlets from other buildings etc.
- Explore means of achieving desired temperatures in bedrooms for these house types. This could include additional investigation through TSB BPE funding.
- Review number and choice of light fittings, for example wall lights on stairs are closed shades, review switch provision and wiring.
- Look at light fitting distribution to avoid dim spot in rooms.
- Consider putting light switches next to bed positions.
- Look at providing a window in bathrooms where possible.
- Review options for eco-bath alternatives, if possible, in terms of comfort.
- Review options for WC flushes to ensure they are intuitive and look like they are dual flush.
- Consider bath to ceiling height to ensure that tall people can shower comfortably. Also ensure the shower hose can accommodate this.
- Review trim materials in bathrooms to avoid maintenance issues for residents.

- Review worktop specification, or humidity at the point of installation.
- Look at ways to address noise transfer between floors in dwellings.
- Check wall lengths between windows and party walls to ensure length is sufficient for wardrobe or curtains etc. without obscuring the window.
- Rather than a one-size-fits all approach, feedback has shown that people do not always use space as envisaged (for example the three storey house). It may be good to anticipate options and the requirements for each.
- When working out furniture layouts, it may be useful to show the movement zones around each to get a feel for circulation space across a whole room; particularly if the design has changed significantly.
- Possibly consider distance between house and Sheffield stand to ensure two bikes can fit without touching the house.
- Look to build in flexibility to accommodate carpet under door swings. If this is not possible, ensure adequate mat wells are provided to homes.

More detailed recommendations from the occupant interviews can be found in Appendix 11.

6.4 Usability review of control interfaces

This section covers the review of the control interfaces for heating and hot water controls, MVHR controls, electrical equipment controls, kitchen appliances, external skin touch points, water services controls and other miscellaneous touch points encountered in a typical terraced house at Forgebank, in particular plot 17. The detail review follows the Building Controls Industry Association (BCIA) guidance collected in their *Controls for End Users* publication and ranks each of the usability criteria from poor to excellent on a five point scale (see figure 4 below). The usability criteria considered are clarity of purpose, intuitive switching, labelling and annotation, ease of use, indication of system response and degree of fine control.

Description and location:					
Usability criteria	**Poor**				**Excellent**
Clarity of purpose					
Intuitive switching					
Labelling and annotation					
Ease of use					
Indication of system response					
Degree of fine control					
Comments					

Figure 4 Typical review of control interfaces table

The review of control interfaces study for Forgebank is summarised in relation to a number of key findings, many of which correlate with findings from the BUS survey and occupant interviews.

The usability of the heating and hot water controls is not intuitive and needs instructions to use it properly. Identifying and labelling switches would improve usability from a resident's perspective. Given this development is occupied by those who wish to get their energy use as low as possible, they will tweak the system. Either demonstrating the most efficient way to run the heating and hot water system or clearly annotating what should and should not be touched would be beneficial. For example, turning their hot water cylinder temperature down too low may encourage Legionella.

Also, an advantage of being in a Passivhaus is the small heat demand. Residents may find short bursts of heat when needed are all that is required rather than setting a weekly heating programme.

The MVHR controls are clear, easy to understand and quick to follow. The panel is well located in the kitchen, on the wall between the cloakroom and stairs. Whilst the system counts down days to a filter change, it is not clear whether it would detect a clogged filter before this date. Inside the MVHR cupboard, annotating parts of the MVHR system; the main unit, heating element and switches etc. would make maintenance easier, as well as making sure relevant warnings are in English. The MVHR unit itself needs to be much more intuitive to use as well as more clearly labelled. Without being taught, users are very likely to struggle to check or replace filters.

Generally the standard lighting switches used are intuitive and clear. The additional switches used for lighting, which include an indicator light, could cause confusion; especially when mounted next to standard light switches. In the kitchen, the main bank of light switches next to the thermostat operate lights in the living space as opposed to the kitchen. This requires the user to get used to them, rather than being informed intuitively. Further clarification of the two socket labels on the electrical consumer unit would be useful.

