Community In A Cube

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InnovateUK project number	450052
Project author	Leeds Beckett University for the Good Homes Alliance
Report date	2013
[1]InnovateUK Evaluator	N/A

No of dwellings	**Location**	**Type**	**Constructed**
Single apartment	Middlesborough	Flat	2011
Area (TFA measured)	**Construction form**	**Space heating target**	**Certification level**
42.9 m^2	Concrete frame	N/A	Building Regulations

Background to evaluation

The apartment studied formed part of a zero carbon, residential-led, mixed-use development comprising 80 residential units and retail/leisure space. The apartment building adopted the BioRegional and WWF International 10 One Planet Living principles (Bioregional Quintain, 2012[2]). The apartment was heated using a communal biomass-fuelled boiler. The scope of the project was limited to the post-construction and initial occupation stages and consisted of physical tests alongside occupant satisfaction analyses.

[2]BioRegional Quintain (2012). *One Planet Living*. London, Bioregional Quintain. Available from http://www.bioregional-quintain.com/one-planet-living

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

Physical tests and energy analysis included a co-heating test air-pressurisation tests, a SAP check, design and construction review, thermographic survey, heat flux measurements, and an installation and commissioning review of systems and services. However, difficulties were encountered while measuring the total heat loss for the apartment, which was outside the control of the research team. Although the apartment tested was found to be of average airtightness by prevailing UK standards it was leakier than would normally be the case with MVHR. The MVHR system was not performing as intended and was probably not commissioned *in situ*. Heat flux measurements also revealed that, with the exception of the windows, the external elements failed to perform close to their design specification. Limited commissioning data was available.

Occupant survey type	**Survey sample (all apartments)**	**Structured interview**
BUS domestic	3 of 57 (5% response rate)	With building manager

Many apartments were unoccupied during the time allocated for BUS questionnaire surveying. Furthermore, the majority of occupied apartments were inhabited by temporary overseas workers, who were attending a six-month training course in the local area. As a result, there was a very poor return rate. Discounting temporary workers, at the time of BUS distribution there were nine permanent occupants. This improved the return rate to 33%, but the sample size was still too small to be considered broadly informative.

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.

1.1 Introduction

This report outlines the findings from a post-construction and initial occupation study (project no. 450052) that was undertaken on a one bedroom 42 m^2 apartment as part of a Technology Strategy Board Building Performance Evaluation Competition. The apartment was completed in December 2011 at Middlehaven, Middlesborough, and the project was carried out by Leeds Metropolitan University in association with the Good Homes Alliance (GHA). The studies were carried out over a seventeen month period from February 2012 to June 2013.

The apartment, that is the subject of this study, forms part of a zero carbon residential-led mixed-use development comprising 80 residential units and retail/leisure space. The building which was designed by FAT architects (responsible for the conceptual design) and was developed by Devereux (the Project Architect) for the client, Bioregional Quintain. It is based upon a simple cubic form, and is constructed over 9 storeys, with the retail and leisure space occupying the ground floor. A range of studios, 1 and 2 bedroom apartments occupy levels one to six, and on levels seven and eight, loft-style living is accommodated via a number of 2 bedroom 'skyhome' apartments. All of the apartments benefit from dual aspect large windows, high ceilings and exposed concrete soffits. The apartments also have broadband, secure covered cycle storage facilities, dedicated parking, electric vehicle charging points and selected apartments have private amenity space. There is also a communal garden located on the first level. The building also adopts the Bioregional and WWF International 10 One Planet Living® principles (Bioregional Quintain, 2012). These principles are designed to provide a comprehensive and lifestyle-orientated approach to sustainability, by making it easy, attractive and affordable to live sustainably.

In terms of location and amenities, the building is located alongside the dock area in Middlesborough, close to the Riverside Stadium (home to Middlesbrough Football Club). It is only a few minutes' walk away from the centre of the town and Middlesbrough railway station is only a 10-15 minute walk away. The North Sea coast is only 10km away.

The building is first to be constructed as part of the Riverside One development, a 40 acre £200 million regeneration project, which will comprise a total of 16 buildings, providing residential accommodation, commercial opportunities and community spaces. It is intended that the regeneration will be undertaken in a number of separate phases. However, due to the current economic climate, the regeneration of this area of Middlesborough has been temporarily halted until more favourable economic conditions prevail. Therefore, construction has not commenced of any of the other 15 buildings proposed for the Riverside One development. This has had implications for the energy strategy adopted within the building, as it was originally designed to use a district system that was intended to supply a number of other buildings on the development. Consequently, the energy strategy within the building had to be revised during construction and now comprises a biomass fuelled communal boiler located on the ground floor. This has had architectural implications for the building, as a wood pellet fuel store had to be added to the ground floor of the building.

1.2 Scope of the Project

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 one of the apartments 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 and a review of the handover and home user guidance.

1.3 Key Findings

The key findings from the project are that the apartment has unfortunately not fulfilled the design intentions. A number of difficulties were encountered whilst measuring the total heat loss for the apartment, which were outside the control of the research team (Leeds Metropolitan University). Although considerable effort and a number of interventions were made during the coheating tests in an attempt to counteract some of these issues, unfortunately, it has not been possible to derive a reliable heat loss figure for the apartment. Despite this a considerable amount of learning was gained by the research team regarding the issues involved in testing apartments, and these issues have been incorporated within the latest iteration of the Leeds Metropolitan University Whole House Heat Loss (Coheating) testing methodology.

In terms of building fabric, although the apartment tested is of average airtightness by UK standards it is leakier than would normally be the case when an MVHR system is to be installed. Heat flux measurements also revealed that, with the exception of the windows, the external elements measured failed to perform close to their design specification. Measurement of the party elements also revealed the problems that can be encountered in dwellings due to ‘heat stealing’. In addition, some significant areas of unexpected heat loss were identified during the thermal imaging surveys, most notably at the separating/external wall junction on the West elevation, through the trickle ventilators and through the concrete frame of the building. The thermal imaging also revealed unregulated heat gain from the poorly insulated IHU as well as the uninsulated communal heat main.

Although all of the services appear to have been installed as designed, very limited commissioning data has been provided. This may in part be a consequence of the fact that the mechanical and electrical contractor on the project has ceased trading. Despite this, observations of the installed lighting, space and water heating system appears to indicate that they have been installed correctly. However, there are a number of sections of pipework, both within the test apartment, and out-with the test apartment where the insulation is not continuous. This is likely to result in increased heat loss from this pipework.

A number of significant issues have been identified with the MVHR system. These issues relate to the design of the system, the layout and type of air supply and extract valves used and filter access. These issues, coupled with the duct flow measurements, suggest that the MVHR system is not performing as intended and has never been commissioned in situ. The lack of appropriate ventilation to the apartments, in conjunction with the unregulated heat gain from the IHU and uninsulated pipework, particularly during the summer, is likely to contribute to overheating within the apartments. Consequently, measures will need to be undertaken by the client to ensure that the MVHR system is fully operational and maintainable, delivers the required flow rates and provides sufficient ventilation to all areas of the apartment.

1.4 References

BIOREGIONAL QUINTAIN (2012) *One Planet Living* [Internet]. London, Bioregional Quintain. Available from:< http://www.bioregional-quintain.com/one-planet-living> [Accessed 25th September 2012].

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 concept design for the building was developed by FAT Architects, whilst the detailed design was developed by Devereux (the Project Architects). The mechanical and electrical design was developed by DSSR Consulting and the main contractor for the development was GB Group. The client, Bioregional Quintain, took the building design to the RIBA Plan of Work Stage E – building regulations design, with the contractor, GB Group, developing the proposal from Stage E onwards.

The development is based upon a simple cubic form, and is constructed over 9 storeys, with the retail and leisure space occupying the ground floor. A range of studios, 1 and 2 bedroom apartments occupy levels one to six, and on levels seven and eight, loft-style living is accommodated via a number of 2 bedroom ‘skyhome’ apartments. All of the apartments benefit from dual aspect large windows, high ceilings and exposed concrete soffits.

The study apartment is one of ten one bedroom apartments of the same form on the development. representing 12.5% of all of the apartments in the building. Five of these apartments are orientated along the South and West façade of the building on Levels 2, 3, 4, 5 and 6, whilst the other five are located along the South and East façade of the building on Level 2, 3, 4, 5 and 6.

The study apartment is located on the 5th floor of the building (see Figure 1). It comprises an open-plan living/kitchen area which is located along the South and West façade of the building, a West-facing bedroom and a South-facing bathroom. An internal storage cupboard is located in the hallway which houses the main consumer unit for the dwelling and the Integrated Heating Unit (IHU). The layout of the apartment is illustrated in Figure 2.

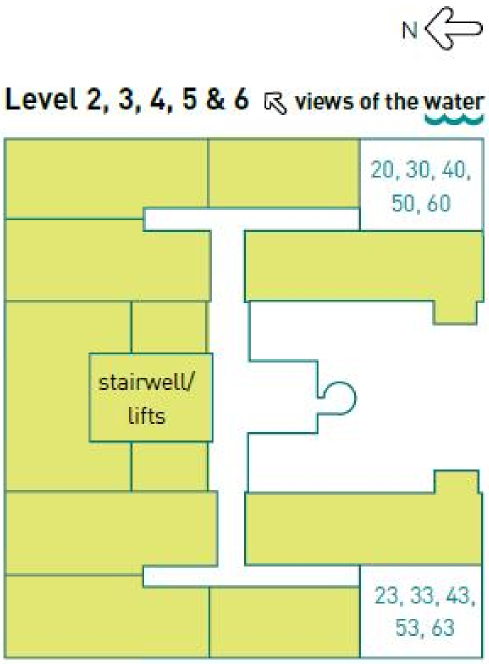


Figure 1 The apartment.

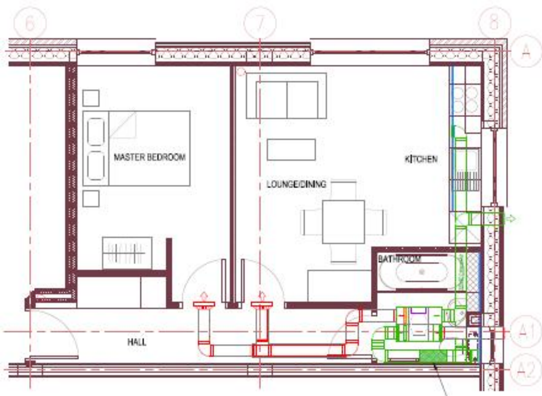


Figure 2 layout of the apartment (handed version).

The building is of a concrete frame construction.The external walls of the apartment generally comprise in-situ site-built timber-frame in-fill panels which are clad externally with either a brick skin or timber cladding. Some of these panels have been constructed around the concrete columns which form part of the building structure. These columns are likely to constitute a thermal bridge if not appropriately insulated. In addition, there is also a glass privacy panel located beneath the bathroom and kitchen window. The windows are double-glazed argon filled low-e aluminium faced composite units (aluminium/insulation/timber) and the doors are timber. 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 3 $m^3/(h.m^2)$ @ 50Pa.

Element	U-value (W/m^2K)
External walls	0.19 Timber clad external wall 0.18 Brick clad external wall 0.19 Brick clad external wall with concrete column
Partition walls between apartment and corridor	0.32
Windows	1.30 (target)
Doors	0.63

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

2.2 Design review

Unfortunately, despite numerous efforts, it has not been possible to obtain a full set of design drawings, as-built drawings or the as-built SAP worksheets for the test apartment. This in part may be due to the fact that the Project Architect and client ceasing trading shortly after practical completion, as a direct result of the poor economic climate. To avoid the loss of such important design information in future projects, it would be advisable to adopt a robust method for storing and documenting the design information at key stages of the process, so that such information can be recovered if firms cease trading either during or shortly after construction of the building. Consequently, it was only possible to undertake the design review on the limited amount of information that was made available to the research team (see Appendix 1). The design review found that a number of changes and challenges were encountered during the construction. These were as follows:

- It was not possible to ensure that all of the materials used to construct the building were locally sourced. Despite this, the building was built by a Yorkshire based contractor who used local labour, where possible, in order to address point 4 of the One Planet Living® principles.
- An error was made by the main contractor when ordering all of the windows for the development, resulting in all of the windows being specified with trickle ventilators. Unfortunately, this issue was not identified until the windows arrived on-site. To rectify the problem, it was decided that all of the trickle ventilators would be sealed on-site. Observations and leakage detection undertaken during the pressure tests revealed that the trickle ventilators have not been sealed on-site, and are in fact fully functioning, despite the client being of the opinion that all of the trickle ventilators have been sealed. They were also identified during leakage detection as one of the main sources of air leakage. Consequently, one implication of this ordering error has been an increase in the background leakage rate of the apartment.
- The mechanical and electrical contractor also ceased trading during the construction phase, resulting in another contractor having to takeover mid-construction. Furthermore, an original subcontractor unfortunately passed away, during the construction phase. These issues caused significant disruption to the construction of CIAC, with impact on time scales and delivery. In addition, issues were also experienced with the commissioning and the delivery of the operation and maintenance manuals.

- The company responsible for the MVHR systems would not visit the site and take ownership of their system, which may explain the incomplete training on the MVHR installation, and the subsequent poor performance.

