SHINE Zero Carbon (East Midlands)

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Innovate UK project number	450067
Project lead, authors, and client	PS Sustainability Ltd
Report date	2013
InnovateUK Evaluator	Fionn Stevenson (Contact via www.bpe-specialists.org.uk)

No of dwellings	**Location**	**Type**	**Constructed**
Six terraced dwellings, three single apartments	East Midlands	Single terraced building	2011
Area	**Construction form**	**Space heating target**	**Certification level**
50 m^2 per dwelling	Insulated concrete	25 kWh/m^2 per annum	SAP 2005 (EPC to SAP 2009)

Purpose of evaluation

The BPE project assessed the performance of the Insulating Concrete Formwork (ICF). It achieved a very high standard of air tightness (1.8 m^3 (m^2.h) @ 50 Pa), thermal insulation (U-value 0.15) and acoustic isolation DnTw + Ctr dB 59 between dwellings. The project also assessed the solar thermal collectors, air-source heat pumps, and biofuel combined heat and power system. Excess heat from the solar collectors and CHP is used to generate warm air that heats an underground thermal store. The thermal store was intended to provide inter-seasonal storage, enabling summertime heat generation to meet wintertime space heating demand.

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

The space heating energy consumed by the tenants was measured over the year 2012, and derived an average figure of 23 kWh/m^2 per annum for the dwellings. This is very close to the design intent of 25 kWh/m^2 per annum, and indicated that overall the building fabric performed to specification. There was some difficulty in modelling the building's heating system, which uses a combination of CHP, solar collectors, and air source heat pumps (ASHP). The primary heating system was modelled as a 'Community Heating Scheme', which incorporated boilers and CHP. However, it was not possible to add the ASHP as an additional heating system. Overall site electrical energy usage (non domestic heating energy) was found to be roughly in line with BREDEM-8 estimation.

Occupant survey type	**Survey sample**	**Structured interview**
BUS (domestic)	N/A	N/A

The BRE report contains very little detail on survey methodology and statistics. The design intent for thermal comfort and air quality was reportedly achieved. The tenants were said to be pleased with the performance of the development, with the BUS satisfaction index in the high 80% percentile range. Tenants reported overall satisfaction with the air quality in the summer months, but some tenants reported stuffiness.

Contents

1 Introduction and overview

The development consists of a single building containing six two storey terraced dwellings, and three single floor apartments, in total providing 495m^2 liveable area. The site is an urban brownfield, previously occupied by a disused industrial unit. The building footprint of 237m^2 occupies slightly over half of the site area of 548m^2. The building is constructed using Insulating Concrete Formwork (ICF), achieving a very high standards of air tightness (1.8), thermal insulation (U-value 0.15) and acoustic isolation DnTw + Ctr dB 59 between dwellings. An innovative approach to low energy-building services was taken. Heating is provided by a combination of solar thermal collectors, air-source heat pumps, and a biofuel combined heat and power (CHP) system. Excess heat from the solar collectors and CHP is used to generate warm air that heats an underground thermal store. The thermal store is intended to provide inter-seasonal storage, enabling summertime heat generation to meet wintertime space heating demand. The stored heat can be recovered using the air-source heat pumps when required.

Figure 1 A picture of the northerly & west elevation of the development shortly after completion

The inner city brown field site upon which it is built, dictates the building orientation. The front of the building faces north. Each dwelling has a living space of approximately 50m^2, and the total internal volume is 1326m^3. The roof area is split in two levels; approximately 160m^2 on the terrace dwellings, and 70m^2 on top of the flats. The 230m^2 roof faces south with a 6^o slope. The surface of the building is partially rendered with an ivory render, and partially clad with treated red cedar panelling.