The kitchen appliances are clearly labelled and intuitive to use. The most complicated one is the induction hob. To work this as efficiently as possible, users would benefit from reading the manual. They may also need to invest in a new set of pans suitable for an induction hob.

The purpose of the windows and doors is clear; however the balcony door being effectively a window means users cannot close it from the outside, thus undermining the MVHR system (this has since been rectified). This could have been a major issue in terms of heat loss. The window locks are a little fiddly and require a "knack" to open and close, there is no intuitive fine control and they feel heavy to use. Overall, the windows are not user friendly and undermine the low energy strategy.

Taps and bath controls are reasonably well labelled. The exception is the kitchen sink where the tap height makes the dots denoting temperature difficult to see. The WC dual flush nature of the cistern is impossible to establish from looking at the handle. Its counter intuitive flush mechanism undermines its good intentions. Ideally it would benefit from instructions being added adjacent to the handle but a verbal warning to guests about how it works could be an effective alternative. Residents may expect their stop cock to be under their kitchen sink, rather than tucked away in the WC cupboard; adding a note to the MVHR cupboard pointing to its location may be beneficial here.

The doorbell works well and can be heard from both inside and outside. The phone line and internet connection is yet to be connected. The intention is for televisions to use this rather than cable or satellite. Connection points have been added to living spaces to accommodate this.

More detailed findings from the usability review can be found in Appendix 12.

Recommendations:

- Consider usability when choosing all control interfaces – think about how clear the purpose of the item is, how intuitive its operation is, whether the labelling is clear, how easy it is to use, whether it gives indication of the system response and whether it allows for a degree of fine control.
- Discuss requirements for usability with manufacturers and provide feedback on their controls when specifying products.

- Provide hands on training for residents of all systems and allow them to interact with the controls and ask questions as to how they find them.
- Consider improving the labelling of controls and provision of instructions nearer to the point of use.

More detailed recommendations from the usability review can be found in Appendix 12.

6.5 Conclusions and key findings for this section

There are many things overlap between the BUS survey, occupant interviews and the usability review; the survey gathers a general picture of the development overall and the interviews and usability review drill down into more detail with specific homes evaluated. Overall, the picture is exceptionally positive; residents are very happy with how their houses are and perform. The high level of resident input has led to the homes meeting needs very well, and where there are shortfalls, residents are extremely forgiving.

The comfort levels generally are very encouraging with residents generally enjoying the temperature levels. The residents find the internal air in their homes dry and still; this was reiterated in the interview as well as the BUS results. It is not clear however, whether the dryness and stillness is perceived negatively or positively as some people misunderstood the survey question and others are clearly enjoying the benefits of a drier home. In this respect, the domestic version of the BUS questionnaire needs further improvement in terms of how these questions are phrased. However overly dry air is a concern, and further tests should be undertaken to establish the actual humidity in the homes, given that 81% felt the air was dry.

It is clear that in terms of process, there is scope to improve the handover and the home user guide. The demonstrations are considered to be very useful however it may be better to hold the training demonstrations quickly after moving in to reduce the number of bad habits picked up. It may be worth considering that some residents will require more than one session.

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, two heat emitters are to be provided within the dwelling - a column radiator in the living area and a heated towel rail in the bathroom. Hot water to the column and the towel radiator are to be supplied from the wood chip biomass boiler which feeds a district heating system. Control of space heating is provided via an electronic digital room thermostat and Danfoss FP715 Si 24 hour programmer (this also controls the water heating). The programmer is deliberately situated in the cupboard under the stairs, to prevent alterations being made to the time control, and the room thermostat is located in the living room.

The district heating system also provides hot water to a 120 litre unvented indirect POWERflow 2000 indirect hot water cylinder which is located in the cupboard under the stairs. Control of the hot water system is via the same 24 hour programmer that controls the space heating. No electric immersion back-up has been provided.

Ventilation is provided via a Paul Focus 200 whole house MVHR system which incorporates a frost protection heater. This is installed in a cupboard located in the downstairs WC. Boost operation of the unit is provided via a Paul remote control coloured TFT touchscreen keypad located on the wall between the kitchen and the living area. The remote control keypad is also used to control and program the operation of the MVHR unit.