In addition to these changes and challenges, the design review also revealed the following:

- Due to the lack of information provided, it has not been possible to ascertain whether any changes were made to the U-values of the main construction elements beyond those stated within the design documentation and the design SAP worksheet.
- There is a lack of detail regarding the U-values associated with the main construction elements contained within the test apartment. Construction details and U-values are not available for all of the external wall types for the test apartment. In addition, regarding the information that is available, it is not always clear from the documentation which areas of the building the design based information relates to. The U-value given in the documentation for the timber door from the apartment to the corridor is also unrealistic. A more representative U-value for a solid timber door would be 2.2 W/m^{2}K.
- The primary air barrier is not identified on any of the drawings for the test apartment. In addition, no pen-on-section test has been undertaken on this apartment to the best of our knowledge, to check the continuity of the air barrier. A pen-on-section test involves using a pen line to mark the location of the primary air barrier on a set of General Arrangement drawings. The line should be continuous and separate the heated (conditioned) spaces from the unheated (unconditioned) spaces. It is used to identify areas of the fabric that will require.additional detailing and attention to detail with respect to airtightness,
- There is some considerable confusion over the air permeability target for the test apartment, as well as the entire development. Conversations with the client revealed that the air permeability target for the apartments was 3 m^3/(h.m^2) @ 50Pa. This is consistent with the value contained within the design SAP worksheet dated 9th November 2010 for a typical 2 bedroom 65m^2 apartment. However, the design SAP worksheet dated 7th August 2011 for the test apartment contains an air permeability target of 10 m^3/(h.m^2) @ 50Pa. Discussions with the client revealed that they were of the opinion that no changes had been made to the air permeability target for the apartments. The research team have not found any documentary evidence to support any revision to the air permeability target.

Unfortunately, as it has not been possible to obtain a copy of the as-built SAP worksheet for the apartment, no comparison between the design and the as-built SAP worksheet has been undertaken. Despite this, an analysis of the available design SAP worksheet was undertaken. The analysis revealed a number of issues associated with the design SAP worksheet. These issues were as follows:

- **Areas –** an on-site measured survey of the apartment has identified a number of discrepancies in the areas of various elements (see Table 2). Although some small differences in areas are to be expected, the 5m^2 or so difference observed in the floor area is considerably greater than expected, particularly for such a small one bedroom apartment.

Element	Design SAP worksheet	Measured survey
Floor area	48.2m^2	42.95m^2
External wall area	27.46m^2	26.09m^2
Windows	8.85m^2	8.55m^2
Doors	1.89m^2	1.94m^2

Table 2 Discrepancies in areas between design SAP worksheet and measured survey.

- **Air permeability –** An air permeability target of 10 m^3/(h.m^2) @ 50Pa has been used within the SAP worksheet, compared to the design air permeability target of 3 m^3/(h.m^2) @ 50Pa.

The target of 10 $m^3/(h.m^2)$ @ 50Pa seems unrealistic, particularly given the fact that the apartment has been designed to incorporate a MVHR system. A design target of ≤3 $m^3/(h.m^2)$ @ 50Pa is usually specified if an MVHR system is to be used.

- **Adjusted infiltration rate –** Based upon the figures contained within the SAP worksheet, this figure should be calculated to be 0.43ach, rather than the 0.48 stated.
- **Fabric U-values –** Three separate external wall areas are contained within the design SAP worksheet. It is also not clear from the SAP worksheet what these wall areas relate to, as there are 5 separate external wall types on the apartment tested. In addition, there is also a small area of wall around the door of the apartment (0.53m^2) to the unheated corridor. Of the six wall types constructed, 3 of them have not been identified within the SAP worksheet. However, due to the lack of information provided in the SAP worksheet, it is not possible to be certain which 3 wall types have been excluded from this worksheet.
- **Thermal bridging –** An aggregate y value of 0.04W/m^2K had been assumed. This assumes that the apartment has been constructed in accordance with the complete set of three Enhanced Construction Details, where appropriate, and that the remaining details achieve the Accredited Construction Detail standards. As it has not been possible to obtain any construction details for the test apartment, it is not possible to determine whether the use of an aggregate y value of 0.04 is appropriate or not.
- **Internal gains –** The internal gains from lights, appliances cooking and metabolic are stated as 418.79 W in the SAP worksheet. In accordance with table 5 of SAP, they should be 323 W.
- **Solar gains –** The area of South and West facing glazing contained within the SAP worksheet does not correlate with the areas of glazing obtained from the measured survey. An analysis of the areas of each of the windows suggests that the area of the South-facing kitchen window (1.88m^2) has been added onto the West-facing glazing in the SAP worksheet, rather than being included within the area of South-facing glazing. The net effect of this error is a small increase in total solar gains using the measured survey data of almost 9W.

Although the precise effect of all of the above issues on the design SAP assessment is outside the scope of this project, it is clear that if the correct information was used as input to the worksheet, a poorer assessment is likely to have been obtained and the apartment may even have failed to meet the regulatory target emission rate. However, errors in the data that is used as input into SAP is not unusual. A study of input errors in the application of SAP for new dwellings found errors in 56 out of 82 assessments (68%), and that when corrected, about 20% of the dwellings failed to meet the regulatory target emission rate (Trinick, Elliott, Green Sheperd amd Orme,2009). This study, along with the work undertaken by Trinick et al. (2009), highlights the requirement for much greater control of SAP and the need for the development and implementation of a quality control process that will minimise these input errors.

2.3 Construction review

It was only possible to undertake one set of site observations on the apartments during the construction phase. The observations took place after the majority of the superstructure had been completed and the majority of the building was wind and watertight. The observations highlighted a number of issues that had the potential to have an adverse effect on the as-built performance of the apartment. These were as follows:

- **Application of airtightness tapes –** Various tapes and membranes had not been used to seal various interfaces within the apartments. In a number of places, the tape had either begun to lose adhesion or had only been fixed at the edge and had not been stuck down across the entire width of the tape, leaving an air gap behind, increasing the risk of failure. If not addressed, this is likely to result in an increased in air leakage through the building envelope.
- **Holes in timber-frame in-fill panel –** Additional holes had been cut into the timber-frame in-fill panel for the MVHR extracts. Removal of the OSB and original tape raises questions on how these will be re-sealed in order to maintain continuity of the air barrier, particularly given that the extract is now sealed to the frame and not the OSB. This may result in an increase in air leakage at this junction.

- **Location of services in party wall –** Numerous services have been installed within the frame of the party wall, rather than through an internal service void.. This will make it difficult to install the insulation effectively. Insulation may not be fully installed or may be over-compressed, reducing its effectiveness. Also raises issues on acoustic performance between the dwellings. If not addressed, there is likely to be heat and noise transfer between adjacent dwellings. Any additional heat transfer will not have been accounted for in the design assessment.
- **Insulation bridging across party wall –** Insulation was observed bridging across party wall, rather than being restrained within the individual frame sections on party wall, limiting its effectiveness.
- **Insulation of privacy panel beneath bathroom window –** It is unclear how the privacy panel beneath window in bathrooms will be adequately insulated for condensation to be prevented on the inner face, potentially resulting in water pooling on the frame forming the sill below it. If condensation does form on this surface, this may result in degradation of the building fabric and increased heat loss.
- **Sealing of party walls –** Party walls and walls to communal areas do not appear to be sealed to the concrete ceilings with the same regard to airtightness as the external walls. This may lead to air leakage between adjacent apartments.
- **Holes in party elements** – A number of holes from services that penetrate through party elements remain, allowing indirect air leakage paths.
- **Retainment of partial fill insulation –** Partial fill insulation is not securely retained against inner face of blockwork at ground floor level. Retaining clips for insulation are also missing. There is the potential for a thermal bypass to form between the insulation and the inner leaf of blockwork, limiting the effectiveness of the insulation.

Photographs of a number of the identified issues are contained within Figure 3,Figure 4, Figure 5 and Figure 6.

Figure 3 Loss of adhesion from tape and gaps in tape at corners of windows.

Figure 4 Insulation bridging across party wall.

Figure 5 Services installed within party wall.

Figure 6 Partial fill insulation not securely retained at ground floor.

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.

Although the precise effect of all of the above issues, on the performance of the study apartment is outside the scope of this project, it is clear that if the issues identified were not addressed later on in the construction process, then the thermal and acoustic performance of the apartment is likely to be compromised and be poorer than intended, and there may be a risk of degradation of the building fabric due to the formation of condensation. In addition, the apartment may even fail to meet the as-designed regulatory target emission rate.

A number of the construction issues identified could be avoided if appropriate quality control processes were in place to monitor insulation and airtightness measures during construction, and if the workforce was appropriately educated to understand the potential implications of the incorrect installation of various measures. It would also be beneficial if each site adopted a dedicated airtightness and thermal insulation champion.

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

2.4 Conclusions and key findings

It is clear from the design review and the observations made of the apartment as-built, that a number of the design intentions were not fulfilled. One of the reasons for this may be in part due to the fact that a number of key stakeholders involved in the project ceased trading either during or immediately after completion of the project, as a direct result of the poor economic climate. In addition, one subcontractor also passed away during the construction phase. This is likely to have resulted in some of the design information not being passed on from one stakeholder to another. To avoid the loss of such important design information in future projects, it would be advisable to adopt a robust method for storing and documenting the design information at key stages of the process, so that such information can be recovered if firms cease trading either during or shortly after construction of the building.

Another reason may be due to the fact that a number of input errors were identified within the design SAP assessment. Although the precise effect of the input errors issues on the design SAP assessment is outside the scope of this project, it is clear that if the correct information was used as input to the worksheet, a poorer assessment is likely to have been obtained and the apartment may even have failed to meet the regulatory target emission rate. However, it should be noted that such input errors are not uncommon (see Trinick et al., 2009). This study, along with the work undertaken by Trinick et al. (2009), highlights the requirement for much greater control of SAP and the need for the development and implementation of a quality control process that will minimise these input errors.

The design review and construction observations also revealed a number of issues that, if not adequately addressed, did have the potential to have an adverse effect on the thermal and acoustic performance of the apartment, and may even result in the degradation of the building fabric, due to the formulation of condensation. In addition, they may also have led to the apartment failing to meet the regulatory carbon emission rate contained within Part L of the Building Regulations. The issues identified ranged from the inappropriate application of airtightness tapes to poor installation of services and thermal insulation. It is felt that a number of these issues could be avoided if appropriate quality control processes were in place to monitor insulation and airtightness measures during construction, and if the workforce was appropriately educated to understand the potential implications of the incorrect installation of various measures. For instance, it would be beneficial if each site adopted a dedicated airtightness and thermal insulation champion.

2.5 References

TRINICK, J. ELLIOTT, E. GREEN, M. SHEPHERD, J. and ORME, M. (2009) EEPH / CLG Research into Compliance with Part L of the Building Regulations for New Homes – Phase 2 Main Report. Faber Maunsell, AECOM.

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 13th February to the 16th May 2012. It comprised:

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

3.2 Pressurisation testing and leakage detection

There is some confusion over the air permeability target for the test apartment, with figures of 3 and 10 $m^3/(h.m^2)$ @ 50Pa being stated. In addition, no strategy has been identified to achieve the airtightness target. The test apartment was pressure tested immediately prior to and after the coheating test. The results of the tests are detailed within Table 3.

Dwelling	Date	Depressurisation only	Pressurisation only	Mean Air Permeability	Comment
		$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	$m^3.h^{-1}.m^{-2}$ @ 50Pa	
Apartment	13/02/12	5.69	5.16	5.43	Pre coheating test
	16/05/12	5.57	5.66	5.61	Post coheating test

Table 3 Pressure test results.

The results indicate that although the apartment is of average airtightness by UK standards, despite having no identified primary air barrier, it does achieve an air permeability figure that is significantly lower than the designed target of 10 $m^3.h^{-1}.m^{-2}$ @ 50Pa that is contained within the design SAP worksheet. However, it is important to note that the design target of 10 $m^3/(h.m^2)$ @ 50Pa for this apartment seems unrealistic, particularly given the fact that the apartment has been designed to incorporate a MVHR system. A design target of ≤3 $m^3/(h.m^2)$ @ 50Pa is usually specified if an MVHR system is to be used and 3 $m^3/(h.m^2)$ @ 50Pawas the design target previously stated by the client (see Section 2.2). The results also indicate that there has been effectively no increase in the air permeability of the dwellings as a result of the elevated temperatures experienced during the coheating test. This suggests that the apartment was fully dried out when the coheating test took place.

A comparison was also made between the LeedsMet test and those undertaken by an external contractor for Building Regulations compliance purposes. This revealed that the LeedsMet results were comparable with those obtained from the external contractor.

Leakage identification revealed only very small amounts of air leakage. The areas identified were as follows:

- Under the window sills at the junction between the sill and the plasterboard lining.
- Small amounts of leakage into electrical sockets on external walls.
- At the top of the closed trickle ventilators – this was the most significant area of air leakage..
- Small amounts of leakage at the exposed ceiling/external wall junction.
- Into the suspended ceiling void in the bathroom.
- At the base of the wash hand basin in the bathroom.
- Through the ventilation gap in the bathroom into the suspended ceiling void.
- Through the ventilation gap in the kitchen/living area into the suspended ceiling void.
- At the external wall/party wall/ground floor junction in the bedroom.

To the research team's knowledge, no measures have been undertaken to address the areas of air leakage noted above.

In future projects, in order to minimise air leakage and achieve a level of airtightness that is commensurate with the adoption of MVHR, it is advised that an airtightness strategy is adopted. This is likely to comprise:

- A well thought through, properly designed and properly executed primary air barrier.
- Adoption of a formal and well communicated airtightness target (≤ 3 $m^3.h^{-1}.m^{-2}$ @ 50Pa if an MVHR system is to be used).
- 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.

