The Old Apple Store, Stawell

Phase 1 study

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

Innovate UK project number	450015
Project author	Oxford Institute for Sustainable Development: Low Carbon Building Research Unit
Report date	2011
InnovateUK Evaluator	Ian Mawditt (Contact via www.bpe-specialists.org.uk)

No of dwellings	**Location**	**Type**	**Constructed**
Five	Stawell, Somerset	Detached and terraced	2009

Area	**Construction form**	**Space heating target**	**Certification level**
Various. See report	Timber frame	29.5 kWh/m^2 per annum	CSH level 5 (SAP 2005)

Background to evaluation

The objectives of the BPE study involved collaborative sub-studies undertaken by the designers, developer and researchers which covered the development process from inception through to early occupancy. The study involved performance assessment of the openpanel timber frame fabric, assessment of occupant satisfaction in relation to orientation, open planning and daylighting. The study examined the design process and the initial design intentions for The Old Apple Store as well as the rationale behind any changes made during the development and construction process. A technical study focused on a 120 m^2 terraced house (No. 2).

Design energy assessment	**In-use energy assessment**	**Sub-system breakdown**
N/A	N/A	N/A

The target of CSH level 5 with zero carbon emissions for heating and lighting was to be achieved by utilising a super insulated timber frame construction with low air permeability, 2.04 kWp photovoltaic panels and solar thermal water heating. Additional water and space heating was provided by a 1 kW wood pellet burner and all houses have rainwater harvesting systems for toilets and washing machines. The research found a significantly better than assumed Standard Assessment Procedure (SAP) value for heat loss and thermal bridging elements, a better heat loss for the external fabric of a tested home than originally predicted by SAP, good occupant satisfaction with the housing in relation to orientation, open planning and daylighting, and satisfaction with overall comfort conditions, with perceived positive health benefits from the detached units.

Occupant survey type	**Survey sample**	**Structured interview**
N/A	N/A	Yes

A structured interview was conducted with the occupants in one of the properties. The occupants found it very easy to live in, with well-balanced environmental conditions. They were pleased with the renewable energy systems (solar hot water and photovoltaic panels) as the initial earnings they got from the PV array almost matched the cost of the electricity they used. They were not satisfied with the handover and information pack received; they felt it was not particularly organised, put together in a hurry and was not thorough enough. The occupants found the mechanical extract system to be relatively poor; it ran constantly and could not be adjusted. Overall, there was very poor control of the ventilation system.

The Old Applestore, Stawell

Technology Strategy Board Building Performance Evaluation Programme: Initial Occupancy Study

Final Report

OXFORD BROOKES UNIVERSITY

Content

Acronyms

ATD: Accredited Thermal Bridge Details.

BPE: Building Performance Evaluation. Typically a study carried out which assesses the performance of a building through its lifecycle compared to design intentions.

BUS: Building Use Studies. Organisation promoting questionnaires for BPE.

CSH: Code for Sustainable Homes. Government standard with levels 3-6, leading to 'Zero Carbon' homes at level 5 and 6.

DER: Dwelling emission rate. This is the amount of carbon dioxide release by a dwelling according a SAP calculation.

HLC: Heat loss co-efficient. The heat loss from the building per degree inside-outside temperature differential.

HLP: Heat loss parameter. The total heat loss for the building envelope divided by the floor area to obtain a comparative benchmark.

MEV: Mechanical Extract Ventilation. Can be centralised or individual units.

MVHR: Mechanical Ventilation with Heat Recovery. Functions like a fridge in reverse by extracting heat from exiting air and pre-heating incoming air with this heat.

SAP: Standard Assessment Procedure. A method of calculating the amount of energy used and carbon dioxide emitted by a dwelling in terms of regulated emissions: heating, ventilation and lighting.

TER: Target emission rate: the maximum carbon emission value that complies with current regulations.

TRV: Thermostatic Radiator Valve. Controlling mechanism on radiator for heat output.

1. Executive Summary

Introduction

1.1. This final report covers the building performance evaluation (BPE) of The Old Apple Store at Stawell in Somerset undertaken by The Oxford Institute for Sustainable Development: Low Carbon Building research unit between December 2010 and May 2011.

Aim and Objectives

1.2. The aim of the BPE was to learn lessons in hindsight in order to improve future housing design, development and management within Ecos Homes leading to improved customer products and services. The objectives consisted of a series of collaborative sub-studies undertaken by the designers, developer and researchers which covered the development process from inception through to early occupancy.

Summary of key findings

1.3. Overall, there have been a number of positive findings in relation to the initial occupancy study of the The Old Apple Store housing development. These include:

- an excellent approach to insulating the fabric and highly ambitious energy standards
- a significantly better than assumed Standard Assessment Procedure (SAP) value for heat loss and thermal bridging elements
- a better heat loss for the external fabric of a tested home than originally predicted by SAP and when the SAP figure is corrected.
- occupant satisfaction with the housing in relation to orientation, open planning and daylighting.
- occupant satisfaction with overall comfort conditions, with perceived positive health benefits from the detached units.

1.4. There have also been a number of findings which highlight particular challenges and opportunities for improving the Ecos Homes housing product. These are:

- continual changes to the design and specification after work had started on site which has resulted in poor integration of services.

- lack of training, co-ordination and communication between the developer, design and build teams in relation to the proposed design, installation and commissioning of heating and ventilation systems
- occupant dissatisfaction with storage facilities, some internal specifications and some specific comfort conditions
- poor occupant and staff understanding of ventilation and heating systems
- lack of feedback at all stages of the development cycle, including lack of adequate handover procedures and guidance for the occupant.

1.5. Key recommendations in response to these findings are set out under three development processes: design, communication, and feedback.

Design recommendations

1.6. Greater iteration and design development of innovative design features are needed prior to the construction stage to ensure that they performed to an optimum level. **A mechanical engineer should be engaged to provide an integrated design strategy for complex heating and ventilation systems, and to complete the servicing design for the remaining houses.**

1.7. It is imperative to establish a detailed and co-ordinated specification and layout plan for services which works in tandem with the design process. This should go right down to the last control feature and its position in the home.

1.8. More detailed design consideration of the external fabric and services should be undertaken and properly tested and co-ordinated with suppliers. Improved detailing of the external fabric of the home, and the party wall, will help avoid thermal bridging. This requires a greater understanding of the thermal bridging consequences of detailing decisions in the first place. It is essential to have services strategy fully integrated with the structure and fabric from the outset of design, as this cannot be bolted on afterwards.

1.9. Occupants require greater accessibility and usability in relation to heating and ventilation controls, as well as a variety of specification improvements.

Communication lessons

1.10. **Establish clear protocols of responsibilities in relation to all aspects of design, construction and handover so that everything is suitably co-ordinated**.

1.11. **More training is needed** for installers, site operatives and customer care staff to ensure that all parties fully understand new technologies being deployed, including how they should be installed, commissioned and maintained.

1.12. Installation and commissioning procedures need to be much more robust. This includes identification of competent persons for the procedures and appropriate certification.

1.13. **Guidance and handover procedures for occupants needs to be more comprehensive** and thoroughly co-ordinated with installers and suppliers. The guidance needs to be clearer to ensure that the occupant is not left confused. Occupants need an explanation and demonstration of how to optimally use ventilation and heating controls.

1.14. There is a major opportunity for Ecos Homes to develop comprehensive yet bespoke home guidance which can also potentially be used as a marketing tool.

Feedback

1.15. **The Ecos housing development cycle requires better feedback systems at all stages to ensure continuous improvement.**

1.16. Once on site, a more formal feedback loop is required between the design team, developer and the construction team, to ensure any unavoidable changes are thoroughly reviewed before being agreed and properly documented.

Further investigation required

1.17. There are a number of findings in this limited study which require further investigation in order to identify causes and solutions for the particular issues identified. In particular, further exploration of the party wall bypass identified between plot no.1 and no.2 would help to provide a better understanding of why this is occurring.

1.18. A further two year monitoring study of plot no.2 and 3 would provide physical evidence to corroborate the findings of this initial study in relation to occupant perceptions, building performance and energy use. It would also build on the monitoring of plot no.5 currently being undertaken by Oxford Brookes University for Ecos and the Good Homes Alliance and funded by the Energy Saving Trust and the Department for Communities and Local Government.

2. Project Overview

2.1. This summary report covers the Technology Strategy Board: Building Performance Evaluation Initial Occupancy Study of The Old Apple Store housing development (project no.1726-16331), which was awarded to Ecos Homes in November 2010. The Oxford Institute for Sustainable Development: Low Carbon Building research unit was commissioned by Ecos Homes to undertake the study. This report was submitted to Ecos Homes on 1st July 2011 and covers seven sub-studies carried out between December 2010 and May 2011 (separately issued as Appendices).

2.2. The development occupies a brownfield site in the middle of the small village of Stawell in Somerset. The site was originally used for sorting and storing apples, giving the development its current name. The five houses were built by Pippin Properties, which was a joint venture between the owners of the site, and Ecos Homes. Design work began in summer 2006 with an initial target of achieving Eco-Homes Excellent. Work on site commenced in 2007 and the first three houses were completed and occupied in spring 2009. Two remaining houses were left as unfinished shells until summer 2010.

2.3. The revised target of CSH level 5 with zero carbon emissions for heating and lighting was to be achieved by utilising a super insulated timber frame construction with low air permeability, photovoltaic panels and solar thermal water heating. Additional water and space heating was provided by a wood pellet burner and all houses have rainwater harvesting systems for toilets and washing machines.

2.4. The build cost of the properties, excluding fees and site exceptions, is approximately £1,400 per sq metre depending on the property. An outline specification for the project as a whole is described in Appendix vi.

2.5. This study firstly examines the design process and the initial design intentions for The Old Apple Store as well as the rationale behind any changes made during the development and construction process. The technical study then focuses on an unoccupied terraced house (No. 2), and consists of the following elements:

- audit of working drawings compared to houses as built
- SAP 2005 check

- accurate calculation of Y-values[1] and Psi[2] values to check thermal bridging assumptions made in SAP 2005
- co-heating test to establish the actual heat-loss through the external building fabric
- party wall bypass[3] test between No.2 and No.3
- review of installation and commissioning of the heating and ventilation systems.

The wider social study consists of the following elements:

- interviews/walkthrough with the developer team and design team
- questionnaire survey completed by 3 households
- evaluation of user guidance and handover procedures
- three semi-structured interviews of occupants
- review of user control interfaces

2.6. This report draws together the findings from these various elements and highlights key lessons for Ecos Homes.

2.7. The documents of the sub-studies associated with the various sections of this report are:

- Design Intentions compared to As Built report (Section 3 and Appendix i)
- SAP check (Section 4 and Appendix ii)
- Co-heating test report (Section 4 and Appendix iii)
- Installation and commissioning report (Section 5 and Appendix iv)
- Specification for The Old Apple Store development (Section 2 and Appendix vi)
- Handover and guidance review report (Section 6 and Appendix vii)
- BUS questionnaire report (Section 7 and Appendix v)
- Occupant interview (Section 8 and Appendix vii)
- User control interfaces (Section 9 and Appendix viii)

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[1] A Y-value is the total heat loss attributed to the linear thermal transmittance divided by the surface area of the thermal envelope considered.

[2] A Psi –value is the *linear* thermal transmittance through a material or combination of materials.

[3] A party wall by-pass is where heat by-passes the insulation provided and creates an unaccounted for additional heat loss via the external envelope or to the adjacent dwelling.

3. Design intentions compared to as built

3.1. This section reviews the study of design intentions compared to the as built reality which included an audit of the drawings available, visits to the site, and interviews with key members of the design and client teams (Appendix i). It focuses on one of The Old Apple Store plots (Plot 2), where the technical tests were carried out, within a more general overview of the housing development.

3.2. The available drawings and specification available for this were examined. These included:

- conceptual hand sketches for planning permission
- original sales brochure for the Old Apple Store
- construction drawings first issued by the architect O2i design consultants in July 2007 with most recent amendment revision A,19 June 2008
- Ecoframe timber drawings issued 22 October 2008

3.3. To record the project team's understanding of the building and of the changes made an interview with the project architect took place in March 2011, and a separate walkthrough with the Executive Director of Ecos Homes took place in plot no. 2 The Old Apple Store in April 2011. Site visits were undertaken to observe the 'as built' home in February and March 2011.

3.4. A number of significant findings were identified during the interview carried out with the developer.

3.5. **The target for the energy efficiency standard for the development changed** during the design as government standards advanced from EcoHomes to the Code for Sustainable Homes. The highest standard possible was sought and the developer settled for the Code for Sustainable Homes level 5 which determined the investment on renewable technologies. The house types were already decided at that point.