In terms of internal lighting, a mixture of pendant and wall-mounted luminaires have been installed within the living area, the WC the stairway and both bedrooms. In addition, LED spotlights have been provided in the kitchen area and an IP X4 luminaire and wall-mounted light incorporating a shaver socket has been installed in the bathroom. Externally, a luminaire incorporating a PIR and a daylight sensor is installed adjacent to the back door.

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 series of duct flow measurements for the MVHR system, a Flow Test Record Sheet for the district heating system, a Thermostatic Mixing Valve (TMV) Temperature Setting Record for the space heating system and a Plumbers Test Out Certificate for the space and hot water heating system. An analysis of the commissioning data revealed that no issues were identified with any of these services.

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 cupboard under the stairs were very well insulated. However, there were a number of areas where the insulation was not continuous and some of the insulation was not securely fastened to the pipework. In addition, it was observed that a 120 litre unvented indirect hot water cylinder has been installed in the cupboard under the stairs. Although this is consistent with the construction specification, it is inconsistent with the design and as-built SAP worksheets, which incorporate a 75 litre hot water cylinder.

In terms of the MVHR system, it was clear that the ductwork that was observed had been installed to a very high standard and the supply grilles had been individually adjusted to meet individual room requirements. Despite this, there were some small sections of the ductwork that were exposed and not adequately insulated.

With regards to the lighting system, the lights that had been installed were in accordance with the construction specification. However, it was noted that the wall-mounted luminaire in the living area is installed in very close proximity to the pendant light for this area. It is possible that the pendant and wall-mounted luminaire could both be switched on at the same time, effectively over illuminating this part of the living area.

Further details relating to the installation and commissioning checks can be found within Appendix 13.

7.3 MVHR duct flow measurements

A series of MVHR supply and extract duct grille flow measurements were also undertaken on the test dwelling. These revealed that under standard flow rates (fan speed setting 2), the whole house supply and extract rates were balanced and the unit satisfied the ventilation requirements contained within Part F of the Building Regulations. However, the measurements also highlighted that at the other fan speed settings, the units were not balanced. At fan speed 1, the extract is 17% greater than supply. At fan speed 3, the extract is 13% lower than the supply. Finally, at boost ventilation, the extract is 10% lower than the extract. Balance of the fan speeds overall is critical in terms of heat exchanger efficiency, with an absolute maximum imbalance of 10% stipulated as a requirement of Passivhaus certification. Conversations with the Services Engineer have revealed that this is likely to be attributable to a known issue with the self-control on the fans incorporated within the unit, resulting in an imbalance being selected during the commissioning process. The results suggest that the imbalance selected has been too high.

Further details regarding to the MVHR duct flow measurements can be found within Appendix 6.

7.4 Conclusions and key findings for this section

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. The only instance where any discrepancy has been identified, relates to the hot water cylinder. A 120 litre unvented indirect hot water cylinder has been installed, which is consistent with the information contained within the construction specification, but is inconsistent with the design and as-built SAP worksheets. The reason for this discrepancy is not known. In addition, a number of the fan speed settings for the MVHR unit are different to those identified within the services specification.

An analysis of the commissioning data obtained from the MVHR system reveals that although the system is balanced under standard flow rates (fan speed setting 2), when the unit is operated at other fan speed settings, the system becomes unbalanced. Balance of the fan speeds overall is critical in terms of heat exchanger efficiency, and equally as importantly, the level of imbalance measured at fan speeds 1 and 3 exceeds the maximum imbalance stipulated as a requirement of Passivhaus Certification. The reasons for the imbalance are not known and, unfortunately, it appears that it is not possible to predict the degree of imbalance during the initial commissioning process. This has important implications for the performance of the MVHR units that are installed at this development, and is likely that further visits and commissioning checks will need to be undertaken on the MVHR systems to ensure that the units are appropriately balanced, perform as efficiently as possible and do not exceed the maximum imbalance that is stipulated as a requirement of Passivhaus Certification. It is also important to note that the imbalance issue with MVHR units from this manufacturer is not isolated to this development. Currently, the supplier of the MVHR units to this development is in discussion with the manufacturer of the MVHR units regarding this issue.