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

3.3 Coheating test

The coheating test was undertaken on the test apartment over the period 14th February to the 4th May 2012. Unfortunately, a number of significant difficulties were experienced undertaking the coheating test on the test apartment, which were outside the control of the research team (Leeds Metropolitan University). These can be summarised as follows:

- Shortly after commencing the coheating test, it was observed that heat was still being supplied from the communal heat main to the IHU located within the apartment. It took some time (until 27th March 2012) to be able to isolate the flow of heat from the communal heat main to the IHU within the test apartment. This appears to have been due to a lack of isolation valves and a lack of understanding regarding the communal heating system.
- Soon after isolating any flow of heat from the communal main into the apartment, a period of unseasonably high external temperatures and high levels of solar radiation was experienced.

To counteract the weather conditions, the mean elevated temperature within the test apartment and the adjacent apartments was increased to 28°C on the 11th April 2012.

- Several days after increasing the temperature to 28°C, the temperature controller in the bedroom of the test apartment failed, resulting in the electric heater supplying heat at a relatively constant rate to the bedroom, irrespective on the internal temperature of this room.
- On the 24th April 2012, it was observed that heat had started to flow back into the test apartment from the communal heat main.

Although considerable effort and a number of interventions were made during the coheating tests in an attempt to counteract some of these issues (see Appendix 3), due to the difficulties experienced in undertaking the coheating test within the apartment, of the 7 weeks or so of coheating data that was recorded, it was only possible to obtain 9 days of usable data.

An analysis of the useable data revealed an ineffective Siviour and multiple regression analysis, due to the dependency of ΔT and solar insolation. This is problem that can occur when undertaking coheating tests in the swing seasons. Therefore, an alternative analysis technique was used. This technique involved manually calculating the solar aperture for the test apartment and then using the data obtained to correct the raw heat loss data. Using this technique, the solar corrected heat loss for the test apartment was 39.4 W/K (the design based SAP assessment was 42.7 W/K). However, due to the small number of useable data points available, coupled with the problems that were encountered undertaking the Siviour and the multivariate regression analysis, the heat loss coefficient figure obtained for the test apartment is not deemed to be reliable. Despite this a considerable amount of learning was gained by the research team regarding the issues involved in testing apartments. These issues have been incorporated within the latest iteration of the Leeds Metropolitan University Whole House Heat Loss (Coheating) testing methodology (see Johnston, Miles-Shenton, Farmer and Wingfield, 2013).

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

3.4 Heat flux measurements

During the course of the coheating test, 30 heat flux plates were strategically positioned at various locations on the test apartment'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 plates could only be positioned on external elements which were subject to direct solar radiation due to the dwelling orientation; therefore effective U-values presented may not be representative of each thermal element as a whole.

Measurements obtained on the timber panel section of external wall, at the location deemed to be least influenced by thermal bridging, resulted in a mean calculated effective U-value of 0.25 W/m^{2}K, with a standard deviation of 0.03 W/m^{2}K. Daily effective U-values at this location ranged between 0.18 W/m^{2}K to 0.30 W/m^{2}K. This value represents a discrepancy of 0.06 W/m2K from the specified design value of 0.19 W/m^{2}K. The discrepancy is outside the range of error associated with the test procedure, the reason for its magnitude could not be established using non-destructive testing methods available to the research team. It is important to realise that the level of heat flux measured was influenced by exposure to direct solar radiation on the façade of the building; this reduces confidence in the result presented. As exposure to direct solar radiation will reduce the rate at which heat is lost from this element, it is quite possible that the daily effective U-value could be higher than that measured.

Measurements obtained on the concrete column section of external wall, resulted in a mean calculated effective U-value of 0.42 W/m^{2}K, with a standard deviation of 0.06 W/m^{2}K. Daily effective U-values at this location ranged between 0.32 W/m²K to 0.66 W/m²K. This value represents a discrepancy of 0.21 W/m²K from the specified design value of 0.21 W/m²K. The discrepancy is outside the range of error associated with the test procedure, the reason for its magnitude could not be established using non-destructive testing methods available to the research team. Again, it is important to realise that the level of heat flux measured was influenced by thermal mass effects and exposure to solar radiation on the internal and external surfaces of the element; this reduces confidence in the result presented. As exposure to solar radiation will reduce the rate at which heat is lost from this element, it is quite possible that the daily effective U-value could be quite different to that measured.

With respect t the windows, the mean calculated centre pane effective U-value for the kitchen and bedroom windows was 1.41 W/m²K, with a standard deviation of 0.006 W/m²K. Daily effective U-values ranged between 1.33 W/m²K to 1.54 W/m²K. The calculated U-value compares favourably with the specified design value of 1.24 W/m²K.

Heat flux measurement of the party elements (floor, ceiling and walls) revealed that the primary driver for heat transfer in these elements was the temperature differential between neighbouring dwellings, not the temperature difference with the external environment. Although all the party elements have a specified design value of 0 W/m²K, in reality this is only achieved if there is no temperature difference between neighbouring dwellings. Calculation of effective U-value using the temperature differential between dwellings, rather than the external environment, resulted in an effective U-value for the party floor and party ceiling of 1.22 W/m²K. Measurements undertaken on the internal concrete column of the building frame also revealed that the superstructure could be acting as heat transfer mechanism between apartments in other areas of the building at a lower temperature. If this is the case, then the actual heat loss from the apartment is likely to be much larger than intended, as the additional heat loss through the superstructure into adjacent apartments has not been accounted for. As this apartment was built to Part L 2006, this additional heat loss was not accounted for within the then applicable edition of the Building Regulations. Part L of the Building Regulations has since been amended to account for heat loss through party walls, but not other elements of the superstructure, such as floors or ceilings.

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

3.5 Thermographic survey

A series of Infra-red thermographic surveys were undertaken on the test apartment on a number of different days under various different weather conditions. Overall, the surveys revealed the following:

- Excessive thermal bridging was visible at the junction between separating floor and external wall. This observation was made at the wall/separating floor junction in several apartments located on the West elevation, suggesting inadequate design or construction of this junction.
- Ineffective sealing around the windows resulted in areas of greater than expected heat loss due to air infiltration.
- Air infiltration was observed through trickle vents in the closed position of all windows in the test apartment, suggesting poor design or manufacture. These vents were supposed to be permanently sealed by the contractor due to improper specification, it is evident this was not undertaken.
- Unregulated heat gain from the poorly insulated integrated heat unit (IHU) and uninsulated communal heat main pipework was transferring heat into the hallway and bedroom of the test apartment.
- Unhindered heat transfer between apartments was evident through the uninsulated party/wall ceiling.
- The concrete frame of the building, both internal and external, was acting as a conduit for heat transfer throughout the superstructure.

To the research team's knowledge, none of the above issues have been rectified.

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

3.6 Conclusions and key findings for this section

A series of fabric tests have been undertaken on the test apartment. These tests have revealed that the apartment is of average airtightness by UK standards. The heat flux density measurements undertaken on the test apartment revealed that, with the exception of the windows, the external elements measured failed to perform close to their design specification. Measurement of the party elements revealed the problems that can be encountered in dwellings due to 'heat stealing', as the only insulation incorporated in these elements is for acoustic purposes. These measurements highlight an instance where generalisations made by the SAP calculations (zero heat loss party elements) have serious implications for occupants of apartments that neighbour less heated or empty/intermittently occupied apartments.

In addition, some significant areas of unexpected heat loss were identified during the thermal imaging surveys, most notably at the separating/external wall junction on the West elevation, through the trickle ventilators and through the concrete frame of the building. The thermal imaging also revealed unregulated heat gain from the poorly insulated IHU as well as the uninsulated communal heat main and heat transfer through the uninsulated party wall/ceiling between apartments.

Significant difficulties were experienced whilst undertaking the coheating test on the test apartment, which were outside the control of the research team. Some of these difficulties were associated with controlling heat input into the test apartment, whilst the others were associated with external climatic conditions experienced during the test period. Although considerable effort and a number of interventions were made during the coheating test in an attempt to counteract some of these issues, unfortunately, it has not been possible to derive a reliable heat loss figure for the apartment. Despite this, the coheating testing work also revealed a number of lesson/messages that would be of benefit to the wider industry. These lessons are as follows:

- Testing apartments is inherently problematic. When testing apartments, careful consideration needs to be given to any heat loss that may occur through any party elements of construction (such as party walls, party floors, etc.) or to any unoccupied spaces (such as stairwells, communal areas, etc.). Ideally, access to adjacent dwellings or spaces should be obtained to maintain these spaces at the same mean elevated internal temperature as the test apartment. By doing so, any heat loss through the party elements of construction that would have occurred due to differences in temperature between the test dwelling and the adjacent spaces, are likely to be eliminated. However, it should be remembered that this will not necessary eliminate all of the heat losses through the party elements of construction, as heat loss will still occur if any thermal bypasses in the construction exist. In some cases, access may need to be gained to a significant number of apartments to undertake a coheating test, which will have implications for the amount of equipment required and the amount of data analysis that will need to be undertaken.
- The communal nature of the heating systems installed within modern apartments can make it difficult to isolate the flow of heat to the test apartment only, without having an impact on surrounding apartments. Experience indicates that it not always possible to isolate the heat from the communal heat main to just the test apartment in question. The services should be designed in such a way that heat from the communal heat main can be isolated to individual apartments without having an impact on the surrounding apartments.
- Apartments that incorporate a large proportion of South-facing glazing in relation to envelope area are likely to have rooms that are susceptible to overheating if tested either at the beginning or towards the end of the coheating testing season. Care needs to be taken to ensure that any excess heat in these rooms is adequately distributed around the rest of the dwelling. Alternatively, attempts should be made to ensure that these apartments are tested at a time when there is expected to be the least amount of solar radiation (typically, around the winter solstice).

- The coheating test, as it currently stands, is not a ‘fit and forget’ test. It is imperative that the data obtained from the test is downloaded and analysed on a regular basis so that any issues associated with the test (equipment failure, very high periods of solar insolation, ‘flattening-out’ of power consumption, etc.) can be identified and appropriate interventions undertaken to minimise the amount of data that is compromised.

A number of the issues that were identified relating to the coheating testing of apartments, have been addressed within the latest iteration of the Leeds Metropolitan University Whole House Heat Loss (Coheating) testing methodology (see Johnston, Miles-Shenton, Farmer and Wingfield, 2013).

3.7 References

JOHNSTON, D. MILES-SHENTON, D. FARMER, D. and WINGFIELD, J. (2013) Whole House Heat Loss Test Method (Coheating). June 2103. Leeds, UK, Centre for the Built Environment, Leeds Metropolitan University.

4 Key findings from the design and delivery team walkthrough

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

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

4.1 Introduction

The design and delivery team walkthrough is based upon numerous discussions, particularly during a meeting held on the 19th February 2013. This meeting included research staff from Leeds Metropolitan University (LMU) that were involved in the Building performance Evaluation (BPE) study, in addition to representatives from organisations responsible for the design and construction of the CIAC development, namely: FAT Architects, the client - Bioregional Quintain (BQ), DSSR Consulting (DSSR), GB Group and Ross Russell. An additional meeting was conducted with members of the CIAC development management and maintenance team.

4.2 Design intent compared to as built

As previously stated in section 1, the development set out challenging sustainability targets, intending to meet the 10 One Planet Living® principles. In order to establish their intentions, the client took the building design to the RIBA Plan of Work Stage E – building regulations design. As such, the contractor developed the proposal from Stage E onwards. This was a deliberate decision made by the client, to allow fine detail and considered instruction. There was close interaction between the architects and designers to provide low energy design. Many low energy features were written into contract, such as an air permeability target of 3 $m^3/(h.m^2)$ @ 50Pa. However, the research team (LeedsMet) have not been provided with any documentary evidence indicating that the air permeability target for the apartments was 3 $m^3/(h.m^2)$ @ 50Pa.

The issues highlighted in section 2 relating to access to original design intentions have meant that drawing direct comparison with design intent and reality is problematic. As section 3 discussed, several fabric areas were found to be underperforming.

Original design intent included a heating system based upon a district heating system that was intended to supply a number of other buildings that form part of the Riverside One development. However, only one building, CIAC, has been constructed. In addition to this, it should be noted that the entire development orientation has changed from the planning stage, with the building rotated by 90^0 compared to initial visualisations. Further aesthetic changes include differing colouration on the lift shaft, and the sky homes changing from a terraced design.

Procurement issues also caused a change in the delivered building. Discussion revealed that windows containing trickle vents were ordered in error, which is in opposition to the inclusion of an MVHR system. Having acknowledged this error, trickle vents were marked to be sealed. As of report writing, this has not been done. Subsequently, there have been complaints of vents blowing open during high winds, allowing water to leak into the apartments. This will have obvious effects on the MVHR system also, which relies on good airtightness to maximise efficiency.

Unfortunately, following the theft of a motorbike, residents have been advised not to use the outdoor bike storage, and to store bikes in their apartments until secure storage is installed. The intention is to locate bike locks on the balcony level, which will be inaccessible to non-residents.

With regards to documentation, it has not been possible to obtain commissioning and handover documents from the contractor to the developer due to issues with the main contractor and several sub-contractors ceasing trading during the course of the project.