3.6. The development consists of two house types. The intention to provide energy efficient sustainable houses remained throughout the project.

3.7. The developer previously tried to implement "live" energy monitoring but the prototype design did not come to fruition.

3.8. **Biodiversity has been a disappointment for the developer**. Their original intention was to provide sedum roofs and more varied gardens but they **abandoned the sedum**

roof in the homes to allow for a clearer ownership of the PVs. The reason not to pursue wild flower mixes in the gardens was to attain a tidier look (more saleable).

3.9. The developer would be happy to repeat the house types with a few modifications to their design:

- For the detached houses, they would **abandon the awkward detail of the stepped window** and the single storey part at ground floor. These houses are easy to build and are a thermally efficient box.
- They are **happier with the design of the terrace but without the archway/drive through which was ruled by the need to give access** to the rear to the fire services.
- The ground floor evolved during the design; initially a sunspace, it was simplified and the glazing reduced to avoid the risk of excessive overheating.

3.10. The developer is **happy with the comfort attained in the terraced house type and have received positive feedback from the occupants**.

3.11. The terrace dwelling has been designed with adaptability in mind and the possibility to expand into the roof, ready built with room in the roof trusses.

3.12. The developer does not like the look of PVs in combination with the pantile roofs.

3.13. The developer encountered a few problems with some of the materials and technologies used including:

- Poor weathering of the timber cladding
- Need to specify a push rod dual flush system for a more robust WC installation
- **Rainwater harvesting system needs greater maintenance of filters than expected** and information from suppliers on installation was poor.
- Difficulties of maintaining the pressure of the hot water system for the solar thermal tanks installed due to unfamiliarity with the system – the developer has since installed a secondary expansion vessel.
- **Poor after installation support from one of the wood pellet manufacturer** (changed suppliers as a result of this).
- On installation, the passive vent system was not compatible with the timber frame design as the outlets could not go through the ridge. The developer opted in the end for a mechanical extract ventilation (MEV) system with low speed fans.
- **Air tightness in the middle terrace dwelling is not as high as they expected possibly due to delays on roof construction**.

- Outside lights PIRs are not robust.

RECOMMENDATIONS

1. ***Continue designing for energy efficiency.***
2. ***Maintain commendable good space standards and quality of light.***
3. ***Review coordination of ventilation system with structure as early as possible to retain clarity of strategy throughout project.***
4. ***Consider requirement of support from suppliers after installation and ensure they understand and communicate all maintenance requirements to be passed on to users in simple user friendly instructions.***
5. ***Consider durability of external finishes during specification.***

3.14. A number of significant additional findings were revealed during the interview with the project architect.

3.15. The project architect inherited a hand drawn scheme on A3 sheets from Ecos after it had planning permission, as the design architect had emigrated. **The drawings did not fit on the site because no one had carried out a survey** and the project architect basically had to fit everything in. The original scheme design was not a particularly 'clean' layout and the limit on footprint and need for number of bedrooms made planning tight. **The arrangement of buildings around the site became quite dense and compact, with small gardens. One less house might have provided a better solution**. Being able to drive into site and have space within the courtyard has helped to provide a good sense of community.

3.16. The project involved significantly cutting into the ground and providing a big retaining wall, which was not originally envisaged because no site levels were established. A CAD model of the retaining wall for plot number 4 and a sunpath study were developed to make sure sunlight reached into the back of the house. This has proved successful in reality.

3.17. Renewable energy was always in mind, but to start with the project architect did not know what area of PV was needed or the proposed positioning for these –calculations came late in the day. In the end PV panels were placed on the garages' and carports. There was **a lot of quick retrospective decision-making required after the buildings had been designed which was not ideal.**

3.18. The original intention was to insulate the homes so well that body heat and heat from appliances would provide all the space heating required.

3.19. A number of decisions were made by the second project manager employed by Ecos Homes, rather than the project architect. The whole procurement process was initially discussed with a local company who advise housing associations on packages. There was some discussion about whether Ecos Homes should act as client and employ main contractor but they decided to be main contractor, to give them more decision-making ability on site. **Having a project manager gave opportunity to adjust and change, but without the rigour of a commercial contractor.**

3.20. The second project manager was employed by Ecos Homes when the project was underway. He took over managing the project from the Ecos Homes Executive Director – who was acting as client, with an original project manager having set up the project before it got to site.

3.21. **The numerous design changes made once works had started on site were not formally recorded as instructions, although they were noted on the drawings**, in order to maintain a joint collaborative process between the project manager and the project architect. This back fired, however, when a fee dispute arose.

3.22. The design of the front terrace changed quite substantially with a decision late in the day to take the conservatory out, before the houses were being built, but after building work on site had commenced. That changed the timber structure and subsequent detailing.

3.23. There was some frustration from the architect, timber frame manufacturer, structural engineer that these matters weren't dealt with earlier by the client**.**

3.24. By the time the timber frame contractor was working on the last three terraced units, there had been many changes which were difficult to deal with. The workmanship on No.1,2 and 3 is subsequently not of the same standard as on No.4 and 5.

3.25. The project architect had a background in laboratory design and provided a service zone in the first floor accessed via floorplate in cupboard to access all services. The intention was to provide flexibility and access in the long run. The electrician did not follow the zoning, drilling through studs. **There were no wiring layouts as such, which might have helped maintain the zoning strategy during construction on site.**

3.26. Time was spent working out where rainwater tanks in terms of access and visibility of controls, but changes still occurred on site.

3.27. Time was spent trying to find the right windows to fit the rear sloping elevation on No.4 and 5. These should have been bespoke, but the architect was trying to find a supplier with an off the shelf kit. Once the supplier realised there was a seven degree tilt, posing potential problems with pooling of water on window cill, they would not provide a guarantee. The timber frame contractor also had difficulties with tilt as designed. In the end the windows had to be put in vertically within tilted frame.

3.28. The ventilation strategy changed several times. The original idea was that all buildings would use a passivent system with no mechanical ventilation at all, but No. 4 and 5 did not have a high enough roof pitch or loft space to accommodate this without having tall tubes sticking out of roof.

3.29. **It is often the case that there is a reluctance to get design completed and finished before the client wants to be on site building it – problems then arise as it is difficult and expensive to rip out work which results in compromises made on site.**

3.30. **The design techniques looking at the insulation values and construction of the skin are cutting edge, involving insulating outside of the frame with no cold bridges as such.**

3.31. The poor ground conditions for the front terrace resulted in a suspended floor using a Celcon reinforced plank which the timber frame was bolted down onto, which worked well.

3.32. The balcony concept worked well.

3.33. New technology keeps changing and it is a struggle to find the way between the sales pitch and the actual calculations required. The project architect used a local specialist to help do the calculations which helped to make decisions.

3.34. The architect was striving for a high quality of finish but this was compromised because the bricklayer and joiner were unfamiliar with details being specified.

3.35. The project architect has parted company with Ecos Homes, and has not been back to development. The project was due to be finished at least year before it was, the delay arising partly because of all the changes that took place. The architect was trying to persuade Ecos Homes to stop making changes and get the development built. The developer was trying to find the greenest solutions possible and treating the development as an experimental one. As a result of the delay, the development was not completed before the housing market crashed.

3.36. The project architect struggled with the timber frame manufacturer’s CAD drawings. When the architect sent their layouts the manufacturer sent his drawing back, and they did not match. The fit of the windows in the openings was also poor.

3.37. Everyone involved with this development wanted it to reach the highest levels of performance. However, there is a need to balance commercial reality with trial and error and avoid different bodies pulling in different directions.

3.38. The architect had hoped to learn from previous Ecos projects, but was not allowed to look at drawings or specifications relating to these.

RECOMMENDATIONS

6. ***Ensure accurate survey of site has been completed prior to planning stage submission of drawings.***
7. ***Pre-plan service and renewable energy strategy at inception stage and carry out detailing of services in tandem with design drawings.***
8. ***The use of environmental modelling to ensure solar penetration into home is commendable.***
9. ***The careful fabric design for high insulation levels and airtightness is commendable***
10. ***Ensure design is completed and finished before going on site building to minimise any changes on site and avoid difficult and expensive abortive work or compromises.***
11. ***Any changes agreed on site should always be recorded in updated drawings and followed by written instruction.***
12. ***The cutting edge design techniques utilised for the fabric construction, involving insulating outside of the frame with no cold bridges, are commendable.***
13. ***Early numerical calculations of the energy requirements will ensure an optimal design – renewable systems should not be bolted onto a pre-existing design.***
14. ***Provision of a service zone is commendable but should be accompanied by layout drawings for the plumber and electrician***
15. ***There is a need to balance commercial reality with experimentation in new housing in order to maintain quality and competency on site.***
16. ***Lessons learnt from one development should ideally be passed onto the project architect of the next one.***

3.39. A number of significant drawing discrepancies have been identified during the drawing audit.

3.40. **Very few changes have taken place in the intentions of the site layout since the original drawing in March 2006 (fig 1).**

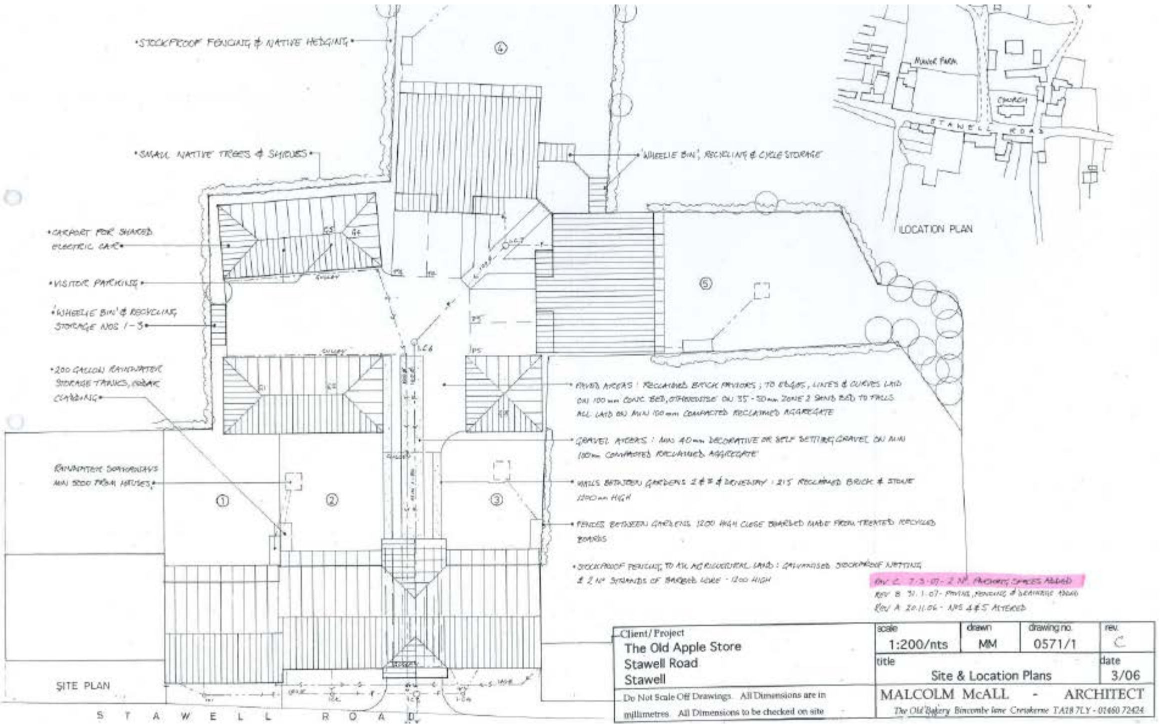

Figure 1 Site plan, March 2006, 0571/1

Fabric and spatial planning

3.41. **A number of changes have taken place to the house type number 2 since the original layouts by the design architect in October 2006.**

3.42. Increased liveable space was achieved by including the sunspace area within the main living room and providing it with an insulated roof. (fig 2 and 3) The main driver for the reduction in glazing was a concern with overheating.