Observations of the installed services reveals that overall, they have been installed to a very high standard. However, there a few small areas of the MVHR ductwork that have not been adequately insulated and there are significant sections of space heating pipework, located in the cupboard under the stairs, that are not adequately insulated. This is likely to result in increased heat loss from this pipework. 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.

With respect to the internal lighting system, the observations revealed that due to the layout of the lighting system, some areas of the dwelling have the potential to be over illuminated. Given this, the design and layout of the lighting for any future schemes should be reviewed to ensure that this is not the case.

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 Wider technical aspects of the development

Although all technical issues identified in this study and their underlying causes have been identified elsewhere in the final report and in the various other reports situated in the appendices to this report, it worth briefly mentioning the wider technical aspects which frame this particular housing development.

This study was conducted during the phased construction and initial occupation stage of the development. While the district heating system had been installed, along with the communal photovoltaic system with its own micro-grid connected to all the homes, the ambitious mini-hydro scheme on the river Lune has yet to be installed. Additionally, a later phase involving conversion of an existing mill building into a business centre with work and storage units has not been completed. As such, it is not possible to comment on how the overall design intentions of this development have been realised.

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

Given the detailed nature of this study and the extensive findings and recommendations, this section summarises the key messages coming through from all ten reports and additional data contained in the appendices. The key findings and recommendations from each of these reports have been highlighted in previous sections of this report. Further more detailed findings and recommendations are contained in each of the reports in the appendices. This section draws out key messages for the developer – in this case the Lancaster Co-housing residents themselves and the Project Manager.

9.2 Construction review and physical testing

The main findings from the construction review and physical testing reports are as follows:

- The design standards for the development were established early in the design phase. The method of working adopted by the Project Team and the procurement route selected facilitated the realisation of the chosen design standards. Despite this, there was a lack of coordination of the design documents.
- Inaccurate data has been used in both the design and the as-built SAP worksheet for the test dwelling. Consequently, both of these assessments do not accurately reflect the test dwelling at the time that they were undertaken.
- The test dwelling has been built to a very high standard with considerable attention given to the detail. This is reflected in the results of the coheating test where a measured heat loss coefficient of 47.1 W/K was obtained. This compares to a predicted heat loss coefficient of 39.6 W/K – representing a small discrepancy of 7.5 W/K. If the result from the test dwelling is compared to the results of some 22 other new build coheating tests undertaken by LeedsMet, it is clear that the dwelling is one of the best performing dwellings in the sample.
- Unfortunately, it has not been possible to identify the reasons for the discrepancy in heat loss coefficient. However, the heat flux measurements revealed that the measured effective U-values tended to be close to the specified design U-values for each of the building elements, with the exception of the masonry external wall. The reasons for this are unknown and require further investigation. In addition, some significant areas of unexpected heat loss were identified during the thermal imaging surveys, most notably at the external wall/eaves junction. The reasons for this are also unknown and require further investigation.
- Overall, the results of the various fabric tests undertaken on the test dwelling 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 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 commissioning data obtained from the MVHR system reveals that the system is only balanced under standard flow rates. Balance of the fan speeds overall is critical in terms of heat exchanger efficiency, and equally as importantly, the level of imbalance measured at fan speeds 1 and 3 exceeds the maximum imbalance stipulated as a requirement of Passivhaus Certification. The reasons for the imbalance are not known and, unfortunately, it appears that it is not possible to predict the degree of imbalance during the initial commissioning process. This has important implications for the performance of the MVHR units that are installed at this development, and is likely that further visits and commissioning checks will need to be undertaken on the MVHR systems to ensure that the units are appropriately balanced, perform as efficiently as possible and do not exceed the maximum imbalance that is stipulated as a requirement of Passivhaus Certification. It is also important to note that the imbalance issue with MVHR units from this manufacturer is not isolated to this development. Currently, the supplier of the MVHR units to this development is in discussion with the manufacturer of the MVHR units regarding this issue.
- Observations of the installed services reveals that overall, they have been installed to a very high standard. However, there a few small areas of the MVHR ductwork that have not been adequately insulated and there are significant sections of space heating pipework, located in the cupboard under the stairs, that are not adequately insulated. This is likely to result in increased heat loss from this pipework. 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.
- With respect to the internal lighting system, the observations revealed that due to the layout of the lighting system, some areas of the dwelling have the potential to be over illuminated. Given this, the design and layout of the lighting for any future schemes should be reviewed to ensure that this is not the case.