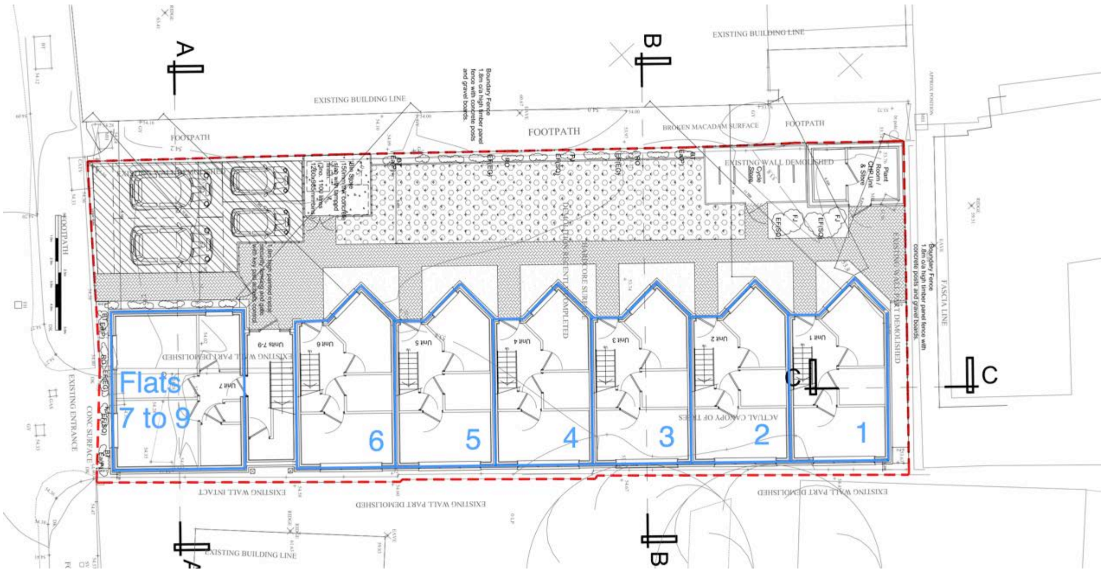

Figure 2

From the outset, the primary drivers for the project were thedelivery of buildings with low energy consumption and running costs, with a view to maximising income from a relatively small site. The proposed development consisted of nine units to be sold. While the constrained site presented several challenges, lack of parking was for example turned to an advantage, supporting the building's sustainability intent by promoting the use of public transport and cycling. During the initial design phase, additional funding became available through EMDA (East Midlands Development Agency),requiring the project to take on more of a research aspect aimed at demonstrating efficiency through innovative modern methods of construction, service systems, and renewable energy sources. The funding enabled the developers to include an innovative thermal store in the design. Given the size of the site, it was necessary to construct the thermal store under the six terraced houses. The development provides extremely affordable housing by virtue of the size of the properties and the cost-effective nature of their construction. In terms of meeting the objective of cost-effective high-density housing, the project is considered by the architect and developer to be a total success. However, the small size of the properties makes them more suitable for rental rather than owner occupied properties. It is too early to determine the success of the integration of the CHP, heat pump and thermal store, however these are the subjects of on-going research.

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

2.1 Construction phase

The planning process was smoother than anticipated given the planner's unfamiliarity with the proposed design and construction. This was actually beneficial, because it forced the planners to consider the development with fresh eyes. The project is now considered an exemplar for future low-energy urban regeneration/brownfield residential developments; achieving industry recognition by both the Housing Forum and Zero Carbon Hub.Both organisations have awardedthe development demonstration project. One of the more significant planning requirements was to avoid window to window overlooking of the opposite building. This resulted in the main windows being oriented at 45 degrees from the street frontage in order to meet this requirement.

The calculations for demonstrating Building Regulations Part L compliance and Code for Sustainable Homes credit, were carried out using SAP 2005. This version has been superseded by SAP 2009, which overcomes some of the limitations of the previous version. It was necessary to use SAP 2005, because the original project application was made before SAP 2009 applied (October 2010). The EPCs were generated using SAP 2009, but no changes to the input parameters were made from the previous version.