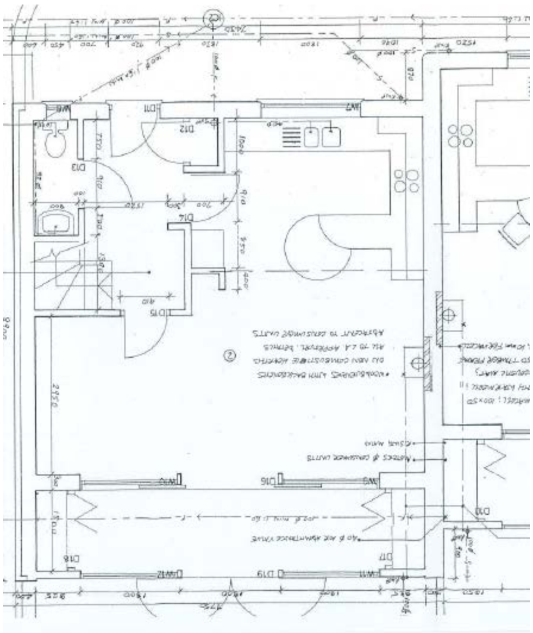

Figure 2 October 2006 ground floor plan, 0571/8

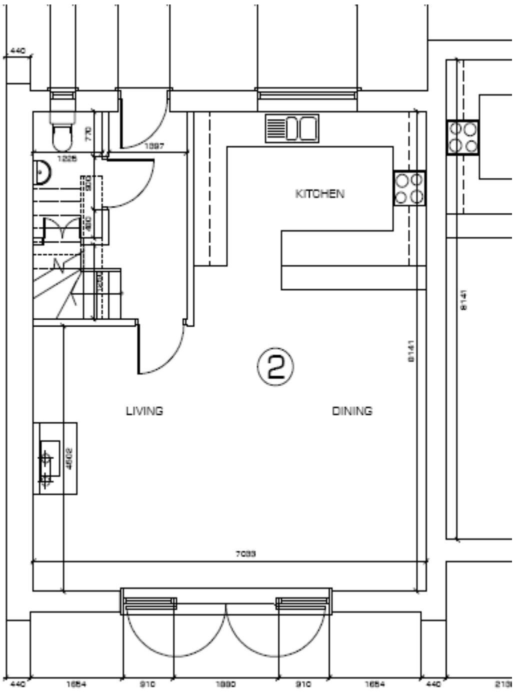

Figure 3 July 2008 Drawing 203(10) 20 rev G

Figure 4 Stores for meter cupboards and invertor by front door

3.43. The arrangement of the front hall is simplified (fig 3); the provision of a bigger meter store would have been better as **the current inverter store overheats considerably and will need substantial ventilation openings** (fig 4).

3.44. The living room is more spacious room and the boiler changes from the kitchen side to the stair side of the building (fig 2 and 3). This has a knock on effect on the upstairs- the water services and the flue (fig 7).

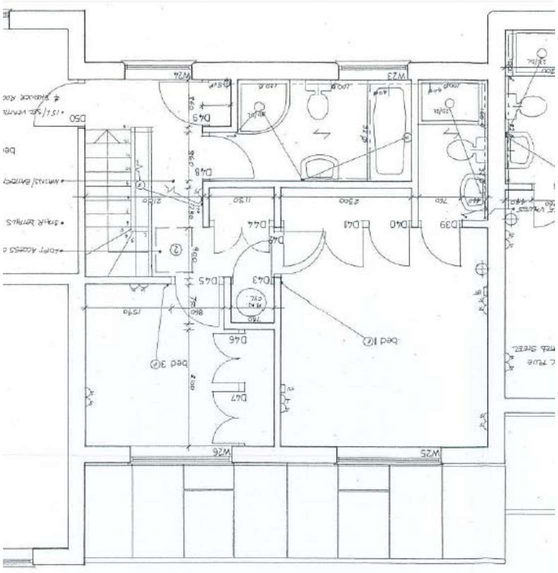

Figure 5 first floor plan October 2006,0571/10

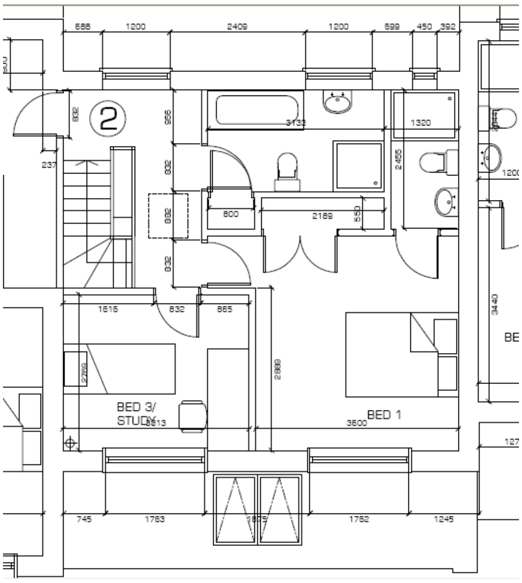

Figure 6 first floor plan July 2007 203(10)21G

Figure 7 Boxed flue in bedroom 3

3.45. **It is apparent from the drawings (fig 5 and 6 above) that the first floor plan has changed considerably.** The cylinder store and cupboards are omitted from bedroom 3, and the cupboards rearranged around the main bathroom which is itself substantially rearranged. The flue has much more impact than the flue pipe drawing might indicate (fig 6 and 7).A small window is now included in the ensuite bathroom (fig 6) where a passive stack vent was planned.

3.46. **The south facing elevations have changed considerably from October 2006 to July 2007** (fig 8 and 9). The conservatory (fig 10) being replaced by a single storey offshoot to the living room, smaller windows to the first floor bedrooms and a smaller window to the bedroom over the alleyway. The additional inclusion of the two roof lights in the front area of the living room helps produce stack ventilation if the space is getting hot.

Figure 8 South elevation October 2006, 0571/14

Figure 9 South elevation, July 2007, 203(10)28

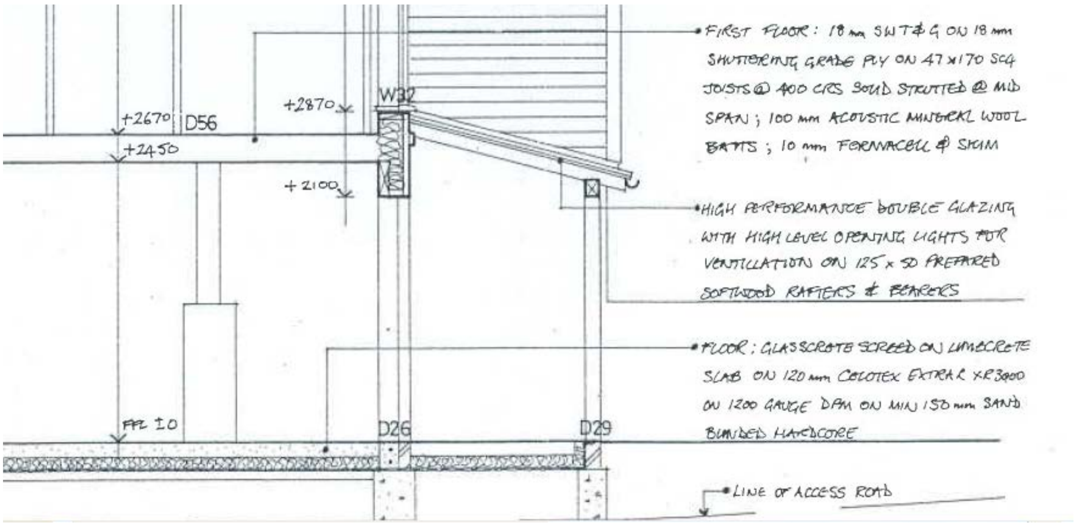

Figure 10 Section through proposed conservatory, , 0571/16,

3.47. Moving the wood pellet stoves has the result of also changing the chimney position, the pitch of the roof over the alley way changes and the PVs appear to be a different size.

3.48. The North elevation first floor window has a raised cill level (fig 12) compared to the original drawing (fig 11). This is to accommodate a splash back from the sink area.

Figure 11 North elevation, October 2006, 0571/12

Figure 12 North elevation, O2i design 2007

Figure 13 North elevation, sales brochure

3.49. The brochure drawings feature a curved archway in the alleyway (fig 13): this was not part of the design drawings.

3.50. The ground floor levels of houses 1, 2 and 3 have been raised by 500 mm from road level to facilitate headroom in the alley way. This gives a difficult level drop of 500 mm outside the french windows of No 1 and 2 and does not achieve a headroom adequate for deliveries of wood pellets which have to be dropped in the alley way and wheel barrowed around into the garages by the building occupants.

3.51. The Ecoframe drawings are incorrectly numbered (more than one drawing has the same number) and although revisions numbers are noted, the nature or detail of the revision is not given. This makes it **very difficult to follow the intentions and revisions.**

3.52. It has been difficult to find drawn or systematic records of the changes that have occurred during construction. In piecing together the information available it has been found that:

- In the working drawing package by the O2i design consultants, the **details are not clearly cross referenced**, except at plinth level.
- **The architects drawings were produced and issued before the timber frame drawings which might explain their lack of referencing of the construction details in the timber frame part of the building** (i.e. above foundation level)
- An un-numbered hand drawing, with the appearance of a drawing produced on site by the builder, indicates that the stud walling detail was possibly still being changed once the project was on site.
- There appears to be air escaping from the construction in a way that it did not from number 4, which has been previously tested. This may be due to the floor construction, block and beam, and the roof construction at the south side of the living room- the joints between the windows are clearly not air tight.
- An unexplained step occurs in the wall of bedroom 1 adjacent to the south elevation- it may be that this step is necessitated by extra insulation as the wall changes from internal to external at a point in the run of the wall.

RECOMMENDATIONS

17. ***Develop a clear and complete reference system between drawings to avoid confusion on the detailing the designers intend.***
18. ***Major design revisions have knock on effects and must be carefully investigated before they are brought forward.***
19. ***The passive stack ventilation option might have been feasible with the earlier layouts and avoided the need for MEV.***
20. ***The commendable reduction of the south facing glazing area helps avoid overheating. Architects need to be increasingly aware of the problems of overheating in well sealed and well insulated buildings.***
21. ***Establish a clear protocol of responsibilities for specification and coordination between designers and manufacturers, particularly when a third party such as a timber frame manufacturer is involved.***
22. ***Ensure all changes are recorded on construction drawings to provide 'as built' set of drawings – commission the architect to provide this service as necessary.***

Heating layout

3.53. **There appears to be no heating layout drawing for the development**. Ecos have pointed out that there was originally no intention to provide a heating system because the houses are so well sealed and insulated. The three upstairs radiators appear to be an afterthought based on experience of other low energy houses.

3.54. The radiators and the two towel rails are fed from the accumulator tank in the roof space which is heated by the solar thermal panels, the wood pellet boiler and an immersion heater with an Oso Solarcyl unvented accumulator (observed in No.3, rather than No.2, because No.2 is not fully fitted out yet) .

3.55. **The residents in No.3 believe that the pump on the heating system is intended to run continuously because this is information they received from the developer.** As there are no obvious controls on the towels rails (fig 14), any hot water from the solar panels is dissipated to the towel rails before it can be used for showering. This additionally results in unnecessary spatial heating of the bathrooms in summer.

Figure 14 Towel rails in bathrooms heated by solar hot water

RECOMMENDATIONS

23. ***A formally designed heating system with comprehensive service drawings and specifications should be in place to enable checking for satisfactory performance prior to installation. This is particularly important when using new technologies.***

24. ***On off or thermostatic controls to towel rails would prevent towel rails getting hot when the weather is hot and also using up the precious hot water from the solar thermal panels.***
25. ***Precise instruction should be issued to the householders on how to use the heating system, particularly in innovative housing, to avoid confusion.***

Ventilation

3.56. No ventilation drawings relating to the housing development appear to be available.

3.57. **There is no mention of an MEV system in the original sales brochure, implying that a passivent system was still being deployed when this had in fact been changed.** The developer stated that they had originally intended to install a passivent system in the three terrace houses (No.1, 2 and 3) but **during the build it was discovered that the ventilation duct runs would not comply with passive vent regulatory requirements** so an MEV fan unit had to be included and positioned in the roof space. This is not ideal for the resident because changes to the ventilation rate (1,2 or 3 speed) can only be achieved by rewiring the unit as there is no dial control (fig 15).

Figure 15 Ventaxia unit in roof space with no dial controls

Figure 16 Long lengths of flexible ducting

3.58. Observations on site noted that:

- The MEV fan unit is installed in the roof space which extracts from the kitchen and the two upstairs bathrooms(in No2). It had been intended to extract from the downstairs bathroom but there was insufficient space to run the ductwork through the first floor to the roof space, so this was omitted and the downstairs WC was simply naturally ventilated using a window.

- **The MEV installation is primarily of flexible ducting which is not recommended in practice** (fig 16) and the occupants of number 3 are unhappy because it the increased noise levels this produces.
- For the MEV to work effectively there must be some incoming air. **This was not explained to the occupants of number 3 when they moved in**: they enjoy the warmth and economy of their unit and find that opening the trickle vents whilst operating the MEV system decreases the temperature considerably (by 1-2 degC) and so have decided against this strategy.
- **The location of services (solar, MEV, immersion heater control) in the roof space makes their servicing/adjustment inaccessible**. This is problematic because it might be desirable to increase the ventilation rate when cooking for example, and then to turn it down afterwards.