9.3 Performance and space standards

One of the overall strengths of this development is the exceptional level of resident input throughout the design, construction, handover and aftercare process. This has helped deliver homes that the community wants and can afford. There has been little compromise on environmental performance and as a result, the houses are extremely comfortable and the co-heating test demonstrates a relatively minor deviation from the predicted thermal performance. It is vital that the co-housing community develop good maintenance and fault reporting procedures to ensure these standards are maintained, particularly in relation to the various environmental technologies and construction techniques deployed to ensure high levels of airtightness and low energy performance.

On the other hand, space has been compromised in some circumstances; residents have collectively agreed with the design team to reduce their dwellings sizes in order to save money. This decision is understandable, given the need to make cost savings against a set budget at the tender stage. Residents at the moment are extremely forgiving; this is natural because they are both the developer and the end user. It will be interesting to see how desirable the houses are in future, or how long this forgiveness lasts, once the original resident moves out. Residents' attitudes towards the development varied depending on the length of time they have been involved in the project; i.e. those who had joined the project more recently were less tolerant when it came to snags identified in the housing. One possible concern is that potential purchasers (who were not involved in the design process), whilst attracted to the environmental credentials of this development, may find that the small bedroom sizes and lack of storage do not meet their needs.

9.4 Resident guidance and training

The amount of training and learning required for occupants to understand how to use all the new technologies that are now deployed in ‘zero carbon housing’ is often underestimated and therefore relatively undeveloped. Handover processes, training and guidance needs improving and need more time spent doing them, although unless other areas of work could be identified to be dropped this would require more human resources at more cost. The Lancaster co-housing technical training is very hands on and other housing developers would benefit from using their techniques. At the same time, these do not necessarily deal with the fact that people often forget how to use things after they have been shown them unless they continuously practice using them. This is why continuously available guidance is essential. The tendency to produce web-based resources is fine, but this does not deal with emergency situations when power is lost – nothing can replace good old fashioned physical quick guides situated next to the complicated ventilation, heating, lighting and renewable energy systems now being installed.

Recommendations for improving the handover process and home user guidance are contained in section five of this report and the associated report in the appendices.

9.5 Environmental controls

The BUS survey, resident interviews, user guidance and usability review all point to a need for greater consideration of the usability of environmental controls relating to heating, lighting, ventilation and water use. It is important to include windows and doors within this context also; the ironmongery on these is vitally important in determining whether or not occupants can use these elements effectively. The design team have delivered a well specified MVHR system with good controls, but the location of equipment needs greater consideration to ensure switches and filters are easy to reach and appropriately located. The heating system controls deserve greater consideration in terms of clarity and usability – in particular the thermostatic controls and boiler controls. It is important to manage residents’ expectations and understanding in relation to water use and consider whether water saving specifications are satisfactory. The toilet flush mechanism, bath size and flow rates were all raised as issues by some residents. Recommendations for improving the usability of these controls are contained in section five and the associated report in the appendices.

At a meeting towards the end of this project, findings were presented to the Contractor, design team and residents in the Common House of the residential development. A lively discussion ensued about the merits of leaving the MVHR system on or off in the summer, when windows can be used as an alternative form of ventilation, thus reducing the wear and tear on the MVHR system as well as reducing the need to replace the three MVHR filters so often and saving marginally on electricity. Some residents were unclear about how to ventilate their homes effectively in a heat wave and were unaware of the benefits of night purging combined with MVHR systems. The deployment of MVHR units without a summer bypass is questionable, because warmer air in the home will add heat to any incoming warm air if the MVHR system is left on.