The input data was derived from a comprehensive set of information, including plans and dimensions provided by the architect. The relevant information was input into the SAP software JPA designer. Thermal transmittances (U-values) for fabric and glazing elements were specified by the manufacturers. The effect of thermal bridging was calculated separately, and a value y, calculated from individual psi-values, was multiplied by the total elemental area. External calculations were also used to obtain input data for the photovoltaic installation size and the primary heating efficiency. These calculations were submitted by the SAP assessors to STROMA (their accrediting body) for approval.

There was some difficulty in modelling the building's heating system, which uses a combination of CHP, solar collectors, and air source heat pumps. The primary heating system was modelled as "Community Heating Scheme" which incorporated boilers and CHP. However, it was not possible to add the air source heat pump as an additional heating system.

SAP 2005 only permitted a single primary heating system type, however the 2009 version has improved the ability to add multiple heat sources. Including the mechanical ventilation heat recovery (MVHR) system was not a problem, as the unit was on the SAP list of approved units.

2.2 PEST Analysis

The following PEST analysis categorises a number of the factors influencing project performance above into political, economic, social and technological factors.

Political	Economic
• Change of government introduced uncertainty about targets and funding sources • Planning constraints influenced design decisions • CfSH requirements influenced design decisions • Funding constraints and requirements influenced contractual arrangements	• Funding mechanism resulted in cash flow issues that impacted on project programme • Site selection and the resulting decision to construct high-density was strongly influenced by economic considerations
Social	**Technological**
• Occupant behaviour influences technological factors • Design for security introduced structural constraints • Risk of disturbance to neighbours influenced construction programme • Site security influenced construction programme	• Problems with initial ICF supplier not providing sufficient performance information • Post-construction quality problems with DPM Layer • Effectiveness of heating control system dependant on occupant behaviour • Compatibility of initial roof design with solar panel fixings

2.3 Conclusions and key findings for this section

The project generated useful lessons both for the architect and the developer. It also highlighted the importance of working as a multidisciplinary team. The architect made the comment that the project was interesting, and that they had learnt a great deal about the building physics during the project. They also felt that the developer started the project relatively inexperienced, but had also learnt a lot through the process. Although it was challenging for both architect and developer tackling a project of this nature for the first time, the lessons learnt should make it easier in the future. The engineering aspects of the project are particularity important for reducing the future cost of similar buildings. The aim is to move beyond the current one-off engineering effort required, and develop more standardised techniques necessary for widespread application of low energy sustainable domestic buildings.

3 Fabric testing (methodology approach)

3.1 Overview of test methodology

The study team elected to do a longitudinal in-situ U-value measurement rather than a co-heating test,due to the development being fully occupied when this phase of the BPE project was scheduled.

The in-situ U-values measurements were taken off a specially instrumented section of wall, over a two-month period during the winter. The instrumentation was designed to measure heat flux through the wall and the temperature at the surface of the interior and exterior walls.

As the development has a relatively high thermal mass in its superstructure,it will tend to exhibit some thermal inertia over time. Therefore, a comparison was made of the in-situ material properties using a theoretical model, and the on site temperatures and heat flux measurements. A mathematical model is used to generate performance predictions over a year, to establish if the thermal capacity of the wall is an aid or hindrance to the overall energy performance of the development.

There is very little empirical evidence of the roll of the thermal mass in the concrete structure of an ICF wall in the UK.

3.2 Conclusions and key findings for this section

Empirical data shows that the thermal time constant of the ICF concrete core is 3.6 days. The time constant of the concrete core of the development is having a stabilising effect on the internal temperature of the building, reducing the impact of adverse ambient temperature conditions. This means that under continuous occupation, the embodied thermal mass in the ICF structure will have a positive impact on the overall thermal comfort of the living spaces within the development despite insulation being both on the external and internal surface of the ICF blocks.