RECOMMENDATIONS

26. ***Resolution of the ventilation system at an early stage will help to avoid compromises later on.***
27. ***Ensure co-ordination of ventilation system and other services at an early stage (i.e. when deciding fabric system) and allow adequate space for these within chosen construction system.***
28. ***Check any changes with specialist installer. Explain and record changes to specification and drawings.***
29. ***Ensure site staff understand the consequences of any changes (e.g. position of stud work in vicinity of ductwork runs) and provide additional training as necessary.***
30. ***Limit use of flexible ducting for MEV as far as possible by integrating duct runs with structural and construction systems.***

4. Fabric Performance

4.1. This section reviews the original SAP 2005 assessment for the study plot (Appendix ii) and then compares the original and corrected SAP 2005 predicted heat loss through the building envelope with the actual heat loss using a co-heating test (see Appendix iii). It also explores the performance of the party walls to see if there is any unusual heat loss occurring through these.

SAP check and Y-values

4.2. The Design SAP05 calculations for the study plot by means of a check on the assumptions made and the U-values[4] used to give a predicted energy use and CO_2 emissions that can be compared with the measured values of the Co-heating test. The y-value[5] for the plot was checked by calculating the psi value[6] for all the two dimensional junctions based on the construction drawing provided by O2i consultants, EcoFrame and some sketch drawings. The programme used was THERM 5.2.

4.3. The review of the Design SAP assessment for the terrace house (No2) showed:

- Assumptions of accredited thermal bridge details (ATD) were used. The y-value calculation (based on drawings) allows for a better value (y=0.026) than the ATD (y=0.08) to be used. This gives a better value on the fabric heat loss than assumed.
- It is unclear what checks have been carried out on site to ensure the thermal bridging details have been implemented as drawn.
- U-values in the design SAP05 provided were taken as a 0.15W/m^{2}K for the Warmcell rendered and timber clad walls, 0.11 W/m^{2}K for the Warmcell archway wall, 0.14 W/m^{2}K for the Warmcell floor above the archway and 0.19 W/m^{2}K for the roof. On our check, we used the details as drawn – and calculated using the assessor's software, we obtained a slightly higher value for the Warmcell walls and floor (0.15 to 0.16W/m^{2}K) but lower (0.14 - 0.15W/m^{2}K) for the roof[7]. The

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[4] A U-value is the thermal transmittance through a material or combination of materials.

[5] A Y-value is the total heat loss attributed to the linear thermal transmittance divided by the surface area of the thermal envelope considered.

[6] A Psi –value is the *linear* thermal transmittance through a material or combination of materials.

7 U-value for the roofs (main and ground floor rear of No2, were based on the drawings for No4 as there was no detail drawings for No2 – this gives a degree of uncertainty about the accuracy of the results.

rooflights installed were double glazed (U-value = 1.4 W/m^{2}K) rather than triple glazed as shown in the design SAP05 calculation. We have considered a slightly larger area for the roof as we measured the area of the ground floor roof on the slope[8]. All these combined they give a very slightly higher value for the fabric heat loss (+1%).

- **U-values and y-value changes combined give a reduction of 17% on the fabric heat loss and almost 10% improvement on the calculated heat loss parameter**[9].
- For this SAP check the wood pellet stove efficiency and hot water cylinder details have been taken from manufacturer's values (91% wood pellet boiler efficiency and 2.19kWh/day cylinder losses) which are better than those used in the original design calculation (67% SAP standard wood stove efficiency for HETAS unit and 5kWh/day cylinder losses).
- The area of solar hot water panels is larger than originally stated (4.12 m^2 aperture rather than 3.71m^2 assumed at design stage) whereas the cylinder's manufacturer's declared dedicated solar hot water storage (97 litres) is slightly lower than assumed (125 litres), pushing it below than the SAP05 requirement of 25litres/m^2 of solar hot water panel or 80% average daily hot water use (103 litres)[10].
- The dwelling also has a 2.04 kWp photovoltaic array providing more energy than the array assumed by the design calculation (1669kWh/year rather than 1519kWh/year).
- With all the above, the DER[11] = -0.56 kgCO$_2$/m^2 per year which still **better than the Zero SAP05 requirement for the Code for Sustainable Homes Level 5** (albeit worse than the predicted -1.14 kgCO$_2$/m^2 per year in the design SAP05)
- The above excludes party wall heat losses which were not taken into account in SAP 2005. Using SAP 2009 U-value of 0.2W/m^{2}K (uninsulated cavity sealed at top), **the predicted losses through the party wall would add 11.3W/K to the**

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[8] SAP 05 guidance convention measures roof area on the ceiling plane.

[9] The heat loss parameter combines the fabric heat loss with the ventilation heat loss of a building and divides it by the floor area of the building.

[10] In SAP 09 the assumptions for water use have been reviewed. SAP09 would allow a smaller figure for the minimum solar hot water storage (based on 80% of average daily hot water use), for this dwelling it would be 86 litres.

[11] DER= Dwelling Emission Rate of the new building which is compared in SAP with the TER=Target Emission Rate which gives the maximum carbon emission value that complies with current regulations.

fabric heat loss, which represents over 15% of the heat losses through the fabric.

- Based on SAP05 the space heating demand would be of 29.5 kWh/m^2 year [SAP05box81/Area], the building still needs heating, it stands a long way from a passive house standard – the calculations are different and not easily comparable but, as a reference, Passive Houses that only need MVHR to supply the heating have a space heating demand below 15kWh/m^2 per year. The calculation of the space heating demand greatly depends on the assumptions taken and the complexity of the calculation – as a comparison we have included in appendix ii a table comparing the assumptions and results for the study plot for the UK's regulatory SAP05 and SAP09 calculations

4.4. Overall the y-value calculation showed:

- The geometry of the house is very complex which made the y-value calculation an arduous task, which would be unimaginable in a small scheme.
- The design had a calculated y-value = 0.026, much better than the assumed Accredited Detail figure assumed of 0.08. **However, the certainty on the construction details used is low as the drawn information was not complete** (roof details junction details were not drawn for this unit and the psi-value calculations were based on the available information for unit 4 and the timber frame drawings for unit 2; wall junction details were provided in a sketch format for only one instance on which other wall junctions psi-value calculation were based on)[12].
- A few details have a psi value greater or close to the accredited details (appendix K SAP2009) and greatest contributors to y-value are ground floor party wall (19.7%) windows head/jamb on timber wall (17.6%), window cills (10.3%), external wall timber clad corner (6.5%) and low roof eaves (6.3%) details (fig. 17 and 18).

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[12] For further details see y-value check in Appendix ii

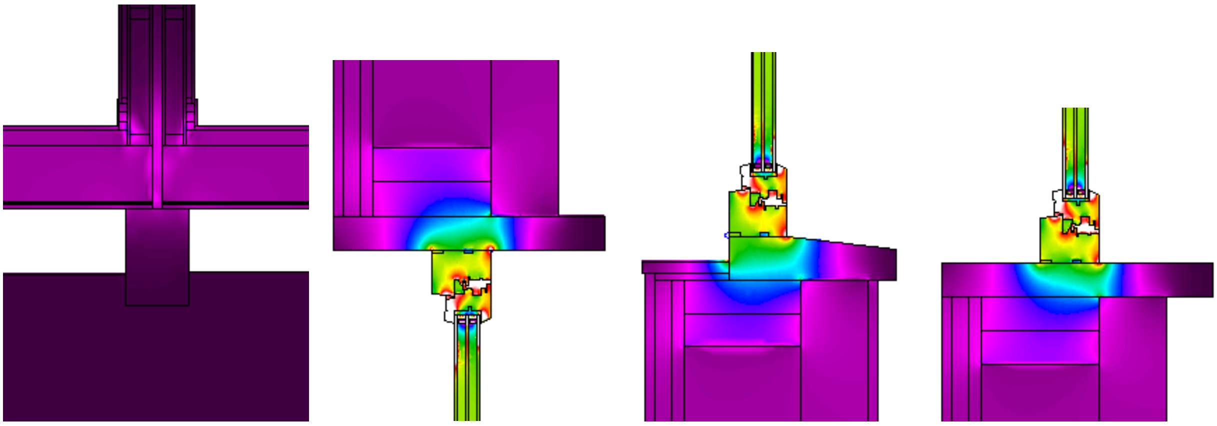

Figure 17 Thermal bridges with greatest contribution to y-value: Ground floor party wall(left), window head/jamb on timber wall (middle) and window cills (render and timber) (right).

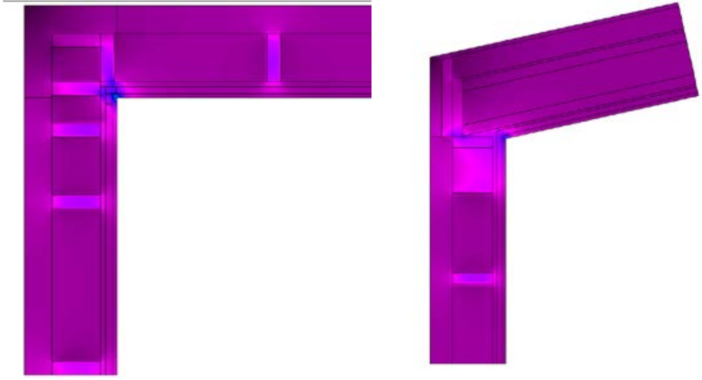

Figure 18 Thermal bridges with greatest contribution to y-value: External wall timber clad corner (left), and low roof eaves (right).

- Overall, thermal bridging represents 9% of the fabric heat loss for this dwelling type.
- Window head, jamb and cill junctions on timber cladding create a clear thermal bridge with the timber going all the way through the wall at these junctions.

RECOMMENDATIONS

1. ***Greater efficiency of fabric performance (U-values, thermal bridges and air tightness) is needed to push towards Zero Carbon Homes***
2. ***Ensure that there is adequate insulation at all key junctions in the external thermal envelope (including party walls).***
3. ***Avoid materials that bridge through the fabric construction.***
4. ***The effect of both thermal bridges and party walls in heat loss needs to be better communicated to design, clients and construction teams as greater attention to detail is needed both design and construction. Clearer detail information is required to allow for psi values to be modelled.***

5. ***Psi value and y-value calculations need to be better understood and a simpler methodology and guidance developed to allow smaller schemes to benefit from improving these values.***
6. ***There needs to be an understanding of the assumptions made by the SAP assessor by both the designer and the client's technical team in order to advise the assessor whether they reflect or not the actual construction of the building.***
7. ***Changes from the design stage should inform the as built calculation – using actual U-values of products and efficiencies of products installed.***
8. ***Ensure that there are procedures on site to confirm thermal bridging details are carried out as designed.***

Co-heating test process

4.5. Co-heating testing aims to determine actual as-built building heat loss through the fabric and by air infiltration (Appendix iii). The main output is a measurement of the actual Heat Loss Coefficient (HLC) for the building[13]. The measured heat loss can then be compared with the predicted heat loss as calculated in SAP2005.

4.6. Co-heating tests are usually carried out in a completed but unoccupied house over a period of at least three weeks between November and March. Outside this period it is unlikely that the required temperature differential of 15°C will be achieved. The house is heated by electric fan heaters to bring it up to 25°C, using large fans to ensure even heat distribution. Temperature and relative humidity are recorded at ten minute intervals in the rooms using wireless sensors communicating with a central datalogger.

4.7. Air permeability (blower door) tests are carried out before and after the test, using both depressurisation and pressurisation to 50Pa to establish an average figure for air leakage and hence air infiltration heat loss.

4.8. Tracer gas (carbon dioxide) decay tests are also run every day during co-heating to measure the actual infiltration in this period. Wireless CO_2 sensors monitor CO_2 concentration (parts per million, ppm) both upstairs and downstairs throughout the test period.

4.9. All electrical consumption by heaters, fans and sensors is measured by pulse output meters connected to each extension lead used and recorded at ten minute intervals by pulse transmitters communicating with the central datalogger.

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[13] HLC (units of W/K) is defined as the heat loss from the building per degree inside-outside temperature differential.

4.10. A weather station mounted at roof level records outside temperature, relative humidity, solar radiation on the vertical plane (South-facing), wind speed and direction.

4.11. Data is averaged over each day, and corrected for solar radiation and wind influences.

4.12. Heat flux sensors are placed on party walls to measure the heat flow across the wall. Next door houses are kept at 25°C also to ensure zero heat loss (theoretically).