9.6 Conclusions and key findings for this section

A key issue for the participatory design process is how to ensure that design decisions are thought about not just in relation to the current residents but also future residents and that the consequential effects of space saving to reduce costs are considered more carefully.

The high level of participatory design involved in this project and the close attention of the design team working in partnership with the Contractor and Developer has meant that many of the usual faults found in so-called ‘zero carbon’ housing development have been overcome. Additional minor issues identified in the construction review and physical testing reports have been identified with suggestions for how these might be tackled.

Achieving a good physical performance in housing is only one half of the problem, however.

Ensuring that occupants are empowered to change their behaviour and to get the best performance out of their homes is equally important. This study has shown the benefits of setting up a holistic housing development which allows residents to share facilities and resources. This has had the added benefit of helping to change residents their lifestyle to a more low carbon one. Additional work is needed to help ensure that residents understand how to use their homes effectively, particularly in relation to the use of environmental controls and the response of the home to temperature changes.

Part of empowering occupants is giving them the ability to compare their perceptions to actual physical performance. Further studies to identify actual temperature and humidity levels over different seasons would be beneficial. Equally a BUS study conducted in the summer months will reveal if there are any perceived overheating issues.

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 Introduction

The Lancaster co-housing development is unique in the UK, being the largest co-housing development to date to aim for both Code for Sustainable Homes level 6 and Passivhaus standards, as well as complying with the Lifetime Homes standard requirements. It is also much more than just a housing development, as it includes a number of shared facilities for residents as well as a future business centre. Given this extremely ambitious agenda, the client and design team have had to overcome numerous barriers in order to achieve the outcome desired. These are discussed here, together with general lessons and messages for the wider industry relating to 'zero carbon' housing developments which adopt a Passivhaus standard.

10.2 Achieving good airtightness

The delivery of a relatively airtight external envelope has been exemplary in this development. This is due to the design team learning from precedent in terms of delivering a masonry based Passivhaus design. The level of attention given to this aspect through careful detailing, extensive training of operatives, having an airtightness champion on site, rigorous site inspections, is something that is necessary in all developments if we are to achieve performance targets in practice. Wider dissemination of this best practice to trade associations and the architecture profession is recommended. CPD events would be an excellent vehicle for this.

This project has revealed a number of lesson and 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. These included: well-sealed service penetrations and wind posts, appropriate sequencing of the parging coat, effective sealing around windows using the correct airtightness tapes and the effective use of airtightness tapes a ceiling/wall junctions.
- The pressurisation test illustrated that it is possible to construct very airtight cavity masonry dwellings in the UK. However, this is likely to require:

1. A well thought through, properly designed and properly executed primary air barrier.

2. Adoption of a formal well communicated airtightness target.

3. Plans and details annotated to include information on airtightness

4. Inclusion of an airtightness testing strategy into the construction programme that enabled the dwelling to be pressure tested at various different stages of construction.

5. Well communicated construction strategy and training programme for on-site personnel.

The project highlighted that it is imperative that the correct areas and volumes are used when calculating the air permeability and air leakage rates, particularly if a very high level of airtightness has been specified. Even if an airtightness testing regime has been incorporated into the construction programme, if the wrong figures have been used, then there is a risk that construction could progress on the assumption that the dwelling is within the specified airtightness target, when in reality it may not be. This may result in the dwelling failing the post completion test. Undertaken airtightness remedial work at post completion stage is practically difficult and expensive.

10.3 Lessons for coheating testing

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.

10.4 Lessons for co-housing developments in the UK

Procurement proved particularly challenging as there was no freely available and transferable financial model for this type of collective custom build development. It would be sensible for housing organisations to consolidate best practice in this area and share this.

Without a central paid administrative and technical staff, a lot of pressure is placed on the Project Manager who becomes the main conduit between the design team, Contractor and the residents. Involvement in research studies, prior to final completion of a project, increases this pressure further. The development of transferable governance models specifically designed for co-housing developments would help to make this process easier for others embarking on this type of development.