The in-situ U-value measurements show a good correlation with those produced by the mathematical model. Although the empirical data shows a higher than expected heat flux and hence in-situ U-value measurement, this can be accounted for by experimental error due to heat flux measured bring of such a low magnitude. To collaborate this we have taken the space heating energy consumed by the tenants over the year 2012, and derived an average figure of 23kWh/m^2/year for the dwellings. This is very close to the design intent of 25kWh/m^2/year, and indicates that overall the building fabrics are performing to specification.

When compared to the Fabric Energy Efficiency Standard (FEES) specification rating the development would fall into the D band category or passivhaus equivalent. The FEES standard recommends a fabric efficiency figure of 39kWh/m^2/year for an apartment block; and the development energy footprint is falling well within this at approximately 23kWh/m^2/year. This demonstrates that ICF structures actually perform to their claimed thermal performance and do not suffer from 'The Performance Gap' found by The Carbon Hub to exist with most other housing structural frame systems(see Zero Carbon Hub (2014) Closing the gap between Design & As-Built Performance, London, UK see http://www.zerocarbonhub.org).

All of the instrumentation for the in-situ U-value measurement has been left in place so that data can be collected for a more detailed longitudinal study.

4 Key findings from the design and delivery team walkthrough

4.1 Maintenance

Excellent records have been maintained of maintenance activity on the site, and it can be seen from these that the issues on site are representative of residential developments of this nature. No major hardware failures have been recorded within the first twelve months of occupancy; records show minor equipment failure that is more attributable to random failure of new equipment.The only exception to this is three central heating pumps, replaced during a maintenance sweep of the development in preparation for the heating season. Failure of the pumps in all three cases was a seized rotor; the probable cause is due the non-operation of the pumps. When questioned, the tenants stated that they had not operated the space heating system in the last six months. Higher quality pumps designed for low duty cycle operation, may have to be used in the future. These pumps are generally not fitted in domestic application because of their higher cost.

Both the solar heating and the photovoltaic array will require cleaning on abi-annual basis due tothe low pitch of the roof preventing dirt from being effectively washed off during rainfall. This was not anticipated at design time.

MVHR units were opened to look at dirt ingress, and the general state of the disposable filters. Of the three units that were opened, in all cases, the filters were highly contaminated. The development has been occupied for almost one year at this point, suggesting that the filters need to be changed on a yearly basis.

It was noted during post commissioning checks that the MVHR was failing to deliver boost air extraction rates. Heavily contaminated filters maybe a reason for this.

1.1.1 Energy foot print

The first year's worth of data collected from the site indicates that on average the domestic heating foot print of 22kWh/m^2/year was achieved. This compares very well with the predicted domestic heating energy footprint of 25kWh/m^2/year. Thermal envelop mathematical modelling was developed as part of a PhD thesis sponsored by PS Sustainability Ltd, and developed in collaboration with Loughborough Universities Centre for Renewable Energy and System Technology (CREST). Overall site electrical energy usage (non domestic heating energy) was found to be roughly in line with BREDEM-8 estimation.

1.1.2 Site water management

The average water consumption per dwelling, per day, over the first year is 220 litres. Occupancy on the site has varied over the year, so it is problematical getting an exact usage figure per individual, especially as there are some tenant families with young children. Assuming a static figure of seventeen individuals on site, this equates to a figure of 120 litres per person. During the site walk through, it was noted that some tenants had removed water aerators on the taps on the baths and kitchen sinks. Additionally it was noted that the grey water system was not operational for the majority of the year. When questioned, tenants cited the reason for the removal of the aerators, as reduced flow preventing baths filling within a reasonable period of time. SHINE-ZC was developed with low water appliance, and was designed to allow occupants to use as little as 80 litres of water per day. Water consumption is an area that needs more monitoring. Average water consumption has dropped post the grey water system being commissioned, however this would still not achieve the lower water consumption figure targeted by the designers.