Figure 19: Co-heating test equipment in kitchen/dining/living area

Figure 20: Co-heating test equipment in living room

Figure 21: Co-heating test equipment in Bedroom 1

Figure 22: Weather station on post

4.13. No. 2 is an unoccupied terraced property, having a party wall with two neighbouring houses. No 3 was occupied and heated by the occupants and could not be closely monitored (the party wall is in Bedroom 2 only, which sits over the entrance tunnel to the site). No 1 was unoccupied and heated to 25°C using the same equipment as Plot 2. The party wall to No 1 was in the living/kitchen area, Bedroom 1, and the bathroom.

Evaluation

4.14. Air permeability results were obtained from two tests by BAT Limited, before and after the co-heating test. ***The averaged results of 6.10 m^3/h/m^2 were higher than the predicted SAP values of 5 m^3/h/m^2.***

4.15. It should be noted that the second test was undertaken in very windy conditions and therefore did not meet Air Tightness Testing and Measurement Association (ATTMA) criteria.

4.16. The house was not in a fully finished state, and it was thought that there was scope for some additional air sealing in the roof space.

Figure 23: Air pressure testing – blower door in front door

4.17. Infra-red imaging was carried out during the air pressure testing identified ***air leakage under skirting boards, around door thresholds and seals, window frames and***

the flue collar for the woodstove.

Figure 24: Living area party wall (to No1): air leakage around floor

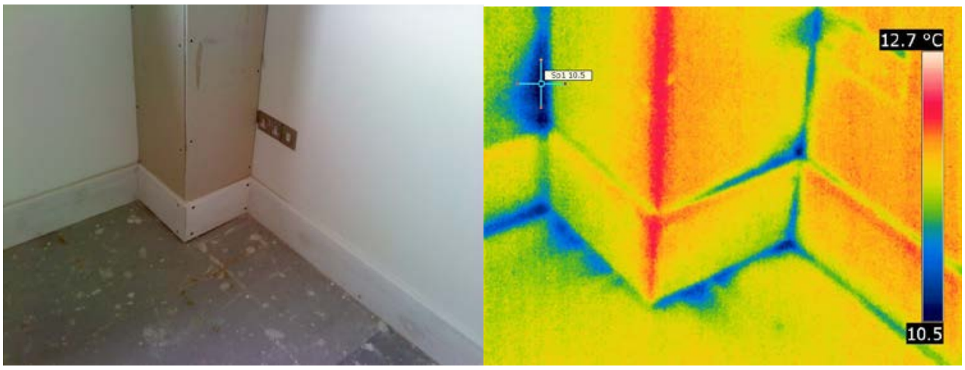


Figure 25: Air leakage around boxed in section

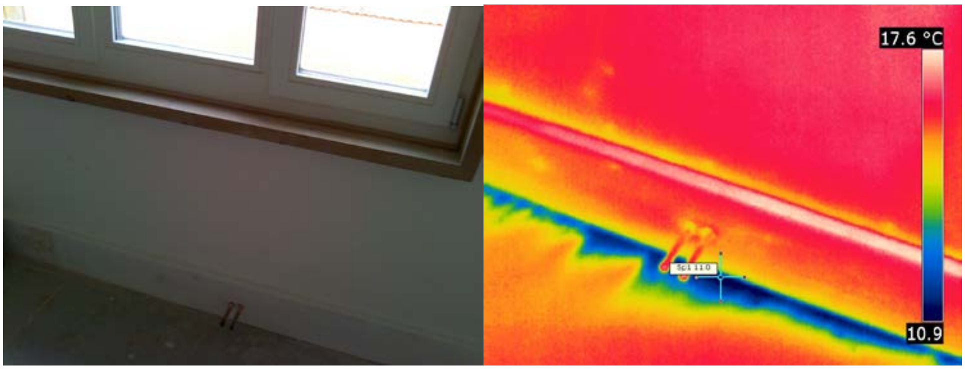


Figure 26: Air leakage under skirtingboard

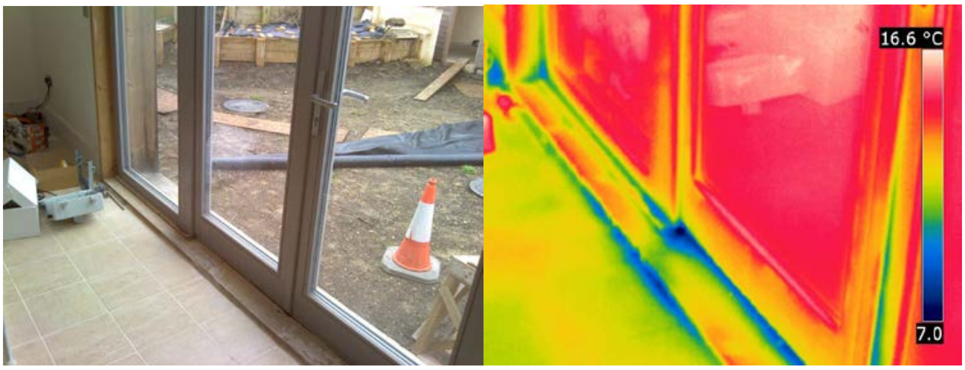


Figure 27: Air leakage around door thresholds and seals

Figure 28: Air leakage around bathroom window frame

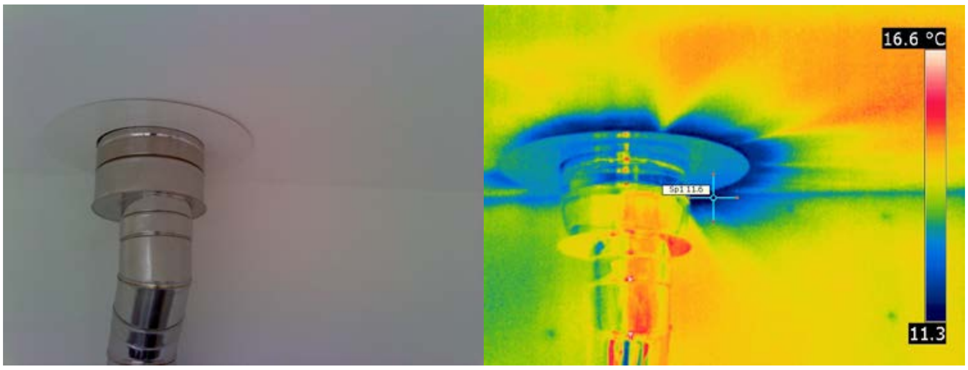


Figure 29: Air leakage through flue collar

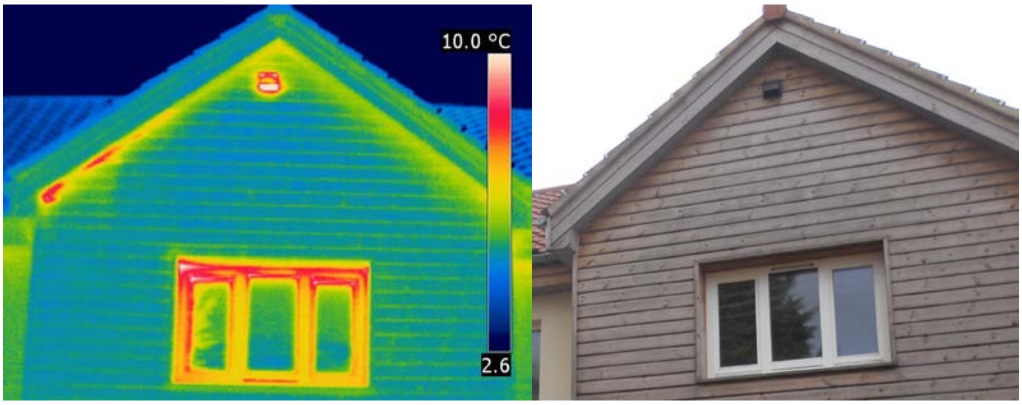
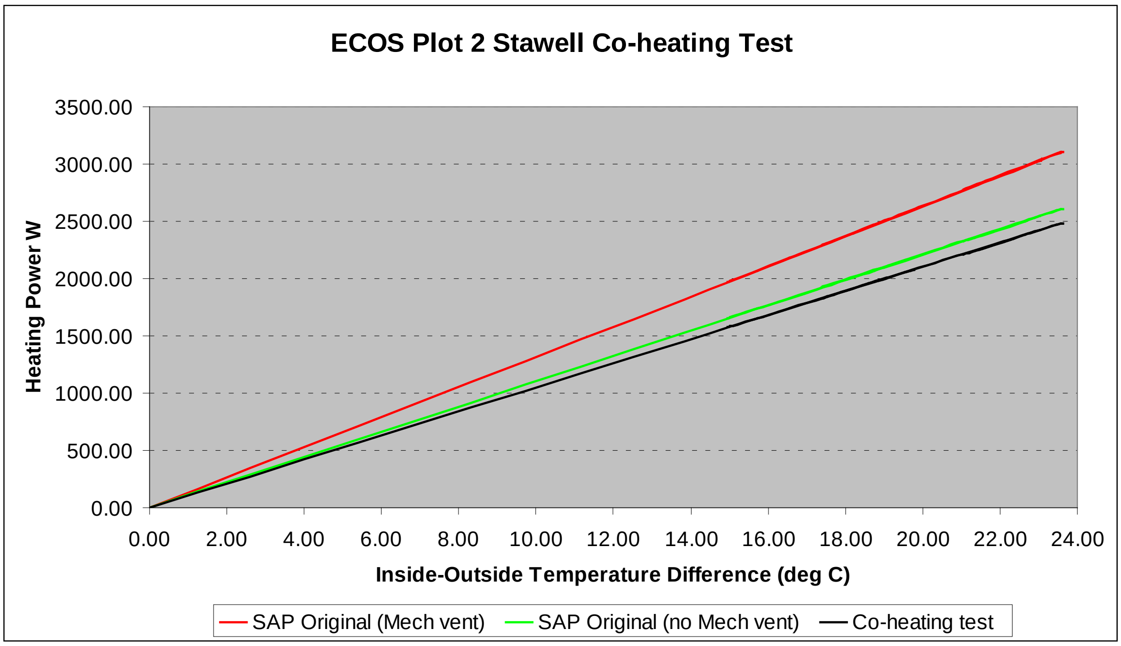


Figure 30: Air leakage at gable of Bedroom 2

Co-heating test results

4.18. Daily average values for **heating power consumption**, corrected for solar and wind influences, were plotted against **inside-outside temperature difference**.



4.19. The top red line of the graph represents the original SAP2005 prediction with the MEV assumed to be switched on and the gradient of the second black line shows the actual measured Heat Loss Coefficient (HLC) gradient using corrected data. The third green line represents the original SAP 2005 prediction when the MEV assumption is taken out.

Actual HLC (measured, mech vent off)	= 105.17W/K
Predicted HLC (SAP2005 with mech vent off)	= 110.53W/K
Predicted HLC (original SAP2005)	= 131.69W/K

This shows an improvement of 20% on the predicted heat loss flowing through the fabric using the original SAP2005 assumption of the MVHR switched on, and by 4.3 % when the MEV assumption is taken out.

4.20. When this heat loss is divided by the floor area of 119.57m^2 we obtain what is called a Heat Loss Parameter (HLP) which gives a benchmark per square metre which can be used for comparative purposes with other dwellings:

Actual HLP (measured, mech vent off)	= 0.88W/m^{2}K
Predicted HLP (SAP2005 with mech vent off)	= 0.92W/m^{2}K
Predicted HLP (original SAP2005)	= 1.10W/m^{2}K

Comparison with SAP

4.21. The figures from the co-heating test are now compared with the original SAP 2005 calculation and the corrected figures obtained from the SAP check using a y-value of 0.025.

Heat Loss Coefficient		**Total**	**HLC**	**Thermal**	**Air changes**
	Ventilation	**Fabric**	**Total**	**Bridging**	**per hour**
	W/K	**W/K**	**W/K**	**y**	**ac/h**
Predicted SAP (Mech vent)	56.33	75.36	131.69	0.080	0.560
SAP check y=0.025 (Mech vent)	56.54	62.32	118.86	0.026	0.560
Measured test (no Mech vent)	11.71	93.46	105.17	0.026	0.117
Predicted SAP (no Mech vent)	35.07	75.46	110.53	0.080	0.350
SAP check (no Mech vent)	35.07	62.32	97.40	0.026	0.350

4.22. ***As before, the co-heating test result for heat loss is slightly better than the original SAP 2005 prediction but now slightly worse than the corrected SAP check with the MEV turned off.***

4.23. The ventilation loss calculated for the co-heating test is approximately 79% lower than the figure used for the predicted SAP2005. This is because SAP2005 assumes an ‘effective infiltration rate’ that takes into account the effect of the mechanical extract ventilation system. Because the house is terraced, there is some justification in doubting the validity of the one-twentieth rule traditionally used for the predicted SAP2005 ‘air changes per hour’ figures in the table above as the house has only two fully exposed facades (see Appendix iii for full explanation of how the various predicted ventilation losses were calculated).