Co-housing developers could adopt the rigorous handovers and written guidance provided by larger commercial house builders which cover all aspects not just for the first residents but also future residents. However they may struggle to find the resources to do this, particularly as they lack the same economies of scale. Some cross-over between these sectors could be mutually beneficial, as co-housing has much to offer commercial developers in terms of showing how residents can collectively learn how to use their homes.

10.5 Managing new technologies in housing

The UK housing industry is undergoing unprecedented change, largely driven by the rapid changes in building regulations to save energy, reduce carbon emissions and mitigate climate change.

The use of a NEC Partnering contract between the design team, Contractor and housing developer is particularly helpful when innovative technologies and construction techniques are being deployed, and is recommended to be used more widely by housing developers.

The installation and commissioning processes on this development have been relatively robust. However, the assurance of correct MVHR settings and performance is an issue which needs wider improvement in the industry. This requires manufacturers to develop improved products, and more training and certification for site operatives and installers. In particular, it is recommended that product manufacturers carry out more detailed field studies in housing developments to understand the impact of their products in-situ and on residents.

10.6 Managing changes to the design

As with many housing developments, changes to the design took place due to the need to save costs at tender stage. This is a particularly tricky process to manage with ‘zero carbon’ and Passivhaus housing as the margins for change are narrower, given the need for exceptional high performance. Cutting down on space is the obvious thing to do, given that the technologies have to remain in place, but this can lead to consequential issues such as not being able to accommodate enough storage or furniture in rooms. It may be better to make savings on items that can be upgraded more easily in the future.

The construction audit and thermographic survey in this study revealed a small number of anomalies relating to the insulation of the loft and heating pipework. These can be traced back to design changes in some cases, the thermal consequences of which were not always apparent to the Contractor and site operatives. Given the exacting demands of ‘zero carbon’ and Passivhaus standards, the construction industry will need to significantly improve the level of training given to site operatives particularly in relation to the implication of construction changes on thermal performance.

10.7 The role of feedback in achieving ‘zero carbon housing’

Feedback is a two way process in housing – the design team, project manager and contractor need to know what is working well and what needs attention using feedback from the residents, but at the same time the residents need to be told how to feedback effectively. They need to know who to report what to and when. This should be clearly communicated in guidance documentation and through training sessions, particularly for new residents. As housing technologies become more complex, simply systems for providing feedback become more essential and housing developers will need to invest more in developing these.

Occupants also need feedback from the various technologies in their home to tell them whether their home is performing as it should. At the moment feedback from energy and environmental control systems is patchy – some provide good feedback which tells them how much energy they are using on an hourly, daily, monthly and annual basis, others do not. Equally some systems are good at telling occupants whether they are functioning correctly, others are not. The manufacturing industry needs to rapidly improve these technologies to ensure the occupants know what is going on in an easy to understand way.

During this study, interim findings and final findings have been fed back to the residents, design team, contractor and Project Manager with an ongoing dialogue that has resulted in improvements being made to the development during the process of the study. This is the best that can be hoped for – an honest feedback loop where all are striving to ensure continuous product improvement.

Findings from the study have also been delivered as part of a ‘Soft Landings’ seminar at Ecobuild 2013, ensuring a wide audience, and to the Good Homes Alliance – a leading organisation for improving housing development in the UK. The work will also be presented to the UK Co-housing Network and it is anticipated that it will be disseminated internationally at the Passive Low Energy Architecture International Conference in September 2013. The authors of this study are involved in a wide array of housing performance studies and it is anticipated that this study will be compared to other Passivhaus housing developments which have carried out BPE studies as well as to the LILAC Co-housing development completed in Leeds in April 2013, where an extensive BPE study is being carried out by one of the authors.

10.8 Conclusions and key findings for this section

Considering this study as a whole, it is clear that the Lancaster Co-housing development has performed exceptionally well during the post-construction and initial occupancy phase and has largely achieved its high ambitions in terms of design. There are a number of positive lessons and recommendations which, if taken on board by the wider housing industry, should help to significantly improve housing procurement, design and construction in the UK. It is clear that the rigour of the Passivhaus design and construction process can help to significantly narrow the performance gap in housing.