4.3 Replicability of the design

Overall response to the development from the design and build team was positive. BQ certainly felt that they would undertake similar work again, and in a largely similar way, with a few aspects done differently:

- Reduce the design phase, which lasted 18 months. It is felt that during this time, original aspirations may have been misinterpreted or lost.
- BQ would not use SAP as a guide for determining success or failure of their design, and would instead focus on specific issues such as overheating, with the intention of minimising these risks.
- On-site training should be supervised and recorded, to ensure adequate levels of expertise – particularly when dealing with novel technologies.
- The MVHR system would be readdressed by a competent professional, as in current form it is poorly designed and not fit for purpose. As a result of the poor experience with MVHR, BQ felt that they would move towards a different technology, and focus on demand controlled ventilation in future projects, as opposed to MVHR.
- Procurement would be more thoroughly managed to avoid costly mistakes, such as the ordering of incorrect windows.
- Unintentional heat gains due to poorly insulated pipework would be addressed at the earliest stage.
- A rainwater harvesting system would be an additional feature added.

4.4 Comfort and Control

Feedback from the client indicates that there has been overheating in the apartments, particularly apparent in communal hallways. The cause of this was found to be poorly insulated pipework, which contributed large unintentional heat gains. This issue is currently being resolved, with the insulation of pipework occurring.

The MVHR system proved to be unsuitable for the apartment, with weak flow speeds and poorly sited vents leading to stale regions of air within the apartment. It was suggested that the original design may have been modified to save money through the reduction of ductwork. In addition to this, the MVHR system has no apparent access to change the filters – currently the only way to do this is to unscrew the base from the unit. This may have serious implications, as the user will be unable to clean the fan filters, leading to a further drop in performance, enhancing ‘dead zones’ of stale air due to further reduction in air flow. During occupant handover, residents were told that filters will be maintained and cleaned once a year by maintenance staff at the CIAC development, which should help to mitigate this issue, but the access issue will still be present.

Further issues with the MVHR include several apartments complaining of issues with fuses and plastic relays. This led to MVHR unit tripping and subsequently not working. Fuses have since been replaced, and CIAC maintenance teams are fixing any subsequent issues. During handover, residents are made aware of this past issue and given contact instructions should they experience similar difficulties.

Residents have raised concerns regarding the thermostat heating display. Specifically, feedback indicated that whilst the thermostat reads 28^0C, the room does not achieve that temperature. Such high temperature requirements are believed to be a result of temporary residents from equatorial regions, who have warmer comfort requirements. Feedback indicated that a 'low medium high' scale would be preferred.

An issue found in the sky homes was that the acoustic flooring caused problems when fitting carpets. Due to carpets being unable to attach to the flooring, floors had to be covered with hardboard, vinyl and underlay before carpet fitting. There were consequent concerns that this could be easily pierced by sharp points, such as chair legs.

The lighting system at CIAC has caused considerable problems. Firstly, the bulbs initially installed into apartments frequently blew out; unfortunately, the particular bulbs in question were no longer in production, and as such could not be replaced. As a result, all lighting in the apartments had to be replaced. In addition to this, there were issues with fusing of corridor lighting in exposed areas (i.e. outdoor corridors) due to water ingress.

4.5 Best and worst aspects of the development

The client felt that the best aspect overall was the architecture and overall image of the CIAC development. The Biomass heating system was also regarded as successful, despite the lack of development for supply to other properties.

The MVHR was regarded as the worst aspect of the property, with several issues all compounding on its poor performance. The inclusion of incorrect windows was regrettable, but regarded to be fixable moving forward. The issues with overheating represent an on-going problem which is being addressed at the time of writing.

4.6 Conclusions and key findings for this section

Overall, BQ were pleased with the final construction, particularly the architecture. BQ felt that their original concept was sound, but there were changes that would be made should the project be undertaken again, namely a movement towards demand controlled ventilation systems and away from MVHR. In addition, BQ were happy with the biomass system overall, although recognise the overheating issue that the un-insulated communal heating pipework has caused. In contrast, DSSR would prefer a CHP or solar hot water system due to concerns about feedstock supply in the future.

The two main areas for concern highlighted by the BPE were the MVHR systems and the issue of overheating as a result of poorly insulated pipework. Issues with the MVHR unit appear to be resulting from poor design and delivery. Insufficient fan power and poorly designed ductwork are responsible for failure, and as such should be addressed. Of immediate concern is the lack of access to allow filter change. Further discussions with Expelair must occur to remedy this. Unintentional heat gains leading to overheating in apartments and hallways is currently being addressed by the insulation of exposed piping. This should go some way to remedying the related issues.

It was suggested that full training for contractors may not have taken place during the construction phase. When dealing with novel technologies, it is essential that contractors are given the sufficient training to allow for correct installation. Furthermore, the construction and service installation phases should be closely monitored to ensure compliance with best practice.

When procurement errors are made, such as the window issues in this development, steps should be taken to remedy the error where possible. As such, it is recommended that all trickle vents be permanently sealed to allow effective performance of the MVHR system.

To overcome ductwork issues, on-going maintenance should be proactive, and options given to residents with regards to changing their duct filters. If possible, access should be improved to allow for easier maintenance.

Further details relating to the design and delivery team walkthrough can be found within Appendix 6.

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

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

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

5.1 Introduction

The materials given to occupants when they moved into the properties were critically evaluated as part of this study. Additionally, the handover process used to induct new residents has been observed and evaluated. This evaluation was then compared to the original aspirations of the design team, and also the initial usage of the property.

5.2 Handover Materials

New occupants are given two documents upon arrival: the 'Information for New Tenants' guide, and the 'Homeowners Manual'. The Homeowners Manual is presented in a ring binder folder, with sections separated into plastic wallets. Within this folder, the Information for New Tenants guide is given on a CD. These documents are designed to provide information to the occupants relating to the various systems and services both within their dwelling and the CIAC development as a whole. Occupants are also directed to the CIAC resident's website, which provides further information on the development and allows them to contact the maintenance and management teams, in addition to checking their bills amongst other things.

The 'Information for New Tenants' guide is a 208 page document, largely composed of user manuals for appliances and services within the dwelling, in addition to some contact details and usage guidance for the operation of their home. This is distributed as an electronic document in PDF form, due to its size. The size and presentation of the 'Information for New Tenants' guide makes it difficult to use, and the overall presentation and layout is unattractive, with poor quality images that are often too small. That taken into consideration, when the correct information is located the text instructions are often clear and concise, with instruction easy to follow. A key criticism of the 'Information for New Tenants' guide is the inclusion of all system and appliance manuals in the middle of the guide. This leads to inconsistent page numbering, making information very difficult to find. Furthermore, there is a separate contents page for manuals within the body of the document. It is unknown why the decision was taken for this layout – a separate folder dedicated to user manuals would be more appropriate. The 'Information for New Tenants' guide also contains a contacts section which was blank at the time of review. It is expected that this section was completed prior to distribution.

Despite some duplication of information and generic advice, overall the 'Information for New Tenants' guide was regarded to be a reasonable document if manuals were organised better or relocated to another document pack.

The 'Homeowners Manual' is a 27 page document containing background information on the CIAC development and dwelling occupation guidance for the occupant. This was presented as an A4 size booklet. Initially, presentation is fine, with the document given in a ring binder and sections separated with plastic wallets. Some sections, however, are poor, with low image quality, several spelling and grammar errors, lack of colour and an overall unappealing and intimidating layout. Information is laid out in large blocks of text, making the guide tedious to read and engage with. This is a key concern, as the guide often mentions information critical to the tenant with regard to safety and correct operation of their home. It is highly unlikely a resident would engage with and fully absorb the document.

Introduction

BioRegional Quintain (Middlesbrough) Limited

BioRegional Quintain was set up as a joint venture partnership between BioRegional Properties Ltd and Quintain Estates and Development plc and is a UK wide market-leading zero carbon business. BioRegional Quintain's vision is that people will live healthier, happier and more fulfilling lives in the sustainable communities that are created in line with BioRegional Quintain's guiding principles of people; place; planet. BioRegional Quintain aim to deliver on three key promises:

People: We believe that the concept of quality lifestyles should be at the heart of every community that we build, so our key objective is to enhance the health and happiness of our residents. We will work tirelessly to establish a genuine sense of community where our residents can feel safe, happy and assured.

Place: We will set standards for design that produce world class, characterful and inspirational buildings employing the best international architects and designers. We will deliver sustainable buildings, public realm and landscape of the highest quality.

Planet: We believe that sustainable living should be attractive, affordable and fun. We also believe that we should leave our planet in a better condition than we found it. But if everybody in the world lived as we do in the UK, then we would need three planets to support us. We will provide the lifestyle support and estate management services to help you live sustainably - contributing to a healthier you and a healthier planet.

about one planet living®

BioRegional Quintain and their design team have used the framework of One Planet Living® to inspire and structure their vision for RiversideOne.

One Planet Living® is the challenge of our times. Globally, we are consuming resources and polluting 30% more than the planet can sustain. Our increasing consumption means we leave less and less space for other species to flourish, and we are losing biodiversity at an alarming rate.

To achieve a sustainable future, we are designing communities which enable people to live sustainably. Factors such as the commuting distance between home and work, where the food comes from, and how waste is dealt with will be as important as, if not more important than, the energy performance of the buildings.

Energy Services

Riverside One Management Limited supply zero carbon energy for heating, water and electricity to your property.

Riverside One Management Limited operates and maintains all of the energy generation and distribution equipment at the development. This includes the communal boilers, hot water storage tanks, as well as the pumps, controls, pipes, etc needed to get the energy to all the properties. The cost of this maintenance is funded through the fixed Energy Charges you will find on your bill.

Image: Example of Homeowner Manual presentation style

Electricity

Each property is separately metered for electricity.

Electricity meters are located in the utility cupboard, either in your hall or bedroom, which are also linked to your water and heat meters to enable signals to be sent to a remote service manager to enable bills to be calculated.

Electricity failure

Please note that electricity failure is most likely to be caused by a malfunction within an individual

Image: Example of image quality in Homeowner Manual

The 'Homeowners Manual' proved to be hard to use, as information was often misrepresented in the contents page. One example was contact details, which were scattered throughout the document rather than being concentrated to one location as indicated by the contents page. Contacts on the 'useful contacts' page were generic emergency services and wellbeing only. This could lead to problems in the event of emergency relating to the building operation such as a water leak.

Content is often unnecessary and excessive – particularly information about the CIAC development and overall ethos. By opening the document with several pages of background information the reader may become disengaged, resulting in them missing important information in subsequent sections.

Key instructions are given in red boxes, which is a useful tool for identification. These are often mainly concerned with safety, however, with guidance minimal. When guidance is offered it is often vague – for example:

"By keeping your home at a reasonably even temperature at all times during the drying out period and ensuring it is sufficiently ventilated you should minimise any problems associated with shrinkage and condensation." (Homeowner's Manual, Page 9)

In the above extract, occupants are advised to ventilate the apartment to minimise condensation but are given no guidance on how best to ventilate. With conflicting technologies present within the apartment (MVHR, trickle vents, opening windows) this may lead to confusion and subsequent poor operation.

A guide to the operation and use of the electricity consumer unit

Electricity is potentially very dangerous.

DO NOT rely on the local light switch or pull cord switch for isolation.

ALWAYS SWITCH OFF the appropriate circuit breaker before changing any lamps or doing any electrical work.

A switch only switches a live wire.

The neutral is continuous and if touched whilst feeding another circuit under load, an electric shock will occur.

Image: Example of safety instructions given in red box.

The CIAC user website is by far the most useful aspect of the handover materials available. The website is appealingly designed and very easy to navigate. Occupants have direct access to contact details for maintenance and management teams. An additional bonus is the community aspect engendered in the website, with residents able to use a shared noticeboard to arrange events and talk about communal aspects e.g. the CIAC herb gardens. Residents are also able to check their energy bills, and receive live updates on any news on the CIAC development. This active method of giving live updates is very effective.