4.2 Conclusions and key findings for this section

The building from the tenant survey is well constructed and aesthetically pleasing, andprovides a good quality living environment. The physical performance of the development has been very close to the design intent, particularly in respect to the thermal footprint, airtightness, and acoustics performance. The only area where there was found to be a large deviation from the expected performance was water consumption. Water consumption on the site has remained in line or slightly below national averages; the intent of the developers was a significantly reduced water footprint for the site. Tenants have bypassed water saving measures because of the additional time it takes to fill a bath, saucepan or kettle. This is an area that needs more investigation, as there does not appear to be a straightforward solution to the issue.

The tenant feedback is supportive of the construction and aesthetics; further evidence of this is the low turn over of tenants on site, and the high number of referrals from tenants.

Unexpectedly high professional fees led to a cost overrun on this project. The design and delivery team stated that they expected these costs to be more inline with industry norms on future builds, as the additional costs were related to the innovative nature of the development, non-conventional building techniques, and one off legal costs.

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

5.1 Handover of literature

The tenants where given a pack of original manufacturers documentation in addition to three brochures outlining how the heating control, the mechanical heat and ventilation recovery (MVHR), and immersion heater were operated. It was not possible at the time of the review to fully test all of the functionality described in the brochures; for example the high carbon dioxide warning indicator described in the MVHR brochure.

The original manufacturer's documentation was comprehensive, and matched the equipment installed within the dwelling.

Brochures provided,describing the operation of the heating systems within the dwelling were excellent, giving a good graphical overview of the controls and how to operate them. The only criticism was that the language in some instances was deemed overly technical for the target audience.

Overall the documentation provided was excellent with clear details and comprehensive contact details in the event of breakdown.

5.2 Handover process

The handover process observed, was carried out very professionally, and a clear understanding of the technical details of the workings of the dwelling was demonstrated. A check was made to ensure that the tenant did understand the basic controls of the dwelling asking them to adjust key settings to their requirements,referring to the control brochure in each instance.

There was no formal log of problems observed during the handover, although the trainer did state that if anything major was noted, then this was formally registered with the landlord. This was the process that had prompted the development of the brochures detailing heating control, as there had been a number of issues with the first tenants.

The tenants stated that they were content with the handover process, the most questions being asked regarding local amenities, utility billing, storage space within the dwelling, and operation of the living room windows. Tenants did not appear overly concerned about the energy footprint of the dwelling, but did seem to appreciate the dry, warm, and well-lit interior; and contrasted this with their previous tenancy. The statement regarding the lighting levels and interior comfort did resonate well with the design intent of the dwellings.

5.3 Conclusions and key findings for this section

Literature provided specifically for the development was found to extremely useful when guiding tenants through the control of their dwelling.

The tenants observed during the handover process appeared content with the handover process, and readily understood dwellings controls. From observation, the process of guiding new occupants through basic settings appeared beneficial to their overall level of understanding and comfort with controls.

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

6.1 Air quality

The design intent for the dwellings thermal comfort and air quality has been achieved. When comparing the results of the BUS study, and the semi-structured interviews with the findings of the design team, there is a high degree of agreement. The tenants seem generally pleased with the performance of the development with the BUS satisfaction index in the high 80% percentile range. Tenants reported overall satisfaction with the air quality in the summer months, but some tenants reported stuffiness. This agrees to an extent with the findings of the design team, which showed that the living space did have a tendency to overheat on the very warmest days of summer. The guidance literature for the tenants states that on hot sunny days all windows should be closed during daylight hours, and south-facing windows should be shaded. This may add to the sensation of stuffiness.

6.2 Control over heating

Control over heating scored slightly below average from the tenants. This was at odds with the intent of the design team who stated that they had gone to some lengths to use conventional domestic controls in the build. One approach to closing this gap might be to revise the language used in the tenants dwelling operational manual; anecdotal evidence from some tenants indicated that this might be a problem. Another thought is that perhaps this is more a reflection of the usability of standard domestic heating control, rather than a reflection of this particular implementation.