4.24. The MEV system was completely sealed and turned off during the co-heating test and the very low measured value of air infiltration, as measured by the CO_2 decay, was used to calculate ventilation heat loss.

4.25. Overall, the actual measured heat-loss co-efficient for the external fabric alone is higher than original SAP 2005 values. This may be attributable partly to the poor performance of the party wall (which did not need to be taken into account for SAP2005 or the building regulations in operation at the time The Old Apple Store was designed).

Heat flux testing

4.26. The property tested is a terrace, sharing one party wall with No 3 (occupied) and one with No 1 (empty and heated to 25°C) as shown in the diagram below:

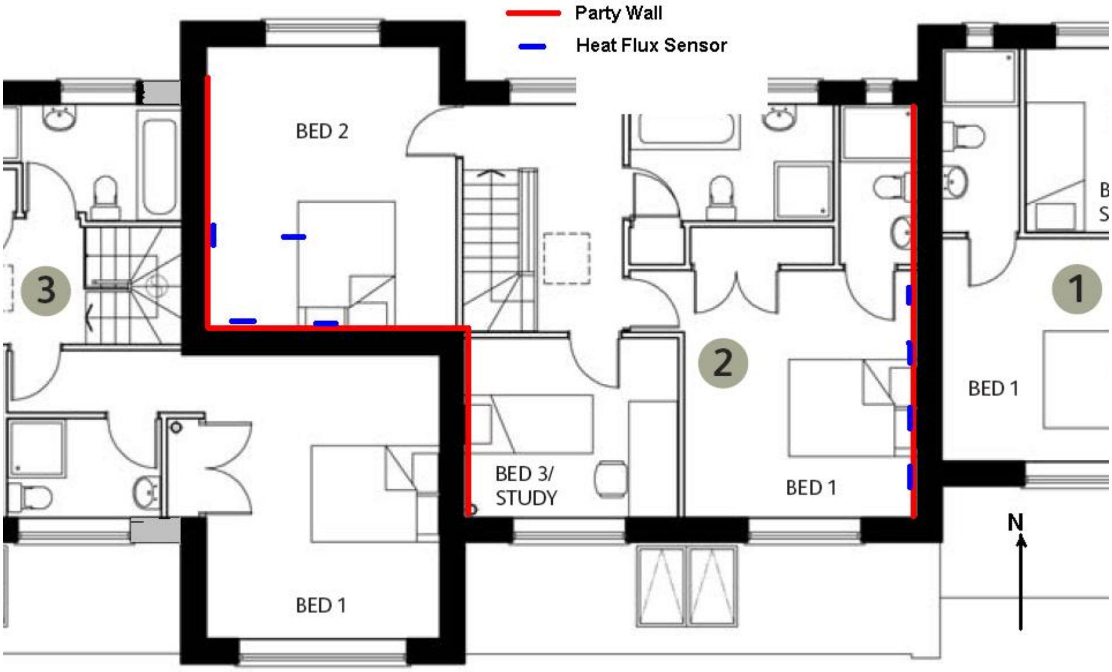


Figure 31: 1st floor plan of No.2 showing position of heat flux sensors and identified party walls.

4.27. An array of three heat flux sensors (HFS) was installed initially on the Bedroom 2 party wall adjoining No 3 to record heat flux every ten minutes throughout the co-heating test. Two sensors were fixed to the south wall and one to the west wall. In addition ones sensor was fixed to the floor of Bedroom 2 because exposed floors were known to be problematic.

Figure 32: Heat flux sensors on Bedroom 2 party wall and floor

Total party wall area to Plot 3 = 24.13m^2				
HFS (17th Feb – 8th March)	**South 1**	**South 2**	**West**	**Average**
Average flux W/m^2	1.25	1.13	1.27	1.22
Average flux W	30.16	27.27	30.72	29.35
Average ΔT (°C)				Not known

Total floor area bedroom 2 =15.82m^2	
HFS (17th Feb – 8th March)	**Floor 1**
Average flux W/m^2	7.08
Average flux W	112.03

4.28. These tables assume that the array gives a representative sample of the heat flux across the party wall and that the average value can be used for the whole wall area. The floor has a U-value of 0.16W/m^{2}K, and the average temperature differential across the test was 19.7°C, resulting in a theoretical average heat flux of 0.16 x 15.82 x 19.7 = 49.86W. The measured heat flux is over twice this value, and the reasons for this discrepancy should be investigated.

4.29. ***The measured rate of average heat loss of 29.35 Watts for the whole party wall is bigger than expected.***

4.30. A second array of four heat flux sensors (HFS) was installed on the Bedroom 1 party wall adjoining No 1 to record heat flux every ten minutes from 28th February to 8th March.

Total party wall area to Plot 1 = 33.23m^2					
HFS (28th Feb – 8th March)	**1**	**2**	**3**	**4**	**Average**
Average flux W/m^2	0.84	1.04	0.98	3.07	1.48
Average flux W	27.07	33.5	33.5	98.95	48.26
Average ΔT (°C)		2	1	5	+0.26°C

4.31. This table also assumes that the array gives a representative sample of the heat flux across the party wall and that the average value can be used for the whole wall area.

4.32. The U-value for a cavity party wall in SAP 2009 is 0.2W/m^{2}K. The average temperature differential (ΔT) between No.2 and No.1 over the test period was 0.26°C. The total theoretical heat flow across the party wall is thus:

U x A x ΔT = 0.2 x 32.23 x 0.26= 1.68W

4.33. ***The measured rate of average heat loss of 48.26W is much bigger than expected and was found to be approximately 2.65% of the total heat loss from the building.***

4.34. There is some party wall thermal bypass, most probably due to the party wall to foundation construction as shown below, which shows an unfilled cavity in the wall allowing air currents and thermal bridging to occur at the base of the Celcon blocks abutting the foundations:

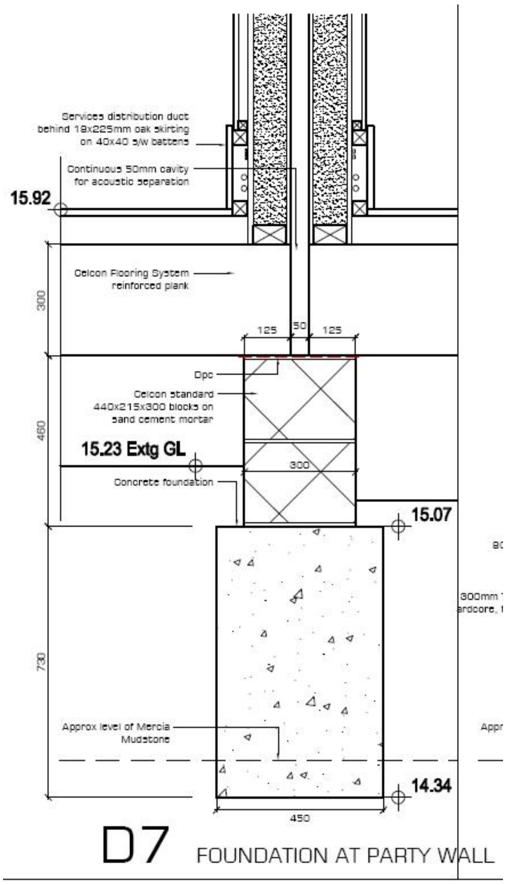


Figure 33: Section through party wall

RECOMMENDATIONS:

1. ***The air permeability measured by air pressure testing at 50Pa was higher than the target value, possibly due to the incomplete nature of the building work. Inspection by the testing house revealed air leakage in the roof space. All detailing should be fully complete before undertaking air pressure tests, and service penetrations require particular care.***
2. ***Calculation of thermal bridging factor (y-value) is worthwhile for large projects as the default value can lead to errors in the projected heat loss. In this case, the thermal bridging was overestimated in SAP by a factor of 3.2***
3. ***The party wall should be investigated further because heat flux measurements indicate greater than predicted heat flows. Further infra-red, heat flux testing, and inspection would yield valuable lessons for future houses.***

4. ***The exposed floor in Bedroom 2 is not performing as expected either, with greater heat loss than predicted. This could be due to incomplete or badly fitted insulation, and should be investigated.***

5. Installation and Commissioning

5.1. This section summarises the review of the compliances and effectiveness of the commissioning processes for the **heating, solar domestic hot water and ventilation installations** (Appendix iv). The review is based upon site inspections and interviews with the occupants and a review of the information contained within the home owner's manual.

5.2. Site inspections included observations on installation compliances, both regulatory and good practice, checks on set points for controls and ancillaries, such as pumps and valves, etc. For the ventilation system, measurements were taken of the flow rates at each extract terminal to determine whether the measured flows met the design values.

Heating and hot water key issues

5.3. **The design intent of the heating system is inadequately documented and operation for optimum performance does not appear to be documented, or communicated to the owner occupants.** An example of this is the provision of a pumped charging unit on the heating distribution circuit. This unit diverts heat energy in the return pipework back into the flow pipework; although it is unclear if is necessary, or worse, if it conflicts with the operational efficiency of the wood pellet boiler.

5.4. Commissioning data is not available for the charging unit, which has three pump speed settings and should activate during firing of the boiler only. Instead, the unit operates continuously and has been set to the highest speed. The resulting **noise nuisance generated by the charging unit** has led to the occupants switching the unit off at the mains, even when the pellet boiler is on.

5.5. **The pipework emanating from the hot water cylinder has not been insulated.** Insulation should be applied to all pipework from the cylinder for at least 1 metre from the point of connection.

5.6. **Hot water pasteurisation procedures are not defined and facilities for this have not been provided.** This facility is good practice, particularly in the case of solar/ manually operated biomass hot water generation where temperatures of 60°C within the store cannot be guaranteed. This can be overcome by provision of a time switch to operate the electrical immersion on a once weekly basis to top up the temperature of the stored water.

5.7. Controls for the solar system are inaccessibly located within the loft. Consideration should be given to relocating these within the accommodation space of the dwelling.

Ventilation key issues

5.8. Flexible ductwork has been employed throughout the installation of the continuous mechanical extract ventilation system (MEV). This type of ducting system, in conjunction with the excessive amount of installed bends will lead to unnecessary duct resistances, reducing air flow performances and increasing noise levels from the system. The main extract duct runs directly over the main bedroom ceiling (plasterboard with no acoustic insulation) to the external terminal. It is noted that occupants have complained about noise nuisance during the night.

5.9. Flow rate measurements revealed that the system was delivering only 25% of the required performance. It highly probable that the system had not been commissioned as adjustments were made during this review such that the system now delivers 100% of the minimum air flow rates required by Part F of the Building Regulations.

5.10. Controls have not been provided for the ventilation installation. Adjustment of fan speeds is currently only afforded by re-wiring the fan terminal block. **It is highly recommended that, as a minimum, a speed selection switch, possibly with timer for set-back mode (e.g. over-night to minimise noise nuisance) be fitted.**

5.11. Supply air inlets are provided via trickle ventilators in the windows. These ventilators should not be fitted in rooms containing extract terminals. The ventilators were found to be closed upon initial inspection as the occupants believed that they were unnecessary.

5.12. Cross ventilation (door undercuts) provision has been compromised. This is due to both insufficient undercuts, but mostly resulting from additional door seals installed by the occupants.

5.13. Based upon these observations, it is clear that guidance on ventilation within the dwelling has not been offered, or that this process has been ineffective or poorly understood.

RECOMMENDATIONS:

1. ***Flexible ductwork for MEV should be kept to an absolute minimum, preferably eliminated.***
2. ***Ensure MEV installer has been fully trained and carry out sample testing of air-flow rates during commissioning stage.***
3. ***Check commissioning of all currently occupied houses to ensure adequate air-flow rates are being achieved.***
4. ***Maintain adequate undercuts to ALL doors for cross-ventilation.***

5. ***Avoid fitting trickle ventilators to rooms with MEV extract terminals.***
6. ***Provide speed switch where it can be easily reached for occupant to be able to adjust fan speeds for MEV.***
7. ***Provide effective guidance to user on the default settings and how to optimise heating and ventilation in relation to these.***
8. ***Locate controls for renewable energy systems in an easily accessible place for the occupant.***
9. ***Ensure that competent persons are identified for carrying out installation and commissioning with suitable certification.***
10. ***Ensure commissioning documents are available for all installed systems, i.e.***
    - ***heating***
    - ***hot water***
    - ***ventilation***

6. Handover and Guidance

6.1. This section summarises the review of the documentation homeowners receive from Ecos and the personalised handover process of their home (Appendix vii). The purpose of the review is to understand the information that the home owners receive and how it is presented in order to provide guidance on how it can be improved.