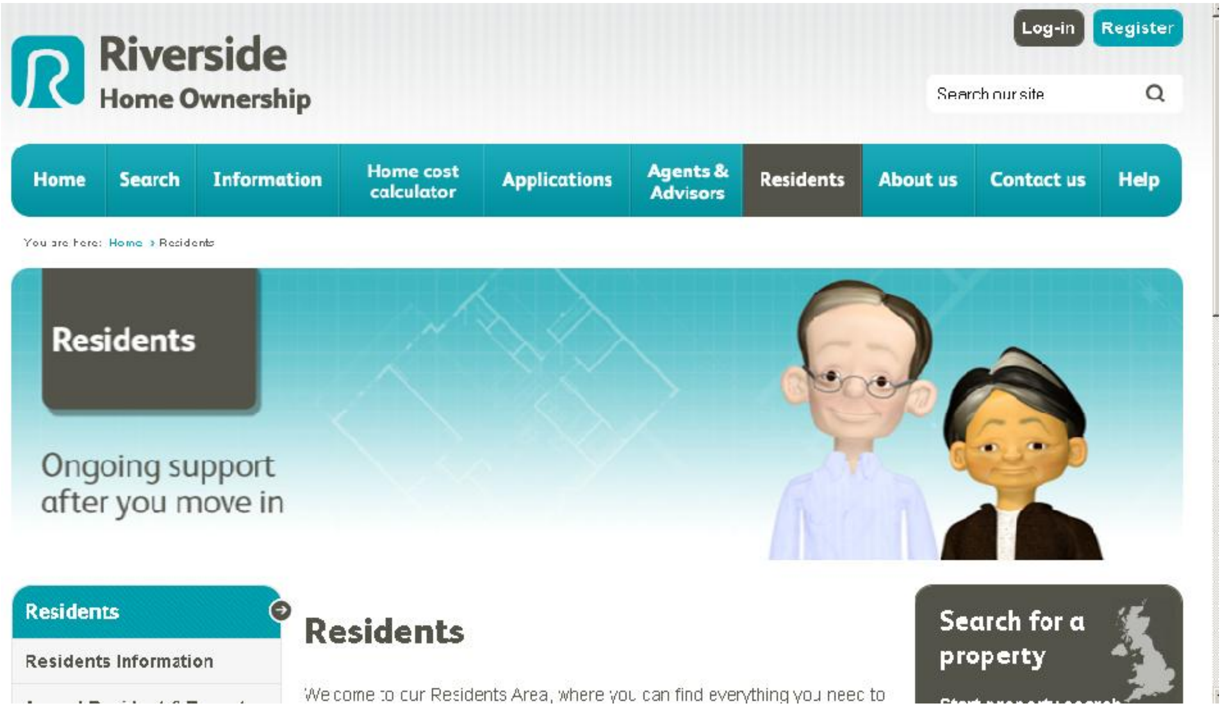


Image: Screenshot of Riverside Home Ownership website

5.3 Handover process and walkthrough

The handover for a single bedroom property was observed on 21st June 2013. For this, the new owner/occupier of the apartment was guided around their home by a member of the CIAC sales staff. The property in question was a South-East facing, single bedroom apartment for single person occupancy. As per TSB guidelines, the researcher did not intervene in any way during the handover process, operating as ‘silent witness’ to proceedings.

The handover process given was thorough and effective, with most aspects of the development not only indicated but explained and demonstrated. This was particularly true of apartment systems, with modes of operation for the MVHR system demonstrated, in addition to the heat exchanger and fans. The full handover process can be found in the appendices of this document.

Building and system maintenance schedules were all thoroughly explained with the exception of guidance regarding the cooker extract filter schedule. Occupants were shown all fuses, shut off valves and modes of operation for each system, and care taken to ensure they were happy with the information. Occupants were encouraged to try everything for themselves after being shown operation, to ensure they were confident.

Issues and mitigation were also covered with regards to window trickle vents. The occupant was informed that in high winds the vent may blow open and allow water to enter, and that the best solution was to seal the vent.

There is a risk that some information given may conflict with advice given in the user guides, and also with the building performance. Specifically, residents are told that they may increase the flow temperature for their hot water by turning a highlighted screw. This will have an impact on energy use and heating.

Aftercare was covered at length, with reference to the building maintenance team made several times, in addition to their contact details and hours of work. Occupants were also encouraged to consult their handover packs, the resident website and to contact the building manager if they have queries after the handover. As much care as possible was taken to ensure the occupant was happy with their new home before the handover was concluded.

Overall the handover was very good. Improvements could be made, however, with regards to making the occupant aware of the maintenance schedule for the cooker extract hood, and ensuring that advice given is not conflicting with the advice from system designers.

5.4 Initial occupant use and design aspirations

It was observed that, during post completion occupation, occupant s complained of overheating in apartments. As described in earlier sections of this document, the cause of this has been identified as the simultaneous effect of poorly insulated hot water pipes and failings in the MVHR system. In terms of occupant guidance and operation, it is not felt that the occupant could impact upon this in any significant way, save for dumping heat by opening windows.

Issues were also experienced with trickle vents blowing open during periods of high winds, allowing water to enter. Advice was given to seal the vents permanently.

Through comparison with the design intent as highlighted in the design and delivery team walkthrough, it was found that occupants did value several of the building features, specifically those related to improving the environmental credentials of the development. There was an expectation for more environmentally friendly features to be included, however. Specifically, features such as the biomass heating system were not as occupants would have expected owing to the issues across the development – the systems was initially intended to serve many more buildings.

Similarly, the problems relating to security have been unfortunately, with bike storage and entrance gates found to be unsafe. These are features that are undergoing upgrade at time of writing.

5.5 Conclusions and key findings for this section

The view of the 'Homeowners Manual' is that, at present, it is a permissible document. However, it could easily be improved with editing. The removal of much of the text would make it easier to use. Such depth about the background of the development is unnecessary in this document, and could be summarised in one page. Similarly, gathering all important contact details onto one page would improve the usability of the document greatly, as would a "dos and don'ts" reference section for the advice given in red boxes. These measures, combined with a more appealing design and presentation, would improve the document greatly.

The 'Information for New Tenants' guide would not require much modification to be improved. A reorganisation of service and appliance manuals together with improved images is all that is required.

The CIAC resident's website is certainly the most useful tool given, and was found to be of a very high standard, both for the initial and on-going occupation of the resident. Of particular note was the attractive design, ease of use and functionality.

The overall view of the documents used to introduce new tenants to their homes is that although some require attention to reach a high standard, overall they provide a sufficient level of detail.

The handover process used to induct new residents was very good, with all systems fully explained and demonstrated. The only criticism was some advice has potential to conflict with the advice of written documentation and system providers. This may need clarification for future handovers.

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

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

6.1 Introduction

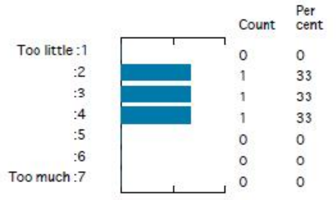
The BUS seeks to inform the research team about issues from the side of the user. The information gathered highlights any issues that arise through lived in experience, and can then be cross referenced with measured data to highlight potential reasons for any poor performance. A total of 57 BUS questionnaires were distributed to residents of the CIAC development, of which 3 were completed and returned. Due to a poor return rate, an interview with the CIAC building manager was also undertaken to gather any feedback that had been received.

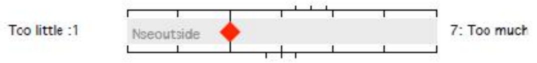
6.2 Key findings from BUS questionnaires

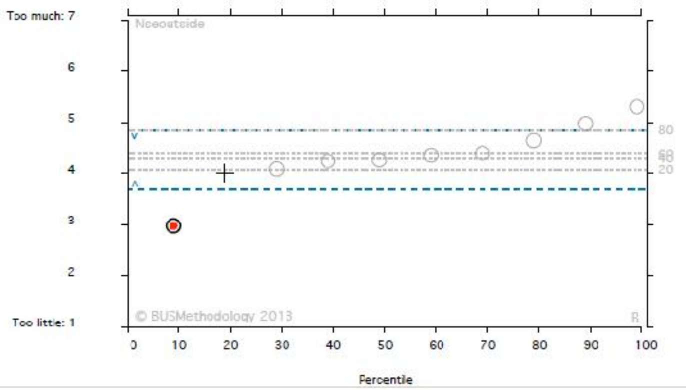
Unfortunately, during the time allocated for BUS questionnaire surveying, many of the apartments were unoccupied. Furthermore, the majority of occupied apartments were inhabited by temporary overseas workers, who were attending a 6 month training course in the local area. As a result, there was a very poor return rate of only 5.3%. Discounting temporary workers, at the time of BUS distribution there were 9 permanent occupants. This does improve return rate to 3/9 or 33%, but in real terms the sample size is too small to be considered broadly informative, and serves only as an anecdotal tool.

From the results obtained, most features were found to be good or ok. There were some consistent exceptions, however, which are discussed below.

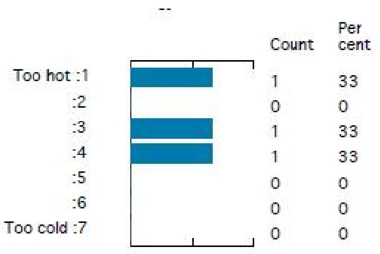
- **Noise levels –** Feedback indicated that many residents found noise levels to be too quiet. It is assumed that this is a direct result of the dwelling being away from roads and made of materials with superior soundproofing to the occupant's previous property. It should also be noted that this is not a negative aspect of the dwellings – feedback indicated that residents liked this feature of their homes.

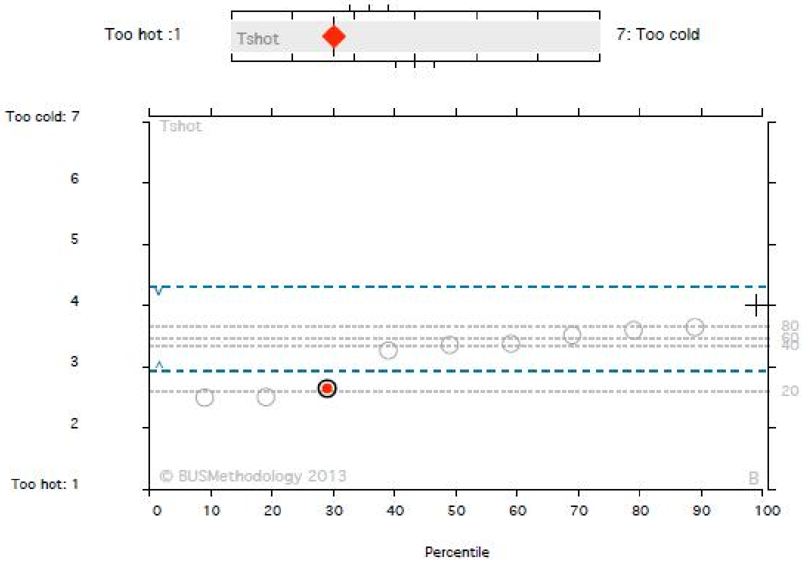






- **Temperature –** Residents have reported that they find the temperature in the dwelling too hot.. This may be due to a combination of several factors which are discussed in previous sections of this report. In particular, it is thought that the cause of this overheating is a combination of poorly insulated piping and an underperforming MVHR system. These issues are certainly something to be aware of and address in future projects of a similar nature.





Overheating also featured in comments left by residents, with remarks taken from section B of the BUS survey results including:

"No cooling option for the flat. Leaving windows open attracts insects that live around the water"

A reluctance to use windows to cool the apartments sufficiently during hot weather is an issue that may require future resolution if similar complaints are received from other residents.

It must be stressed that these observations are based on a small sample size, and as such cannot be considered conclusive.

6.3 Occupant feedback

Due to the poor feedback resulting from the BUS survey, an interview was conducted with the CIAC manager to consolidate any feedback that she had received from residents.

Access for the CIAC development has recently undergone change following negative feedback from residents. Originally, the entrance code for the front gate was a 6 digit number. It was felt that this was unsafe, and represented a risk if a resident needed immediate access to the property (i.e. if they were under threat). The key code has since been replaced with a key fob entry system.

Residents did not respond well to the exposed concrete ceilings in the apartments. Although solely an aesthetic complaint, it warrants further consideration. In contradiction to this, the most positive aspect highlighted by residents was the building aesthetics. Users reported great satisfaction in the design and aspect, with location and apartment view particular highlights.

Residents complained about trickle vents being forced open during periods of high wind, and allowing water to enter their property. This issue has been acknowledged, and occupants are advised to seal their trickle vents. It is unknown whether the sealing of trickle vents by the CIAC maintenance team will be done as a matter of course in the future.

Some residents also expressed a desire for rainwater harvesting to be installed, for use on the communal gardens and window boxes.

6.4 Conclusions and key findings for this section

Unfortunately, due to the low return rate and poor quality sample, information obtained from the BUS presented here cannot be relied upon for conclusions pertaining to the whole development, and as such are considered anecdotal.

Even with low feedback rates, it should be acknowledged that occupant feedback suggested overheating to be an issue. This is consistent with findings and potential outcomes from the technical review of apartment services, and as such may be considered significant.

The reluctance of residents to use windows to cool apartments due to local insect life may require further investigation. It is suggested that complaints of this nature are monitored and steps taken if necessary.

Of the feedback received, the overall consensus was that the dwellings were of high quality, with residents enjoying living in them and happy with their performance. In terms of negative aspects, the key area of concern is that of overheating, which hopefully will be lessened now remedial work has begun to super insulate pipework.

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

Observations of the space and hot water heating system installed in the test apartment revealed that the space heating is provided via a LTHW heating coil installed within the Xpelair Xcel 300 LTHW whole house MVHR system. In addition to the heater battery, a wet heated towel radiator is provided in the bathroom. A Danfoss Gemina Termix VVX-B IHU, installed in the cupboard in the hallway of the apartment, provides LTHW to the MVHR heating coil and the bathroom towel radiator. This unit also supplies domestic hot water to the apartment. Hot water to the IHU is provided via a communal Fröling Turbomat 320kW biomass boiler located on the ground floor of the building. The boiler is fed using 6mm wood pellets and two thermal stores are provided, each of which has a capacity of 9300 litres. A gas-fired Buderus Logano GE515 is provided as backup. Unfortunately, due to the low level of occupancy within the building, only the gas-fired boiler has so far been used to provide communal heat. The biomass boiler will only become operational once the 75% occupancy threshold within the building has been met. Therefore, it has not been possible to gain any feedback relating to the operation of the biomass boiler. With respect to the gas-fired boiler, no issues have been identified regarding the operation or maintenance of this boiler to date.