6.3 Natural light

The BUS analysis of the tenant's perception of natural light levels was that they were a little too high. This differed from the design teams perception that the light levels were optimal. It should be noted that the BUS study was conducted in the summer months and that the walk through was carried out during the shoulder season. Design optimisation was for maximum natural light levels during the winter season. When questioned on this issue, the tenants stated that the windows on the southern elevation were unusual sizes, and that this made purchasing blinds problematical. On future builds it would be worth considering fitting blinds as part of the standard fit out.

6.4 Control over noise

Tenants rated the properties above average for noise control. Acoustic isolation tests made post construction showed that party wall isolation was DnTw + Ctr dB 59, well in excess of current building regulations.

6.5 Conclusions and key findings for this section

Overall the BUS survey and semi-structured interviews have proved a valuable resource when trying to evaluate the design intent,providing the real world performance of the dwellings. Area's where the tenants have voiced strongly positive views are indicators of dwelling comfort. These can be characterised as noise isolation, thermal comfort,space comfort,and indoor air quality.

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

7.1 Ventilation systems

Plots 1 through 8 use mechanical ventilation and heat recovery (MVHR) systems supplied by Nuaire. The Nuaire units are MRXBOX95-WALL units, and are fitted with a summer bypass system, allowing the internal heat exchanger to be bypassed in high ambient air temperature conditions. The summer bypass function allows some possibility to regulate the apartment temperature using cooler ambient air, bypassing the heat recovery heat exchanger. This is particularly useful in the summer months to prevent dwelling overheating due to internal heat gains. Plot 9 has a more conventional trickle vent solution fitted to the windows, and extraction only mechanical ventilation in the kitchen and bathroom/toilet.

On plots 1 through 8, the audit found that the quality of the installation work for the MVHR units, and the associated duct work was to a high standard. Both sealing around ductwork passing through external walls, and the observable insulation levels were to a high standard. Work package 1.4 the Infra-red thermographic report stated that the apartments showed little or no evidence of thermal bridging issues. This provides corroborative evidence to back the findings of this audit. Thermal bridging would be evident in the presence of poor sealing or insulation. In addition work package 1.6 Air-tightness and leakage test, shows a high degree of air tightness within the apartments. The air tightness audit results, support the observed quality of the air seals achieved around the MVHR ductwork where it penetrates external walls.

Tested airflow rates into the dwellings in plots 1 through 8, were found to meet building regulations. Air extract rates plots 1 to 8 were found to be lower than those required to meet building regulations. This seemed to particularly affect the cooker hob extract unit. These results were compared to the building compliance regulation tests undertaken during construction; and it was observed that the extract rates only just met compliance levels at the time of installation. The MVHR units and cooker hoods were opened for inspection, and it was observed that the air filters were highly contaminated. The development had been occupied for an average of four months at the time of inspection, and the filter contamination levels were felt to be abnormally high for this period of occupation. This led to speculation that some of the contamination might be due to operation of the MVHR before the dwellings had been cleaned from fine construction debris.

The inspection of the ventilation systems in plot 9 found that the installation was generally to a high standard, and complied fully with building regulations.

7.2 Heating and hot water systems

The heating and hot water within the apartments was designed to be as conventional as possible given the nature of the project. Space heating is provided via oversized radiators; hot water is sourced from a thermal store located in each apartment. The thermal store was designed by PS SustainabiltyLtd for the development, and built by Newark Copper Cylinders Ltd. Domestic hot water is supplied at main pressure via a heat exchange element at the top of the thermal store (see Figure 3).