6.2. The exercise was carried out in two stages in two neighbouring properties. We analysed the Handover Folder as presented to one of the terraced houses, and we witnessed a handover mock-up[14] for one of the unoccupied properties (No.2).

6.3. **In general, Ecos documents and activities relating to the handover of the houses do not give confidence to the users that they can operate the house systems.**

6.4. The information in the **Handover Folder** is arranged in sections in a logical manner, gives information on how the house was built, the materials used and lists the specified technologies in a succinct way. However, it would benefit from:

- merging the information of the *“Guide to your Home”* with the sections of the folder
- ensuring only relevant information provided for each property, for greater clarity,
- **providing diagrams and pointing out all unusual features** of the scheme (e.g. construction, ventilation, heating/hot water, photovoltaic panels, rainwater harvesting).
- avoiding the use of lengthy specialised manuals and, instead, explaining in simple terms:
  a. what the construction is
  b. what the heating and ventilation strategy (and any other plant) is
  c. where the emergency stops are
  d. where controls are provided
  e. how to operate them for best efficiency

6.5. the witnessing of the **Handover mock up** highlighted that:

- There was **no clear strategy of what the Handover should cover** – the visit was structured more as a first visit to the property by a prospective buyer (as such this was less clear in detail content).

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[14] A non technical person acted as the prospective buyer/owner of the property. The house was not complete so many fixings (e.g. bathrooms, kitchen) were not yet installed.

- There was an expectation from suppliers to carry out their own handover with the occupants. This has not happened in the other properties and unless it is coordinated and managed by the developer it is unlikely to happen.
- No explanation of controls was possible as the systems were not operational. However, there was **no hands-on experience of windows operation** by the customer, and **the hot water tank and ventilation system were not shown** due to lack of easy access (in the loft). Many other items were not installed so it was not possible to demonstrate these.

RECOMMENDATIONS

1. ***Review Handover Folder and provide a single document with focus on relevant information, including diagrammatic visual explanations and giving simple user friendly explanations of the operation and maintenance of systems installed.***
2. ***Review Handover process in terms of content and timing. Allow for time for user to ask questions and interact with systems.***
3. ***Ensure that the demonstration includes all items of plant installed and consider access to these prior to the handover.***
4. ***Clarify responsibility of the delivery of the Home demonstration and coordinate other parties if specialists are due to provide the training.***
5. ***Allow for training of the developer team members in charge of the handover to understand and interact with the systems so that they are able to respond to customer queries.***

7. Building Use Studies Questionnaire

7.1. This section covers the results of the BUS Questionnaire survey that was carried out at The Old Apple Store in early March 2011 (Appendix V). This was a small sample of the 3 occupied houses in the development from which 3 responses were received, giving a high response rate (100%). The purpose of the survey is to understand how well the dwellings meet the occupants' needs, how successful the design features are for occupants and what levels of comfort and control they are experiencing.

7.2. As the survey is very small (3 dwellings) and it covers two house types there is little possibility for great statistical analysis but it provides an impression of the occupants experiences and points to areas where further attention would be needed

7.3. **Positive aspects** of the development are its consideration by the occupants as generally comfortable (less so in one of the detached dwellings) and **the detached dwellings are perceived to have a positive effect on health**.

7.4. There were mixed feelings about layout, appearance and location with comments about the **lack of nearby amenities.**

7.5. **Storage** provision seems worse in the detached dwellings and concerns on both building types on the **lack of planned storage space for the wood pellets**.

7.6. Temperature conditions in the terrace are reported as variable and hot in summer and one of the detached dwellings complains of cold winter temperatures which may be due to problems in operating the wood pellet boiler to their satisfaction and/or the use of continuous mechanical ventilation without heat recovery.

7.7. The terrace dwelling has reported **air quality** to be 'dry', 'stuffy' and 'smelly' which reflect problems with effective ventilation which they are unable to control. Another dwelling also reported air quality to be 'smelly'.

7.8. **Noise** was perceived as non satisfactory with noise concerns reported between rooms within the dwelling and from outside. Ventilation ducting may help transmit noise between upstairs/downstairs. The acoustic performance internal partitions and floors need testing and reviewing to ensure as constructed they perform as expected.

7.9. Lighting overall seems satisfactory but tending to excess provision of both natural and artificial lighting.

7.10. The occupants feel they have little control over the different heating and ventilation technologies installed – with poor access to the controls (some items are installed in the loft) and they feel the induction process and the handbook were not adequate to explain the technologies in detail.

RECOMMENDATIONS:

1. ***Review the provision of storage in general, and in particular with regards to the wood pellets – in addition to the car parking space – otherwise occupants feel they are losing space.***
2. ***Consider location of developments with regards to proximity to amenities.***
3. ***Feedback comments to designers for consideration on future projects, to improve and reinforce the positive aspects and evolve the features to be improved.***
4. ***Review heating provision to ensure efficient and effective operation of wood pellet boiler. Ensure sufficient induction of occupants on the pellet boiler maintenance.***
5. ***Review summer and winter modes of heating operation for the dwelling. In summer avoid heating radiators.***
6. ***Review shading provision and/or provision of thermal mass to avoid summer overheating. Retain good daylight provision.***
7. ***Review kitchen ventilation strategy and ensure efficient induction of occupants on the ventilation system to ensure they can boost it when needed***
8. ***Review acoustic performance of designs to understand what the levels of noise transmission are and find the weak points. Consider acoustic testing to monitor the construction achieves the expected noise insulation levels.***
9. ***Consider artificial lighting layout for amount and control.***
10. ***Review control of all services. Ensure accessibility of all control points.***
11. ***Allow for sufficient training to be provided to occupant at handover giving clear instruction and hands on experience of service interfaces.***
12. ***Compile relevant handbook and allow for sufficient training to be provided to occupants at handover to enable them to understand, operate and maintain correctly all the technologies installed in the dwelling.***

8. Occupant Interview

8.1. This section analyses the interview carried out with the occupants in one of the properties at The Old Apple Store in March 2011. The purpose of the interview is to find out their level of satisfaction with the handover process and the appeal of the house, to qualitatively evaluate their views on the comfort and control of the different systems in their home (heating and hot water, ventilation, daylight and lighting, noise) and what they think about the space standards and flexibility in the home. The walkthrough goes through these specific items in each of the rooms of the house.

8.2. The key findings analysed from the interview and walkthrough are described next.

8.3. The occupants **love living in the house** and they find it very easy to live in, with well balanced environmental conditions: *“it is comfortable, light, spacious and warm”*. They feel it works well for them but they are unsure how well it would suit other families, with more children (noise within open plan layout would become a greater problem) or older people as it would not be possible to fit a stair lift in the narrow staircase and the village location does not provide any local amenities.

8.4. They are very **pleased with the renewable energy systems** (solar hot water and photovoltaic panels fig 34). The earnings they get from the PV array almost match the cost of the electricity they use. This is, however, about to go down as they missed out on the new Feed In Tariff. This is because their system was in use three months before the government’s retroactive deadline.

8.5. The occupants do not seem to use the boiler from mid May to October relying mostly on the solar hot water panel to provide all the hot water in the summer months. They have found their own way of integrating the use of the three potential sources of hot water and they feel a better display of the hot water temperature and the effect of each source would help them. The current temperature display (fig 35) for the hot water gives readings for the solar panel input and the immersion heater but it does not give feedback on the effect of the wood pellet boiler, which they find confusing.

8.6. There is **no easy way of controlling** the flow or temperature of the **hot water towel rails** in bathrooms and airing cupboard which seems wasteful in terms of energy use.

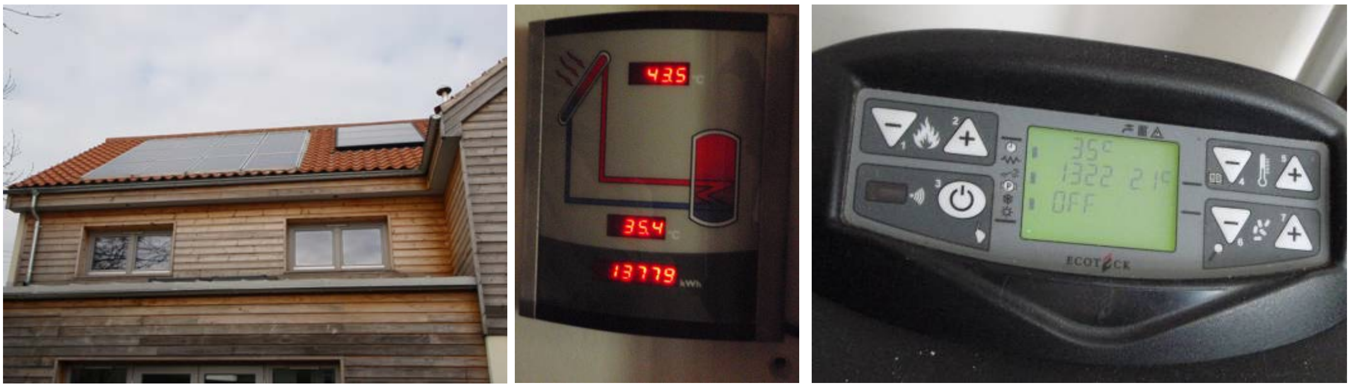

Figure 34 (left) PVs and solar hot water panel in roof, Figure 35 (middle) Hot water temperature display in airing cupboard, Figure 36 (right) Control panel for wood pellet boiler.

8.7. Customers were **not satisfied with the handover and information pack received**; they felt it was not particularly organised, put together in a hurry and was not thorough enough. The handover took place on the day they moved in, which was not ideal. They felt the **information pack was too technical and not aimed at the end user**. As the technologies in place are not conventional (e.g. the boiler controls is a panel with a lot of menus fig 36) it is important that a clear and detailed induction is arranged at a time when the occupant is likely to be attentive.

8.8. They found that there was **more maintenance required than expected** for some of the technologies (wood pellet stove and rainwater harvesting system). They have adapted to the requirements. **The stove needs cleaning two or three times a week** and an annual service – they keep a dedicated vacuum for this purpose. The rainwater harvester has two filters one above the tank that needs cleaning out every three months and one under the sink that does not seem to need any cleaning. The rainwater harvester took a while to commission properly as the suppliers did not want to get involved in the process.

8.9. **Access to the hot water tank** in the loft (fig 37) is **difficult**. Occupants have also experienced problems with the water pressure. The system pressure made it difficult to operate the taps in basins and showers and at one point they would not switch off. A new pressure release tank has been installed (next to the hot water tank in the loft).

8.10. The **MEV system is relatively poor; it runs constantly and cannot be adjusted** without rewiring the unit which is located in the loft and not easily accessible (fig 38). As the system is noisy, the customers asked for it to be reset to a lower fan speed soon after they moved in. This setting does not seem sufficient to get rid of smells when cooking which linger around the house and in fact the installation and commissioning report (see section 5 of this report) found the MEV unit did not provide sufficient air flow with this setting. They feel frustrated by the fact that the settings cannot be adjusted to suit the need.

8.11. Occupants are generally happy with the wood pellet boiler. However, they found that there was **no provision made for storing the pellets** (they get deliveries in 15 kg bags of 1 tonne a time). They use the car port for this purpose, having to forfeit the car being kept there (fig 39)

Figure 37 (left) hot water tank in roof with new pressure release tank, Figure 38 (middle) mechanical ventilation system in roof, Figure 39 (right) car port with pellet stored in it

8.12. **Noise around the house is a problem**. There is more than they expected given the insulation that went into the walls. Also, the constant noise of the equipment (ventilation, pumps) is found to be annoying.

8.13. **Daylight in this house is a positive feature** remarked upon. There are no dark rooms. Artificial lighting is also fine but occupants find the fittings unusual (different ways of taking the bulb in and out) and difficult to come by. That said they ‘last a long time’ – only one light bulb has been changed in two years.

8.14. **Space standards in this house type are good** and storage (in the home) is generally satisfactory, better in the bedrooms than downstairs (more limited). The main shortcoming is the lack of storage space for the pellets.

8.15. Occupants found the finishes throughout the house to be very poor indeed with gaps under skirting boards, badly fitted doors, unfinished wardrobes, balustrade not primed, unsealed window boards. Bathroom fittings were found to be strange and operated oddly.