The thermostat for the space heating system forms part of the remote command module, which is located in the living room. The module also controls the speed of the fans within the MVHR system. Time control of the space and hot water heating system is undertaken via a 24 hour programmer located within the IHU enclosure. The towel radiator in the bathroom is controlled both by the thermostat in parallel with the 24 hour programmer. There is no manually operated boost switch for the towel radiator, therefore it cannot be activated when the space heating is otherwise not needed. Billing for space heating and hot water is provided via a heat meter incorporated within the IHU in each dwelling which incorporates an Mbus card, enabling remote meter reading.

Ventilation is provided via an Applied Energy Products Ltd Xpelair Xcel 300 LTHW whole house MVHR system which incorporates a motorised by-pass damper (summer bypass). This is installed in the ceiling void in the bathroom. Boost operation of the unit is provided via a manually operated light switch in the bathroom, the remote command module located in the open plan living room/kitchen of the apartment and a boost switch located in the kitchen area. This module not only controls the fan speed of the unit but is also used to control the setpoint temperature within the apartment. Air is supplied to the bedroom and living/kitchen area via a high level grille situated above the door. Extract from the bathroom and open plan living/kitchen area is unusual in that it is provided via a channel located in the plasterboard ceiling (see Figure 7). This channel is positioned above the window in the bathroom and above the cupboards in the kitchen. Air extracted through the channel is fed into an air plenum behind the plasterboard ceiling and then enters the MVHR extract ductwork through the extract air valve.

In terms of internal lighting, low energy lights have been used throughout the study apartment. In the hallway and the recessed compact fluorescent downlighters have been installed in the ceiling. In the kitchen, directly above the cupboards, recessed led lights have been installed and in the living area and bedroom, wall-mounted uplighters containing a compact fluorescent lamp have been installed. Low energy lighting is also provided in the communal areas of the building, such as the circulation corridors, which is PIR controlled. The only area where this is not the case is the entrance lobby, where low energy lighting is provided, but the lighting is left on constantly.

Figure 7 Extract slot above the external window in the bathroom and above the cupboards in the kitchen.

7.2 Installation and commissioning checks

Commissioning data was only provided for the MVHR system and the biomass boiler only. Unfortunately, no information has been provided to the Leeds Met research team regarding the commissioning of the space and hot water heating system (the IHU) installed within the apartment. This may in part be due to the fact that the mechanical and electrical contractor on the project is no longer trading. The information provided for the MVHR system and the biomass boiler vary considerably. For the MVHR system, a checklist was provided which covered the temperature sensors, fan speed operation, inputs and outputs and the settings of the unit. No information was provided regarding duct flow rates, either whole unit flow rates or individual room flow rates. For the biomass boiler, a very simple commissioning certificate was provided. As very little information has been provided on each of these services, it has not been possible to undertake any cross checks on the commissioning process, so it is not possible to say whether the systems have been commissioned correctly or not. From the limited information provided on the MVHR system, it suggests that this system has not been commissioned correctly in situ.

Observations were also undertaken on the space and hot water heating system, the MVHR system and the lighting system. These revealed that the majority of the pipework within the test apartment was well insulated. However, it was observed that the insulation was not continuous over isolation valves and at drain-off points that the temperature within the cupboard that houses the IHU was very warm, despite the fact that the IHU had been isolated and was not calling for heat. Observations of the pipework located outside the test apartment revealed that the pipework insulation was also not always continuous and areas of missing insulation were noticeable at the access panels in the ceiling of the corridor leading to the test apartment, particularly at isolation valves. It was also observed that the corridor was noticeably 'warm' on cold days, even though no source of space heating was provided to these corridor areas and the lighting had not been activated. Any areas of uninsulated communal heat main or insulated pipework within the dwelling will result in an increase in the heat loss from the pipework and may contribute towards overheating. This heat loss could be mitigated against by providing sufficient insulation to those areas of pipe that are currently uninsulated and installing insulated jackets around any isolation valves. Initial feedback for the client has revealed overheating in the communal corridors and the cause of this was found to be poorly insulated pipework, which has contributed to large unintentional heat gains. This issue is currently being resolved, with insulation being applied to previously uninsulated communal pipework.

In terms of the MVHR system, observations revealed that the MVHR unit had been installed in the intended location (in the ceiling void in the bathroom) within the apartment and all of the rectangular plastic ductwork visible in the ceiling void appears to have been installed correctly and to the appropriate standard. The extract and supply valves have also been installed in the intended locations, as indicated on the drawings (see Figure 8). The supply valves used in the bedroom and living/kitchen area are located directly above the doors (see Figure 9) and are adjustable (see Figure 10), although they can only be adjusted once the grille has been unscrewed from the wall. Given the type of air valve used, it is difficult to see how adjustments could be made during commissioning to achieve a particular flow rate, as the main grille would have to be continually removed from the wall to make any fine adjustments. The supply air valves also incorporate a thin filter medium (see Figure 11), which can only be accessed by unscrewing the supply air valve from the wall. The exact purpose of this filter is not known, as the main unit also incorporates a supply and extract filter. The position of the supply air valves within the apartment also means that there is a risk, particularly in the bedroom, that a significant proportion of this room will be inadequately ventilated as the type of supply air valve used is not capable of supplying air deep into the room. Instead, it is likely that the supply air will be drawn directly into the corridor towards the extract valves located in the bathroom and/or open plan living room/kitchen area. The use of a directional throw valve designed to exploit the 'coanda effect' would have been more appropriate. Alternatively, the air supply valve should have ideally been located diagonally opposite the doors to each room to maximise cross flow. However, this would have meant that the exposed soffit feature would have to have been compromised. Initial feedback from the occupants has revealed that they perceive there to be stale regions of air within the apartment, suggesting that the current design and configuration of the MVHR system is not providing adequate ventilation to all areas of the apartment.

Extract from the bathroom and open plan living/kitchen area is provided via a channel located in the plasterboard ceiling. This channel is positioned above the window in the bathroom and above the cupboards in the kitchen. Air extracted through the channel is fed into an air plenum behind the plasterboard ceiling. This air then enters the MVHR extract ductwork via an extract air valve. The extract air valve comprises a metal slot grille (the same as that fitted on the supply air valve) that has been crudely taped onto the end of the rectangular extract ductwork (see Figure 12). In order to gain access to the extract air valve, a small access hatch is provided in the plasterboard ceiling in the bathroom and the plasterboard in the living/kitchen area (see Figure 13). However, due to the location of the extract valves in relation to the access hatch, access to the valve is limited, making it difficult to make any fine adjustments to the metal slot grille attached to the end of the extract ductwork. As with the supply air valves, it does not appear to be easily possible to make individual adjustments to the extract air valve to the bathroom or kitchen area to meet particular room requirements.

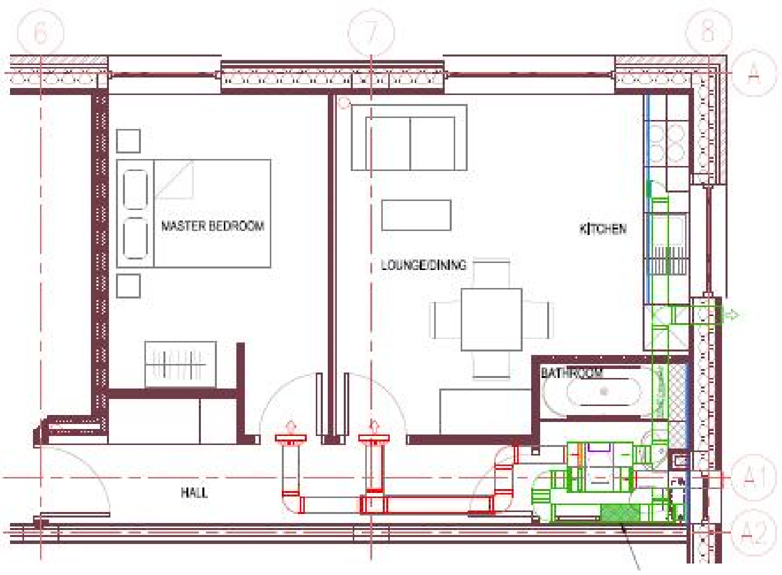


Figure 8 MVHR layout in apartment (handed version).

Figure 9 Supply air valve located above the door in the living room/kitchen.

Figure 10 Adjustable grille on supply air valve.

Figure 11 MVHR supply air valve and filter.

Figure 12 Grille taped to the end of the extract ductwork above the kitchen cupboards.

Figure 13 Extract air valve access hatch in the bathroom and living/kitchen area.

Further inspection of the MVHR system revealed that the main filters are located within the main MVHR unit installed in the bathroom ceiling void and that these filters can only be accessed by unscrewing the base plate from the unit (see Figure 14), so there are issues regarding accessibility. There is also no filter change, maintenance or service indicator light on the unit, and even if there were, it is not easily read by the occupants of the apartment. Therefore, apart from undertaking a periodic service and filter change, there is no mechanism of knowing whether the unit is functioning correctly. This is not unusual for MVHR systems. The implications in terms of maintenance are mitigated to a degree, as the maintenance team at CIAC will be responsible for replacing the MVHR filters on a yearly basis. However, if this situation were to change, and responsibility were to be passed back to the occupants of the apartments, there would be significant issues associate within maintenance, as it is highly likely that the occupants would never change the MVHR system filters.

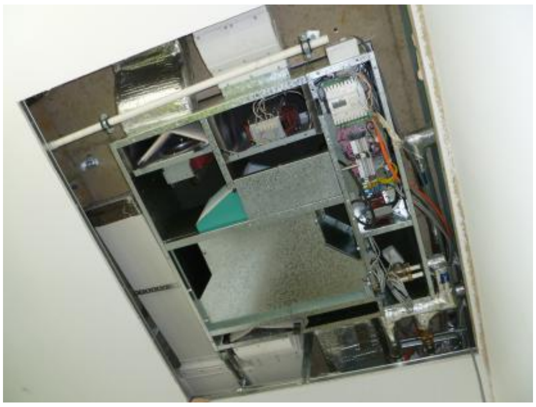


Figure 14 Base plate of MVHR unit removed to access filters.

Taking into consideration all of the issues identified with the MVHR system, there appears to have been a lack of integration between the conceptual design, particularly the use of the plasterboard extract channels in the bathroom and kitchen area, and installation and commissioning.

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

7.3 MVHR duct flow measurements

A number of air temperature and velocity measurements were undertaken on the supply and extract valves of the apartments immediately above (identical to test apartment), below (identical to test apartment) and adjacent (2 bedroom apartment) to the test apartment during trickle operation. These measurements were undertaken during the coheating test, so it was not possible to undertake the same measurements on the test apartment. The measurements were undertaken using an Airflow Instruments TA35 hot wire anemometer. It is also important to realise that the figures obtained from these measurements were based upon a single point measurement that was undertaken immediately in front of the air supply grilles in each of the apartments, so the measurements are only indicative. The measurements suggested the following:

- In dwellings of identical size and configuration, quite different air flow velocity readings have been obtained. The reasons for this are not known.
- The extract air flow velocity readings measured in all apartments tested are greater than the corresponding supply airflow velocity readings, and in 2 of the dwellings by a considerable margin. This suggests that the units in all 3 dwellings are not balanced. Balance of the fan speeds overall is critical in terms of heat exchanger efficiency. This issue could be addressed via re-commissioning.
- In all of the dwellings where measurements were undertaken, it is not possible to determine whether the units satisfy the ventilation requirements contained within Approved Document Part F 2006 (ODPM, 2006).

A series of duct flow measurements were also undertaken on the test apartment on the 16th October 2012 using a Swemaflow 125D hot wire lattice anemometer (see Figure 15). Unfortunately, due to the configuration of the extract valves, it was not possible to obtain any extract readings using the flow hood. It was possible to undertake a number of supply air valve readings at various different fan speeds (see Table 4), although these reading are of little valve without the corresponding extract valve flow rates. The measurements revealed very low flow rates in both the living/kitchen area and bedrroom 1 at fan speed settings 2 and 3 (boost) and no measurable flow was recorded at trickle fan speed settings (1 and auto). These readings suggest that the MVHR system is not delivering the required flow rates to the individual rooms and fails to comply with Part F of the Building Regulations. This is not unusual for MVHR systems. A recent study undertaken by BSRIA on the airflow performance of MVHR systems (see Gilbert, 2013) found that 95% of systems failed to meet the requirements contained within the Building Regulations. Further investigation of the MVHR unit and ductwork also revealed that no pilot holes exist to undertake other duct flow measurements, such as pitot tube measurements. This suggests that the MVHR unit has not been commissioned in situ.

Figure 15 MVHR duct grille flow measurements undertaken using a Swemaflow 125D.

	Auto (m^3h^{-1})	**Fan speed 1** (m^3h^{-1})	**Fan speed 2** (m^3h^{-1})	**Fan speed 3** (m^3h^{-1})
Living/kitchen area	0	0	11.2	17.6
Bedroom 1	0	0	11.5	18.7
Total supply				

Table 4 Test apartment MVHR supply and extract duct grille flow measurements in m^3h^{-1}.

A further investigation on the MVHR system was undertaken on the 13th March 2013. This involved undertaking a borescopic and thermal imaging survey of a small area of supply and extract ductwork was also undertaken. The borescopic survey revealed a significant build-up of particulates on the filter positioned immediately behind the supply air grille to the bedroom, suggesting that the filter had not been changed since the dwelling had been handed-over. In addition, an accumulation of particulates was observed on the inside of the ductwork. Although it is difficult to be certain, it is thought that this build-up has either been caused during the construction process, or is the result of particulate build-up due to leakage through the ductwork during the operation of the unit. This has important implications for the maintenance regime associated with the test apartment and potentially the health and well-being of the eventual occupants of this apartment.