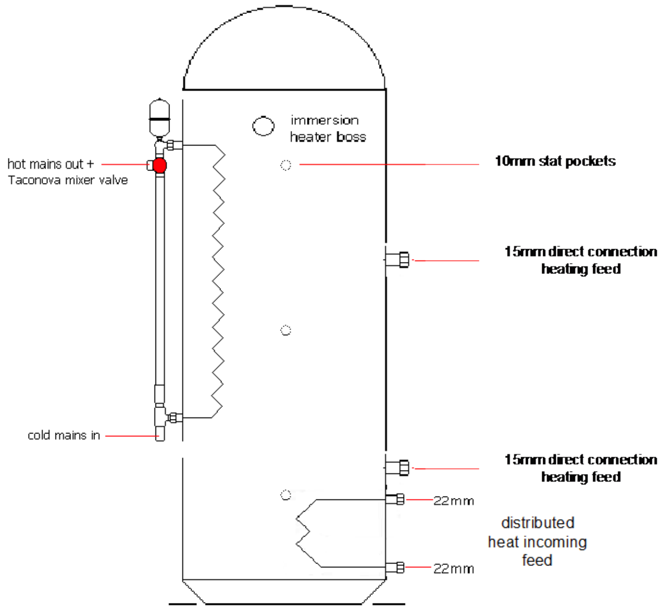

Figure 3 Thermal store fitted in each apartment

The inspection found that the installation of the heating and hot water systems was to a high standard. It was noted in work package 1.4 the Infra-red thermographic report, that the insulation around some of the isolation valves associated with the thermal store were not to a high enough specification. During the inspection it was also noted that there were minor gaps in some of the insulation around pipe junctions, and that this could have been improved. In work package '2.0 Occupant survey' using a standardised housing questionnaire, it was noted that one consistent theme from occupants, was a reported draft in the entrance hall of plots 1 to 6. It was observed that there was no space heating in the hallway, and we speculate that given the achieved air tightness results for the dwellings and lack of thermal bridging, that this could be the reason for the reported draft.

7.3 Lighting

The inspection found that the installation and lighting type was to a high standard. During the inspection it was noted that the natural daylight levels were particularly good in this development, especially in the living area of plots 1 to 6.

7.4 Conclusions and key findings for this section

The single area of non-compliance found in this audit was the measured air extract rates. At installation the extract rates were set, and an audit of the documentation shows that the air extraction rates were compliant. Cooker extract hob filters and the MVHR unit were heavily contaminated, and although an analysis was not made of the filter deposits, we hypothesise that some of the heavy build up was debris from the development build phase. The boost settings of the MVHR still had to be adjusted to achieve compliant extract rates, even when the filters had been replaced. It was noted that none of the MVHR units appeared to have had the fan rates adjusted from there factory set positions. It is clear from this site that the MVHR installations are working well on a technical level, but that tenants need to be made aware of the importance of keeping them running, and that it is unlikely that they will undertake filter changes unless incentivised in some way. In the meantime the landlord has taken on the responsibility of managing the filter exchange regime.

8 Other technical issues

8.1 Technical issues

The few minor design changes were identified during the site audit and walk through were as follows:

There is some routine maintenance that was not planned for at design time. Access to the roof for maintenance is currently via a ladder; a better solution would be to create a secure access door through the shared stairwell of the flats. This would allow simple access to the roof for routine maintenance, reducing the number of staff needed.

The guttering at the rear of the property could be redesigned to improve leaf fall catchment and better surface water drainage.

Internal layout of the flats could be improved. To avoid wind-loading issues on the three-storey flats, a load-bearing wall divides the living space into two equal parts on the ground and first floor. The load-bearing wall could be moved to give tenants on future builds, a larger living area.

Recycle bin and cycle storage space at the rear of the development is currently used only as a drying area for clothes. This could be redesigned as a dedicated clothes-drying area, and dedicated bin storage areas developed for each property, housed where tenants currently prefer to store their bins.

8.2 Conclusions and key findings for this section

Generally the issues raised here are minor ones

9 Key messages for the client, owner andoccupier

9.1 Client

Whist this project did not meet its initial budget targets, it is clear from the analysis of costs undertaken,that in serial production and taking into account the lessons outlined within this report, that construction using this heavy weight building methodology is a commercially viable.