8.16. The provision of an allotment for the use of this dwelling in the village is a positive thing; the gardens are slightly small and the allotment creates an opportunity for sustainable living. Having said that the location is isolated and with few amenities and services so not too well suited in older age.

RECOMMENDATIONS

1. ***Maintain good space standards and quality of light***
2. ***Consider controls of technologies for usability and communicate the operation of the technologies to occupants in an organised, simple manner for ease of operation.***
3. ***Understand all the interaction of the technologies, how they are used and their maintenance requirements. Compile an end user focused handover pack that explains all the systems thoroughly to the customer and allows for their interaction with the equipment.***
4. ***Organise a handover strategy and time it suitably so that does not clash with other moving in arrangements. Consider a phased approach – e.g. critical instructions before they move, followed by detailed induction after a week of moving in.***
5. ***Locate items of plant that may need monitoring (hot water tank, ventilation system) in easily accessible locations.***
6. ***Review ventilation strategy. Ensure suitable controls are provided to ventilation system that allow for flexibility and energy efficiency. Position control switches in logical positions (e.g. boost in kitchen).***
7. ***Provide dedicated storage for wood pellets and consider position with regards to boiler location within the house.***
8. ***Review noise specification standards for internal partitions. Consider any noise interaction of ventilation system provided.***
9. ***Review finishes standards provided.***
10. ***Consider location of developments close to amenities.***

9. User Control Interfaces

9.1. This section summarises the findings of the User Control Interface review (Appendix viii). The aim of this review was to identify all the points in The Old Apple Store housing development that the occupants physically interact with to control their environments and evaluate their usability.

9.2. The theoretical basis for assessing usability was based on ' Controls for End Users: A Guide for Good Design and Implementation' by Bill Bordass *et al,* published by BSRIA, 2007.

9.3. Six key criteria were used for assessing usability:

- Clarity of purpose
- Intuitive switching
- Labelling and annotation
- Ease of use
- Indication of system response
- Degree of fine control

9.4. The various physical control interfaces were scored using a 'traffic light' rating scale based on a visit to site by the researcher, a physical examination of each interface in property No.3 and its surrounding environment. The key findings are summarised below.

Heating controls

9.5. The heating and hot water controls are complicated. In general there is a good provision of equipment; inverters that register amount of electricity generated, meters that register temperature of water in the tank, but **the equipment is not connected together in a way that makes it easy to use in an optimum way**. **Tradesmen were unfamiliar with the installation they were asked to provide.** There is some ambiguity in the heating system (e.g. the tank temperature indicator not indicate the response from the boiler). **Employing an M and E consultant would have potentially avoided some of the problems** that are identified below.

Ventilation controls

9.6. To ventilate, the MEV system requires trickle ventilators to introduce fresh air; this cools the house down in a way that the owners find unsatisfactory and they have closed these. Overall, **there is very poor control of the ventilation system**, with excessive noise due to poor ductwork, and no control provided for changing the ventilation rates on the MEV unit.

Electrical equipment controls and kitchen appliances

9.7. **Standard equipment is installed in an acceptable way**. Where the technology is new, however, there are some problems- for example the meter cupboards sit awkwardly in the front hall and **the lack of ventilation to the inverter will shorten its life due to resultant overheating of the unit.** Generally, the electrical controls are poorly labelled with the exception of the main consumer unit. However **the easily accessible location for all controls is to be commended.**

9.8. **Occupants are generally pleased with the usability and performance of the kitchen equipment** which appears to be well laid out and functional.

External fabric

9.9. **The windows and doors perform well**. Raising the floor levels to accommodate the required head height for the alleyway through into the development has created some difficulties in terms of level access through patio doors. **The door threshold is poorly detailed.**

Water services

9.10. The sink wastes are awkward and likely to get damaged by other materials in the under sink cupboard. Special equipment, such as the rainwater harvesting equipment and tank, needs to labelled in the industry approved way and more thought given to their in-use maintenance. **By using rain water for the washing machine, the energy that can be saved by using solar hot water is reduced.** In unit 3, the occupants are unaware of **deadlegs in hot water pipes which create water wastage and these need to be minimised when the installation is completed in no 2**; In no 4 there are long deadlegs to the showers though the tenant reduces the water (but not energy) wastage by catching this water in a bucket to flush the WCs.

Miscellaneous controls

9.11. **Sustainable housing developments require more space for all aspects of life such as recycling and clothes drying**, which should be done externally. The group of residents act together at The Old Apple Store, helping each other with tasks around the site, perhaps helped by the fact that they are (mostly) recently retired. A shared store could have been provided, in the way of some housing groups in Denmark, that could have housed communal recycling and waste, to encourage even more communality and to save embodied resource use.

RECOMMENDATIONS

1. ***Complex heating systems should be avoided where possible***
2. ***A suitably qualified mechanical engineer with experience of integrating renewable energy appliances into heating systems should be employed to design and specify an overall system that resolves any potential conflicts between controls.***
3. ***Tradesmen should be suitable qualified and trained in the installation of heating and ventilation systems.***
4. ***Flexible ductwork should be avoided in ventilation systems as far as possible to reduce inefficiency and dust build up.***
5. ***Increase ventilation to solar system inverter cupboard to prevent excessive overheating and potential degrading of product efficiency.***
6. ***Ensure all waste service controls are properly labelled and suitably located for easy access (not at the back of cupboards, which fill up).***
7. ***Avoid using harvested rainwater for appliances where pre-heated solar water can be used instead, to save energy.***
8. ***Avoid deadlegs in plumbing to reduce water wastage and waiting time for hot water which wastes energy also.***
9. ***Ensure adequate provision of external space and facilities for drying clothes and recycling –consider grouping recycling facilities in future developments.***

10. Emerging lessons and key recommendations

10.1. This Initial Occupancy study has examined the performance of The Old Apples Store from a number of angles in order to tease out emergent issues arising between different functions during each stage of the development process.

10.2. The seven sub-studies considered within this report have revealed a number of key recommendations throughout this report for process and product development. These recommendations are now considered in relation to three development processes: design (D), communication (C), and feedback (F) and captured in the themes analysis table below. Emergent lessons are identified as they relate to the key challenges and opportunities identified from these studies.

10.3. Each of the overall emerging lessons and all the recommendations in the table need to be taken forward through a developing management framework for Ecos Homes which clearly assigns roles, responsibilities and tasks in relation these findings. This will help to ensure that the knowledge and understanding gained from this study is firmly embedded within the various product and service improvement processes within the organisation.

10.4. It is recognised that changes always occur between the design stage and as-built. However particularly for ambitious smaller developments involving innovative technology that is not in the range of experience of most of the onsite staff, greater training and preparation could help to pre-empt these and prevent unnecessary cost burdens.

10.5. A number of significant omissions and contradictions in information prepared and in the installations provided have been identified particularly in relation to heating and ventilation. There are variety of reasons why this has occurred including lack of co-ordination between suppliers, manufacturers, the design team and site team in relation to integration, positioning, detailing and specification of certain construction elements and services. A key failing here has been the lack of a mechanical engineer to oversee the heating and ventilation design and execution. Confusion and redundancy in the installation can also be avoided by ensuring site staff attend training courses for the installation of specialist low energy equipment and are provided with drawings that integrate the various pieces of technology.

10.6. For the remaining houses, No. 1 and 2 , which are not yet fully fitted out, a specialist services engineer should be appointed to complete the design.

10.7. A key issue for construction appears to have been the progression of an innovative design without a full understanding and integration of services at an earlier enough stage in the design and detailing process to avoid later clashes on site. Complex servicing technologies in housing need to be decided and specified early enough on the design process to allow the spatial and structural strategies to integrate these from the outset.

10.8. A key issue for organisational learning is the lack of formal drawings for some aspects of the build (particularly heating and ventilation services) which fail to provide a clear audit trail for any alterations made on site.

10.9. Numerous changes have been made during the build process without a full awareness of the consequences and suggest that design changes on site should be limited to a minimum. The desire for continuous innovation once a project is on site must be tempered with commercial reality and the need to deliver on time and within budget. The design and construction teams can also become demoralised if the client and project manager make too many changes on site, and ideally a design should be ‘frozen’ before it goes on site, with no further changes explored.

10.10. Occupants wish to operate their new investment in the best possible way and not to damage any part of the installation, but have no clear understanding of what optimising performance might be without adequate guidance. It is vital that a good occupant guide and induction process is developed by the developer which outlines the strategies needed for each installation and, particularly for the servicing, runs through the relationship of each piece of kit to other parts of the installation. The developer needs to co-ordinate any activities potentially provided by suppliers in this regard.

10.11. The spaces achieved in these houses are generally well liked by the occupants and the simple but robust and proven approach to the construction and detailing for high insulation levels, airtightness and minimal thermal bridging is highly commendable. The homes also have an ultra low heat loss co-efficient for their overall external envelope.

10.12. The design of housing is changing rapidly in response to government drivers for major carbon emission reductions in the built environment, and it must be recognised that the ECOS development achieves some delightful and much appreciated sustainable homes and is thoroughly innovative in this respect. The organisation is to be applauded for a forward looking development that has caught the imagination and is truly pioneering. Taking the lessons learned from this study forward will improve the product further still.

10.13. There are a number of specific findings in this limited study which require further investigation:

- The party wall thermal by passes needs more investigation to understand exactly where the heat loss is in relation to potential air passageways.
- **Check commissioning in No.4 and No.5 to ensure adequate air flow rates**
- Acoustic issues identified need to be investigated

10.14. A further monitoring study over two years of a sample of the homes at The Old Apples Store would provide physical evidence to corroborate the findings of this study in relation to occupant perceptions, building performance and energy use.

Emerging lessons and key recommendations from initial occupancy study for The Old Apple Store development

Recommendations	**Design v as built**	**SAP check and Heat loss**	**Installation and commissioning**	**Handover and guidance**	**Questionnaire and interview**	**User Controls Interfaces**
Emerging lessons						
1. Pre-plan and co-ordinate early on to avoid unnecessarily complex services and ensure adequate amenities (D)	pre-plan and co-ordinate services early on with construction and structural design				review provision of storage and consider location of amenities	avoid complex heating systems ensure adequate provision of external spaces for recycling and drying
2. Employ suitable expertise in relation to innovative technologies, their installation and commissioning (D)	employ engineer and provide comprehensive design and drawings for services		ensure competent persons carry out installation and commissioning		ensure suitable ventilation controls are provided	employ engineer with understanding of renewable energy integration with heating
3. Establish clear protocols of responsibilities in relation to all aspects of design, construction and handover (C)	establish a clear protocol of responsibilities between design and manufacturers	communication of assumptions made by SAP assessor needed		clarify responsibilities for home demonstration		
4.Provide training where necessary or ensure that others are suitable trained and qualified in relation to services and innovative technology (C)	ensure site operatives are adequately trained in relation to innovative technology	provide training in thermal bridging calculations	ensure MEV installer is fully trained	provide training for developer in relation to all user systems		ensure tradesmen are suitably qualified and trained in heating and ventilation systems
5. Avoid using flexible ductwork for ventilation	avoid using flexible ductwork for ventilation systems		minimise flexible ductwork in ventilation systems			avoid flexible ductwork in ventilation systems

systems (D)						
6. Provide improved user guidance, labelling of controls, and handover procedures (C)	simple, precise instructions need from suppliers for users		provide user guidance on default settings	review handover folder and process	improve user induction and timing	improve labelling to controls
7. Review design standards for various aspects to achieve best practice (D)	consider durability	greater fabric efficiency needed	maintain adequate undercuts,		review standard of finishes, review acoustic performance	avoid deadlegs, and using rainwater where solar water could be used
8. Ensure all user controls are easily accessible (D)			locate controls in an easily accessible place	ensure all demonstrated items are accessible	ensure accessibility of all control points	
9. Complete ALL design and detailing work before going on site (D)	complete and fix design detailing before going on site	understand and communicate consequences of thermal bridging				
10. Provide a record of all changes made during the design and on site stages (C)	record all changes on site with instructions and drawings	changes from design stage should inform as built calculations				
11. Provide a comprehensive referencing system for all drawings and ensure all documentation is available (C)	Provide complete and clear referencing system for all drawings		ensure commissioning documents are available			
12. Ensure organisational learning takes place by passing on	Pass on lessons learnt to next project				feedback comments to designers	

lesson from one project to the next (F)						

Glossary

Psi –value: the *linear* thermal transmittance through a material or combination of materials.

Thermal bridging: the heat lost through a particular element of the external fabric which has less insulating properties than the elements surrounding it.

Y-value: the total heat loss attributed to the linear thermal transmittance divided by the surface area of the thermal envelope considered.