A number of difficulties were experienced when undertaking the thermal imaging survey of the extract ductwork. These difficulties, coupled with the boxed-in nature of the extract ductwork, meant that it was not possible to determine via thermal imaging whether any air leakage was occurring through this ductwork. In such circumstances, an alternative methodological approach is likely to be required to investigate ductwork leakage. Such approaches include smoke injection or ductwork pressurisation.

Additional observations of the MVHR unit also revealed that the condensate from the unit ran upwards away from the unit. This is likely to result in a build-up of condensate within the condensate pipework and possibly even within the unit itself. If condensate is allowed to build-up within the MVHR unit, this may eventually lead to damage to the unit.

Further details regarding to the MVHR duct flow measurements, the borescopic survey and the thermal imaging survey can be found within Appendix 7 and 8.

7.3 Lighting

With regards to the internal lighting system, the observations revealed that the lighting system has been installed as intended. In the hallway and bathroom, recessed compact fluorescent downlighters have been installed in the ceiling. In the kitchen above the cupboards, recessedled lights have been installed and in the living area and bedroom, wall-mounted uplighters containing a compact fluorescent lamp have been installed.

Discussions with the sales and maintenance staff have revealed that the level of illumination provided has been adequate and no issues regarding the level of lighting provided have been identified. The only problem that has been experienced with the lighting is that the recessed cfls fitted within the bathroom frequently blew and the bulb could not be replaced, as the luminaire required a non-standard cfl and the company that originally supplied the cfl no longer manufactured them. As a result, all of the cfls and luminaire within all of the bathrooms in all of the apartments had to be replaced with a recessed led There was also an issue with outdoor lighting fusing due to moisture ingress. This issue has been addressed.

7.4 Conclusions and key findings for this section

Only a very limited amount of commissioning data was made available for the services installed within the test apartment, with the data relating the MVHR system and the biomass boiler only. This may in part be a consequence of the fact that the mechanical and electrical contractor on the project has ceased trading. An analysis of the data available has revealed that the amount of commissioning data provided for each service was very limited, varied considerably and there does not appear to be any standardised method of commissioning particular services. The development of a standardised method would be useful and would enable comparability between dwellings.

Observations of the installed lighting, space and water heating system appears to indicate that they have been installed correctly. However, there are a number of sections of pipework, both within the test apartment, and out-with the test apartment where the insulation is not continuous. This is particularly noticeable at isolation valves. Although this will result in increased heat loss from this pipework, which in turn, may contribute towards overheating, it is common for these areas of pipework to be uninsulated in new dwellings. This heat loss could be mitigated against by providing sufficient insulation to those areas of pipe that are currently uninsulated and installing insulated jackets around any isolation valves. Issues were also experienced with some of the cfl's, which frequently blew, and a replacement cfl's of the same design were no longer available. This issue could be avoided in the future by ensuring that products are not used where only one available replacement is available on the market.

In terms of the MVHR system, although the system has been designed and installed in accordance with the design drawings, there are a number of significant issues with the current system that indicate that it is not possible for the system to perform as intended. These issues are as follows:

- Due to the location and type of air supply and extract valves used, it is not possible to easily make individual adjustments to these valves to meet particular room ventilation requirements.
- Due to the location of and type of supply air valves used in the bedroom, there is risk that a significant proportion of this room will be inadequately ventilated. This may also be an issue Locating air supply valves above the doors of such rooms is not uncommon, and is usually

done to minimise ductwork runs and the associated costs. In this case, it appears that it has been to avoid compromising the architectural value of the exposed concrete soffit.

- Although the maintenance team at CIAC will be responsible for changing the filters in the MVHR unit, there are accessibility issues, as the base plate needs to be removed to gain access to the filters.
- The condensate from the unit runs upwards away from the unit. This is likely to result in a build-up of condensate which may eventually lead to damage to the unit.
- There is also no filter change, maintenance or service indicator light on the unit, Consequently, apart from undertaking a periodic service and filter change, there is no way of knowing whether the unit is functioning correctly or whether filters will need replacing more regularly than normal.
- Due to the configuration of the extract air valves (behind some plasterboard), it is not possible to undertake a set of robust flow measurements to determine whether the system is balanced or to determine whether the correct flow rates are being achieved in each of the rooms within the apartment.
- It is unlikely that the MVHR unit was ever commissioned in situ, as the configuration of the system makes it impossible to undertake measurements using a conventional flow hood and there is no evidence that any measurements of air flow have been made using a pitot tube.

Given the issues associated with the MVHR system, in conjunction with the duct flow measurements, it is not unreasonable to suggest that the MVHR unit is unlikely to have ever been commissioned in situ. This is extremely important, as it is currently not possible to determine whether the MVHR system is providing sufficient ventilation to each of the rooms within the study apartment. Initial feedback from the occupants In fact, initial feedback from the occupants has revealed that they perceive there to be stale regions of air within the apartment, suggesting that the current design and configuration of the MVHR system is not providing sufficient ventilation to all areas of the apartment. In addition, the lack of appropriate ventilation to the apartments, particularly during the summer, is also likely to contribute to overheating within the apartments. Consequently, measures will need to be undertaken by the client to ensure that the MVHR system is fully operational and maintainable, delivers the required flow rates and provides sufficient ventilation to all areas of the apartment. This is likely to require:

- Re-commissioning of the MVHR system to ensure that it is delivering the correct flow rates to the correct rooms. This is likely to require the installation of additional ductwork comprising a removable grommet so that a series of pitot tube measurements can be undertaken. Alternatively, the extract air valves may have to be changed to enable a series of flow hood measurements to be undertaken.
- Replacement of the bedroom, and possibly the living/kitchen area, air supply valves to prevent any short circuiting of the supply air. Alternatively, the air supply valve could be repositioned diagonally opposite the door of each room to maximise cross flow. However, this will have an architectural consequence, as the exposed concrete soffit will be compromised.

An alternative, and much more radical and expensive solution, would be replace the existing MVHR system with an alternative unit or adopt an alternative ventilation strategy, such as MEV. Ironically, if MEV were to be installed, it may be possible to supply sufficient background ventilation via the trickle ventilators that were inadvertently specified when the windows were ordered.

The borescopic and thermal imaging survey also revealed a number of lessons/messages that would be of benefit to the wider industry, these are:

- There is very limited information available on the condition and presence of particulates within the ductwork of domestic MVHR systems. Further research is required to determine the condition of the ductwork within UK dwellings and to ascertain whether the presence of particulates within the ductwork is prevalent across domestic MVHR systems in the UK.
- There is limited knowledge and experience of the use of thermal imaging to identify areas of air leakage within domestic MVHR systems. Further research is required to assess its suitability and to develop testing protocols.

- The commission process for domestic MVHR systems should incorporate checks to ensure that the filters and the ductwork are free from particulates at the point of commissioning.
- Measures should be undertaken during construction to ensure that all MVHR systems and the associated ducts are sealed to minimise the ingress of particulates into the MVHR unit or the associated ductwork.
- If the filters are contaminated or particulates are found within the MVHR system ductwork, then measures should be undertaken to clean the filters and remove particulates form the ductwork. If this is not the case, then it is likely to shorten the period required between filter changes and may have an adverse effect on the health and well-being of the building occupants.
- All domestic MVHR systems should be re-commissioned on a regular basis. During this process, the filters should be cleaned/replaced as necessary and observations should be made of the MVHR system ductwork to ensure that it remains clean and free from particulates. This would require the positioning of MVHR grilles in locations that facilitate this process.
- All domestic ductwork for MVHR systems should be designed in such a way as to enable an investigation of the ductwork to take place and enable the ductwork to be cleaned as and when required, in some cases this may include the provision of service hatches within the building fabric.
- All domestic ductwork for MVHR systems should be tested, using appropriate techniques, to determine the amount of duct leakage. This should be repeated on a regular basis, to determine if any deterioration of the leakage of the ductwork has taken place over time.
- A range of testing techniques and protocols should be developed to enable the duct leakage of MVHR systems to be determined both qualitatively and quantitatively.

7.5 References

GILBERT, A.(2013) Practical Experience of Common Ventilation Problems.[Internet] Bracknell, UK, BSRIA. Available from: < http://www.goodhomes.org.uk/events/101> [Accessed 1st July 2013].

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 Introduction

This section seeks to highlight any additional issues which may not have been covered in other sections of the report, specifically issues identified in exclusivity in earlier sections of this report that overlap and have had demonstrable effects are also covered.

8.2 Overlapping and compounding issues

The issues identified above with regards to the MVHR system are cause for significant concern, with poor operation performance likely to lead to uncomfortable internal conditions. There is a danger of this being further exacerbated by the unintentional heat gains to the apartments from poorly insulated communal heating system pipework. Such large unintentional heat gains will limit the ability of the resident to control their apartment temperature, and the MVHR system does not appear capable of dealing with this issue. As such, to cool an apartment, the resident is often left with opening the windows as their only effective solution. This has implications, as during periods of rain or high wind windows may be unable to be opened. Similarly, if small children are in the apartment, windows cannot be fully open for safety reasons.

The overheating issue is also in conflict with advice given to occupants regarding the operation of their heating system. Occupants are advised to *“find a comfortable temperature, and then leave the system on constant automatic”.* This does not account for the unintentional heat gains, potential for spikes in temperature during sunny periods, or the inability of the MVHR systems to adequately and rapidly cool the internal space.

Occupants are made aware during handover that they can increase the temperature of their hot water if they wish by turning screws on the heat exchanger. This is in direct conflict with the operating assumptions and energy use calculations considered when looking at the CIAC development. If residents were periodically turning up their heating flow temperature there will be additional energy costs and implications. This information only came to light after testing had occurred, so no further study on the impact of user changes has been possible.

During occupant feedback gathering, it was discovered that concerns were raised about the thermostat set point of 28ºC not actually getting the apartment to that temperature. From this, we know that some residents are intentionally running their heating systems at seemingly maximum capacity for extended periods – something which would not be anticipated. There is potential for this to adversely affect the performance and lifespan of the heating system, if it is being run at maximum as suspected. Similarly, this type of operation may require more regular maintenance. Results of this operation style are unknown, but it would be an interesting study for the future to see the effect this has had on both the heating system and the apartment fabric and finishes.

8.3 Conclusions and key findings for this section

As earlier sections have focussed on specific aspects of the CIAC development, the above has summarised various issues that have compounded and resulted in problems. It is useful to consider issues in this holistic way in order to offer solutions.

The most significant issues which give the most concern are related to the apartment heating systems and temperature control. It is suspected that these issues will cause overheating problems in the future, particularly with regards to large unintentional heat gains combining with an inability to adequately cool the internal space. Although it is difficult to see how the unintentional heat gains from the IHU can be minimised, insulating the communal main where it is currently inadequately insulated, should reduce some of the uncontrollable additional heat gains. If the issues associated with the MVHR system are also resolved, then overheating issues are likely to be minimised.

The advice given to occupants with respect to modifying their water supply temperatures should be discontinued, and residents advised not to tamper with their heating system. The potential effect of tampering is unknown, and should therefore be strongly discouraged.

There is scope to test the issue highlighted by occupants suggesting that room temperatures are not reaching an indicated level. If this is found to be true, there may be an issue with the heating system commissioning or suitability. However, as concerns were only raised by a minority of residents, and the internal environment requested so rare, it is not felt that there is a great need to pursue this perceived issue further.

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 eight reports. 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 the key messages for the client.

9.2 Construction review and physical testing

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

- It is clear that a number of the design intentions have not been fulfilled. This may be in part due to the fact that a number of key stakeholders involved in the project ceased trading either during or immediately after completion of the project, as a direct result of the poor economic climate. This is likely to have resulted in some of the design information not being passed on from one stakeholder to another.
- A number of input errors were identified within the design SAP assessment. If the correct information was used as input to the worksheet, a poorer assessment is likely to have been obtained and the apartment may even have failed to meet the regulatory target emission rate.
- A number of issues were identified during construction that, if not adequately addressed, had the potential to have an adverse effect on the thermal and acoustic performance of the apartment. These issues were primarily related to the inappropriate application of airtightness tapes to poor installation of services and thermal insulation.
- The pressurisation tests revealed that the test apartment is of average airtightness by UK standards, but is leakier than is normally recommended when an MVHR system is to be installed.
- The heat flux density measurements revealed that, with the exception of the windows, the external elements measured failed to perform close to their design specification. Measurement of the party elements revealed the problems that can be encountered in dwellings due to 'heat stealing'. This highlights an instance where generalisations made by the SAP calculations (zero heat loss party elements) could have serious implications for occupants of apartments that neighbour less heated or empty/intermittently occupied apartments.
- In addition, some significant areas of unexpected heat loss were identified during the thermal imaging surveys, most notably at the separating/external wall junction on the West elevation, through the trickle ventilators and through the concrete frame of the building. The thermal imaging also revealed unregulated heat gain from the poorly insulated IHU as well as the uninsulated communal heat main and heat transfer through the uninsulated party wall/ceiling between apartments.

- Significant difficulties were experienced whilst undertaking the coheating test on the test apartment, which were outside the control of the research team. Some of these difficulties were associated with controlling heat input into the test apartment, whilst the others were associated with external climatic conditions experienced during the test period. Although considerable effort and a number of interventions were made during the coheating test in an attempt to counteract some of these issues, unfortunately, it has not been possible to derive a reliable heat loss figure for the apartment.