The overall construction methodology confers a number of key advantages compared to conventional brick building techniques when meeting future regulatory building standards. Thermal performance, noise isolation and airtightness achieved with this development are outstanding when compared to industry norms. No gap is discernable between the design values and the as built performance values. There are also very strong indicators that the structural stability of thisheavy weightbuildingwill lead to the longevity of these results. The airtightness figures for example,showed no degradation over the first year, even under enhanced testing conditions. This means that the technical merits of the project can be leveraged in developments where the business model benefits from defined long-term performance guarantees.When compared to the Fabric Energy Efficiency Standard (FEES) specification rating the development would fall into the D band category or passivhaus equivalent. The FEES standard recommends a fabric efficiency figure of 39kWh/m^2/year for an apartment block and the development energy footprint is falling well within this at approximately 23kWh/m^2/year.

Another benefit conferred using this construction methodology is low levels of scrap material generated on site, unlike a conventional brick build. During the construction of the developments superstructure, only one skip worth of material was removed from site keeping debris to a minimum and reducing the build cost.

9.2 Owner and occupier

The interviews carried out during this study indicate that the dwellings are well liked. Tenants find the living environment very comfortable with good levels of control over the internal environment. The major factors in the liveability of a dwelling can be defined as:

- Thermal comfort – the ability of a dwelling to provide a thermally comfortable draft free environment all year round.
- Acoustic comfort – the dwelling provides a good degree of sound isolation from adjacent buildings and the external environment.

- Space comfort - a flexible interior layout, resilient design i.e. solid walls more robust to impact damage / intrusion and high ceilings in the living space.

- Indoor air quality – the dwellings air should be fresh and have comfortable moisture levels.

The occupiers when questioned, have rated this development highly in all of these categories. This is corroboratedby the empirical data collected throughout this report, demonstrating the excellent thermal, acoustic and space comfort.

The owner of the development states that there has been a low turnover of tenants, and that no dwelling has been vacant since the development was completed in 2011.

9.3 Conclusions and key findings for this section

Overall, the choice of design elements have worked extremely well together providing a simple and aesthetically pleasing structure.

Very little gap is discernable between the design values and the as built performance values, making this construction technique a good candidate for volume product in markets where reliable long-term performance is a key requirement.

Qualitative analysis of the tenant's views of living in the properties demonstrate that the properties perform well in practice, and this is corroborated by the owner of the development who states that there has been very little turnover of tenants since the development was constructed.

10 Wider Lessons

10.1 Site

The nature of the site was an important factor: building on a sloping, tightly constrained site is much more challenging than building on a flat, open site. Reducing the number of units by one would have made the construction process smoother. It might also have improved the internal layout and usability of the dwellings.

10.2 Supply-Chain Partners

The need to change both the project manager and the ICF supplier highlights the importance of due diligence work in supply-chain partner selection; suppliers must be able to provide sufficient information to demonstrate they can meet the project requirements.

10.3 SAP Calculations

The SAP calculation method includes many assumptions that affect the end result. These include an assumption that the dwelling will be heated to 18°C with living areas at 21°C, however the reduction in fuel bills due to higher thermal performance may have the effect of increasing preferred internal temperatures. The domestic hot water demand is determined from average values related to dwelling floor area. This will lead to a variance between calculated and empirical results.

SAP is a tool for compliance calculations and standard ratings, which require a level of standardisation that limits the flexibility to more accurately model dwellings with higher levels of energy and environmental performance. It was not possible to include the benefit from low-energy appliances and reduced cooking energy consumption. Modelling the combination of different heat sources was challenging, even after the improvements to SAP 2009. In order to promote innovation, the calculations carried out in future assessment should have the flexibility to account for these improvements.

10.4 Detail of Brief

It was felt that some of the design issues such as the acoustic could have been addressed more easily had they been identified earlier in the process. A clearer and more detailed brief would have been helpful in this respect.

10.5 Conclusions and key findings for this section

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

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