The study has highlighted areas needing further improvement, particularly in relation to helping residents understand how to use their homes efficiently, the specification of usable environmental controls and the handover process.

The limitations of this study are that it has only covered the first few months of occupation. Further studies are needed to see how well the development performs over the whole year and whether energy targets are actually being met, beyond the fabric performance achievements.

Studying this co-housing development has revealed the opportunities for further carbon reduction in housing developments through sharing resources and the changes in lifestyles that ensue from this. Clearly co-housing is not for everyone, given the intensive engagement it demands, particularly during the procurement stage. What it does offer, however, is another housing option that is clearly very satisfying for almost all of the residents living in the Lancaster co-housing development. This bodes well for the future of co-housing development in the UK.

11 Appendices

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

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

1. Post Construction and Early Occupation Study – Lancaster Co-Housing Design Review Report Authors: Matthew Peat, Dr David Johnston, Dominic Miles-Shenton, David Farmer, Centre for the Built Environment, Leeds Metropolitan University
2. Post Construction and Early Occupation Study - Lancaster Co-Housing Construction review Report. Authors: Dr David Johnston, Dominic Miles-Shenton, David Farmer, Matthew Peat, Centre for the Built Environment, Leeds Metropolitan University
3. Post Construction and Early Occupation Study - Lancaster Co-Housing Pressurisation Test Report. Authors: Dr David Johnston, Dominic Miles-Shenton, David Farmer, Matthew Peat, Centre for the Built Environment, Leeds Metropolitan University
4. Post Construction and Early Occupation Study – Lancaster Co-Housing Coheating Test Report Authors: Dr David Johnston, Dominic Miles-Shenton, David Farmer, Matthew Peat, Centre for the Built Environment, Leeds Metropolitan University
5. Post Construction and Early Occupation Study – Lancaster Co-Housing Heat Flux Measurement Report Authors: David Farmer, Dr David Johnston, Matthew Peat, Dominic Miles-Shenton, Centre for the Built Environment, Leeds Metropolitan University
6. Post Construction and Early Occupation Study – Lancaster Co-Thermography Report Authors: David Farmer, Dr David Johnston, Dominic Miles-Shenton, Matthew Peat, Centre for the Built Environment, Leeds Metropolitan University
7. Lancaster Co-housing Development TSB Building Performance Evaluation Phase 1 Project No.450095 -Forgebank Design Intentions Report. Authors: Professor Fionn Stevenson, The University of Sheffield
8. Lancaster Co-housing Development TSB Building Performance Evaluation Phase 1 Project No.450095 -Forgebank Home User Guidance Review. Authors: Kate Fewson, Closed Loop Projects, Professor Fionn Stevenson, The University of Sheffield.
9. Lancaster Co-housing Development TSB Building Performance Evaluation Phase 1 Project No.450095 -Forgebank Demonstration Report. Authors: Kate Fewson, Closed Loop Projects, Professor Fionn Stevenson, The University of Sheffield.

10. Lancaster Co-housing Development TSB Building Performance Evaluation Phase 1 Project No.450095 - Forgebank BUS Questionnaire Report. Authors: Kate Fewson, Closed Loop Projects, Professor Fionn Stevenson, The University of Sheffield.

11. Lancaster Co-housing Development TSB Building Performance Evaluation Phase 1 Project No.450095 - Forgebank Interview Report. Authors: Kate Fewson, Closed Loop Projects, Professor Fionn Stevenson, The University of Sheffield.

12. Lancaster Co-housing Development TSB Building Performance Evaluation Phase 1 Project No.450095 - Controls Interface Review. Authors: Kate Fewson, Closed Loop Projects, Professor Fionn Stevenson, The University of Sheffield.

13. Post Construction and Early Occupation Study – Lancaster Co-Housing Installation and Commissioning Report. Authors: Dr David Johnston, Dominic Miles-Shenton, David Farmer, Matthew Peat, Centre for the Built Environment, Leeds Metropolitan University

In addition to the above reports, there is also a design and as-built SAP worksheet and a pre-construction based PHPP assessment,