9.3 Installation and commissioning

The main findings from the installation and commissioning reports are as follows:

- 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.
- Only a very limited amount of commissioning data was made available for the services installed within the test apartment, with the data relating the MVHR system and the biomass boiler only. This may in part be a consequence of the fact that the mechanical and electrical contractor on the project has ceased trading. An analysis of the data available has revealed that the amount of commissioning data provided for each service was very limited, varied considerably and there does not appear to be any standardised method of commissioning particular services.
- Observations of the installed lighting, space and water heating system appears to indicate that they have been installed correctly. However, there are a number of sections of pipework, both within the test apartment, and out-with the test apartment where the insulation is not continuous. 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 apartment and the circulation spaces within the building. This will need to be closely monitored to ensure that this is not the case. The heat loss could be mitigated against by providing sufficient insulation to those areas of pipe that are currently uninsulated and installing insulated jackets around any exposed isolation valves.
- Issues have been experienced with the cfl's in the bathroom, which frequently blew, and replacement cfl's were no longer available. The effected cfls and luminaires in the bathrooms of all of the apartments have since been replaced with recessed led's.
- A number of significant issues were identified with the MVHR system. These issues relate to the design of the system as well as the layout and type of air supply and extract valves used. In addition, there are also accessibility issues associated with gaining access to the filters within the MVHR unit and the condensate drain has not been installed correctly, which may lead to damage to the unit. There is also no mechanism to alert the occupants that the system requires the filters to be changed, requires servicing or has malfunctioned.
- The configuration of the MVHR system is such that it is not possible to undertake a set of robust flow measurements to determine whether the system is balanced or to determine whether the correct flow rates are being achieved in each of the rooms within the apartment. It is therefore unlikely that the MVHR unit was ever commissioned in situ.
- More importantly, the observations, duct flow measurements and initial occupant feedback suggest that the MVHR system is not performing as intended. The lack of appropriate ventilation to the apartments, particularly during the summer, is likely to contribute to overheating within the apartments. Consequently, measures will need to be undertaken by the client to ensure that the MVHR system is fully operational and maintainable, delivers the required flow rates and provides sufficient ventilation to all areas of the apartment.

9.4 BUS survey, interviews and occupant guidance

The main findings from the BUS survey, interviews and guidance are as follows:

- The written materials given to occupants at induction were found to be overly long and difficult to engage with. These materials should be revised and substantially condensed, with care taken to ensure spelling and page numbering errors are rectified.
- Advice given to residents during the handover process was sometimes found to be in conflict with written advice or system best practice. This should be addressed, to ensure any advice is consistent throughout.
- Greater reference should be made to the CIAC resident website, as this does not feature in written handover documents, but is a very useful and impressive feature of the occupant care package.
- Although experiencing poor return rate, the BUS questionnaire highlighted overheating concerns which are consistent with the technical findings of this report. These issues should ne addressed as a matter of significance.
- The reluctance of residents to use windows to cool apartments due to local insect life may require future investigation,. It is suggested that complaints of this nature are monitored and steps taken if necessary.

9.5 Other issues

The borescopic survey also revealed a significant build-up of particulates on the filter positioned immediately behind the supply air grille to the bedroom, suggesting that the filter had not been changed since the dwelling had been handed-over. In addition, an accumulation of particulates was observed on the inside of the ductwork. Although it is difficult to be certain, it is thought that this build-up has either been caused during the construction process, or is the result of particulate build-up due to leakage through the ductwork during the operation of the unit. This has important implications for the maintenance regime associated with the test apartment.

During windy periods, window trickle vents have been found to blow open and allow water to leak in from outside. It is suggested that trickle vents should be permanently sealed in order to avoid this happening.

External lighting on exposed walkways has experienced water ingress, causing lights to fuse. Care should be taken to adequately seal lighting in exposed areas in order to avoid this occurring.

9.6 Hindsight review, comparison to One Brighton – Developer's perspective

"One Brighton and Middlehaven are noted for their very close similarities - each followed the One Planet Living concept - but also their significant differences.

Both were the products of joint venture development - One Brighton being a JV with Crest Nicholson and Middlehaven effectively a JV with Quintain. Each of these relationships required considerable energy and effort to manage in order to deliver on the demanding sustainability characteristics that were set.

One Brighton was a medium scale and quite bold urban infill development that was positioned as a sustainability icon in Brighton. It was the first of the projects to be developed and its design process was used to develop a standard technical and sustainability template for residential development that was followed subsequently at Middlehaven.

Middlehaven was a huge waterside mixed use project which was most notable for its very bold and inspiring architecture. The ambition of Middlehaven was no less than to contribute materially to the transformation of Middlesbrough and the Tees Valley social, environmental and economic prospects - so that a lot was expected.

The nature of the different JV partners was such that the level of effective cross learning was not at the level desired, with funding related procurement issues impacting heavily at times on which building materials and technologies were used.

The difference of scale, with Middlehaven masterplanned as a much larger project of 750 homes - as opposed to 172 at One Brighton - resulted initially in a much more ambitious site wide energy strategy at Middlehaven entailing the development of a site wide energy centre. The financial crisis led to a re-assessment of the ambition of the project so that in the end the residential block that was developed had its own biomass boiler and building level ESCO in the same way as One Brighton.

The architectural ambition for Middlehaven resulted in a more complicated and difficult build than One Brighton with the latter having a more dependable external insulted render as opposed to the former's insulated brick cavity.

Arguably one would expect the Brighton building supply chain to have a greater level of environmental capability and sensitivity than at Middlesbrough, but in reality we did not find this to be the case. "

10 Wider Lessons

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

10.1 Wider lessons

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

10.2 Lessons for design

To avoid the loss of important design information, it is advised that projects adopt a robust method for storing and documenting the design information at key stages of the process, so that such information can be recovered if firms cease trading.

There is a requirement for much greater control of SAP and the need for the development and implementation of a quality control process that minimise the number of input errors into SAP. This issue has previously been highlighted in work undertaken by Trinick et al. (2009).

There is a requirement to develop SAP such that it takes into consideration the heat loss through party elements that are not currently addressed in SAP, such as floors and ceilings.

There is a need to avoid specifying products where only one replacement is available on the market. This issue could be avoided in the future by ensuring that products are not used where more than one replacement is available on the market.

The communal nature of the heating systems installed within modern apartments can make it difficult to isolate the flow of heat to the test apartment only, without having an impact on surrounding apartments. Experience indicates that it not always possible to isolate the heat from the communal heat main to just the test apartment in question. The services should be designed in such a way that heat from the communal heat main can be isolated to individual apartments without having an impact on the surrounding apartments.

10.3 Lessons for airtightness and thermal insulation

A number of simple airtightness and thermal insulation issues could be avoided if appropriate quality control processes were in place to monitor insulation and airtightness measures during construction, and if the workforce was appropriately educated to understand the potential implications of the incorrect installation of various measures. For instance, it would be beneficial if each site adopted a dedicated airtightness and thermal insulation champion.

10.4 Lessons for coheating testing

Testing apartments is inherently problematic. When testing apartments, careful consideration needs to be given to any heat loss that may occur through any party elements of construction (such as party walls, party floors, etc.) or to any unoccupied spaces (such as stairwells, communal areas, etc.). Ideally, access to adjacent dwellings or spaces should be obtained to maintain these spaces at the same mean elevated internal temperature as the test apartment. By doing so, any heat loss through the party elements of construction that would have occurred due to differences in temperature between the test dwelling and the adjacent spaces, are likely to be eliminated. However, it should be remembered that this will not necessary eliminate all of the heat losses through the party elements of construction, as heat loss will still occur if any thermal bypasses in the construction exist. In some cases, access may need to be gained to a significant number of apartments to undertake a coheating test, which will have implications for the amount of equipment required and the amount of data analysis that will need to be undertaken.

Apartments that incorporate a large proportion of South-facing glazing in relation to envelope area are likely to have rooms that are susceptible to overheating if tested either at the beginning or towards the end of the coheating testing season. Care needs to be taken to ensure that any excess heat in these rooms is adequately distributed around the rest of the dwelling. Alternatively, attempts should be made to ensure that these apartments are tested at a time when there is expected to be the least amount of solar radiation (typically, around the winter solstice).

The coheating test, as it currently stands, is not a ‘fit and forget’ test. It is imperative that the data obtained from the test is downloaded and analysed on a regular basis so that any issues associated with the test (equipment failure, very high periods of solar insolation, ‘flattening-out’ of power consumption, etc.) can be identified and appropriate interventions undertaken to minimise the amount of data that is compromised.

A number of the above issues have been addressed within the latest iteration of the Leeds Metropolitan University Whole House Heat Loss (Coheating) testing methodology (see Johnston, Miles-Shenton, Farmer and Wingfield, 2013).

10.5 Lessons for installation and commissioning

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

It should be a statutory requirement to provide standardised commissioning data, such as duct flow measurements, for MVHR systems. This will ensure that MVHR systems have been installed correctly, are operating correctly and have been commissioned in situ prior to handover. The commissioning process should include, amongst other things:

- A series of supply and extract valve duct flow measurements at boost and trickle operation.

- A check on the selection and positioning of air valves to ensure that there is adequate cross flow and to minimise the risk of short circuiting of the air flow.

- A check on the condensate drain to ensure that it is installed correctly.

Indicator lights should also be provided on MVHR systems to alert the occupants when the unit requires servicing, to inform them if the unit has malfunctioned and to inform the occupants when the filters need changing.

A number of these issues, such as the selection and positioning of air valves, the position of terminals and the incorporation of visual indicators for maintenance and servicing are proposed in the new NHBC Standards chapter for MVHR (see NHBC, 2013).

10.6 Other lessons

There is very limited information available on the condition and presence of particulates within the ductwork of domestic MVHR systems. Further research is required to determine the condition of the ductwork within UK dwellings and to ascertain whether the presence of particulates within the ductwork is prevalent across domestic MVHR systems in the UK.

There is limited knowledge and experience of the use of thermal imaging to identify areas of air leakage within domestic MVHR systems. Further research is required to assess its suitability and to develop testing protocols.

The commissioning process for domestic MVHR systems should incorporate checks to ensure that the filters and the ductwork are free from particulates at the point of commissioning.

Measures should be undertaken during construction to ensure that all MVHR systems and the associated ducts are sealed to minimise the ingress of particulates into the MVHR unit or the associated ductwork.

If the filters are contaminated or particulates are found within the MVHR system ductwork, then measures should be undertaken to clean the filters and remove particulates form the ductwork. If this is not the case, then it is likely to shorten the period required between filter changes and may have an adverse effect on the health and well-being of the building occupants.

All domestic MVHR systems should be re-commissioned on a regular basis. During this process, the filters should be cleaned/replaced as necessary and observations should be made of the MVHR system ductwork to ensure that it remains clean and free from particulates. This would require the positioning of MVHR grilles in locations that facilitate this process.

All domestic ductwork for MVHR systems should be designed in such a way as to enable an investigation of the ductwork to take place and enable the ductwork to be cleaned as and when required, in some cases this may include the provision of service hatches within the building fabric.

All domestic ductwork for MVHR systems should be tested, using appropriate techniques, to determine the amount of duct leakage. This should be repeated on a regular basis, to determine if any deterioration of the leakage of the ductwork has taken place over time.

A range of testing techniques and protocols should be developed to enable the duct leakage of MVHR systems to be determined both qualitatively and quantitatively.

10.7 Dissemination

Feedback on the findings from this study has been hampered by the fact that a number of the stakeholders involved in this project have ceased trading. Despite this, interim findings and final findings have been fedback to the concept design team, the mechanical and electrical design team, the contractor and the client.

Findings from the study have also been delivered to the Good Homes Alliance, a leading organisation for improving housing development in the UK. A case study on the development has been produced by the GHA and the results will be disseminated to other GHA member organisations (via Capacity Building meetings) and the wider sector via events, published and on-line materials.

The authors of this study are also involved in a wide array of housing performance studies and it is anticipated that this study will be compared to other developments where BPE studies have been undertaken.

10.8 References

NHBC (2013) NHBC, draft MVHR Standards. [Internet] MiltonKeynes, UK, National House Building Council. Available from:
http://www.microgenerationcertification.org/images/NHBC%20MVHR%20Consultation.doc
[Accessed 1st July 2013].

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. These are as follows:

1. JOHNSTON, D. MILES-SHENTON, D. FARMER, D. and PEAT, M. (2013) Post Construction and Early Occupation Study, Middlesborough – Design and Construction Review. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. January 2013. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
2. JOHNSTON, D. MILES-SHENTON, D. and FARMER, D. (2012) Post Construction and Early Occupation Study, Middlesborough – Pressurisation Test Report. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. July 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
3. JOHNSTON, D. MILES-SHENTON, D. and FARMER, D. (2012) Post Construction and Early Occupation Study, Middlesborough – Coheating Test Report. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. July 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
4. FARMER, D. JOHNSTON, D. and MILES-SHENTON, D. (2012) Post Construction and Early Occupation Study, Middlesborough – Heat Flux Measurement Report. A report to the Technology Strategy Board as part of the Technology Strategy Board's Building Performance Evaluation Programme. August 2012. Leeds, UK, Centre for the Built Environment (CeBE), Leeds Metropolitan University.
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