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Energy and environmental performance of the ‘Abertridwr community’ – first winter season


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Abstract

This paper discusses initial findings from the first eight months (July 2013 to February 2014) of the environmental performance monitoring as part of a Technology Strategy Board funded Building Performance Evaluation programme project at the Abertridwr ecological micro-community, in Wales, UK. The case study community includes eight low-impact, ecological, low carbon flats, one additional flat and four houses; occupied from 2010. The community was developed by United Welsh Housing Association and received a grant from the UK Government Department of Energy and Climate Change midway through construction, enabling eight flats to be upgraded to level four of the code for sustainable homes so incorporate ecological materials and systems. All the units use exhaust air source heat pumps (EASHPs) to provide their hot water and space heating needs; a system that has been reported to have significant costs for some housing association tenants across the UK. The project discussed in this paper builds upon earlier research undertaken by the same housing association led by the first author of this paper, which followed a 12 month detailed environmental and energy performance monitoring period, that indicated EASHPs could provide comfortable internal conditions at low monthly and annual costs [1]. Interim results from the first winter’s (2013/14) monitoring at the Abertridwr project indicate that heating (space and water) are not excessive for a flat occupied by two adults and a house occupied by three adults and one child. Yet, there are potential issues of occupancy energy-use strategies disguising overall actual building performance as a function of problems for the designed building fabric and installed energy strategies. The monitoring continues until August 2014, when 12 months analysis will be undertaken before final reporting in September 2014. This paper will be of interest to academics, designers, contractors, environmental engineers and building owners.

Keywords: Building performance evaluation, exhaust air source heat pump, design versus actual performance.
building upon an earlier study reported in [1]. The BPE methodologies adopted are discussed as are the initial results at eight months. The authors acknowledge that conventional practice for post occupancy evaluation is 12 months data, however the project funders suggest dissemination begins after one heating season, which is at eight months; hence this paper.

2. Design performance versus actual performance in Wales

Latest published research data for domestic (end-user) greenhouse gas (GHG)-carbon emissions up to 2010 [2] indicates that in Wales whilst there is a year-on-year decrease against the baseline year 1990, there was an increase of 3.4Mt for the year 2009-2010. By devolved sectors; “end-user” domestic carbon dioxide (CO2) emissions is the second largest contributor to GHG-emissions in Wales with a static 2010 contribution of 7.7Mt from the baseline average for 2006-2010. Caerphilly Local Authority is atypical in recording increases in Domestic GHG-emissions for 2009-2010 after previous years of reductions and which are determined by UK Department for Energy and Climate Change [DCCC], as ‘within the (influence) ‘Scope of Local Authorities’ to take action, including improving (domestic) building energy performances and as demanded by the Code for Sustainable Housing. There is detailed documentary evidence of a potentially large imbalance, referred to as a ‘gap’, between ‘as designed’ and ‘actual’ performance for low carbon dwellings in the UK [3,4]. This discrepancy between design and actual performance can be due to failure of the building fabric, and/or building systems, and/or can be caused by inefficient management and maintenance, and/or inappropriate occupant use of a building [3,5]. Indeed, the actual performance can be as much as plus five times the designed performance [ibid]. Current UK building regulations require minimal post-occupancy monitoring and evaluations, though it is recognized that BPE and monitoring is an essential methodology-tool to investigate whether the actual building performance meets the design expectations, to identify performance issues and reveal the lessons of ‘what works in practice and what does not work’ [6,7]. Certainly, one of the most severe results of the discrepancies between designed performance and actual performance is that of significant overheating in dwellings, particularly flats; which has consequences on occupant health and wellness and in extreme cases has led to deaths in the UK [3, 8].

3. Building Performance Evaluation overview

The United Welsh Group, in collaboration with the lead author of this paper, received funding from the Technology Strategy Board, in 2012 as part of its BPE programme; for a ‘post construction in-use’ study at the Abertridwr ecological micro-community, Caerphilly, Wales, UK. In summary, the Technology Strategy Board BPE programme was launched in 2010 and runs until 2014, with a £8Million fund to conduct environmental and energy performance monitoring alongside building user and design and delivery teams feedback and observations; on a range of low and zero carbon, domestic and non-domestic, innovative buildings across the UK [9]. The design and installation of EASHPs with under-floor heating as a domestic heating energy-strategy is exceptional both within the UK and Wales, and especially within the social-housing sector. Building and system design impacts including installation and commissioning problems coupled with poor end-user interactions are identified as impacting on the efficiency of EASHPs within the UK [1]. United Welsh won the Technology Strategy Board BPE grant on the basis of an earlier monitoring project of one of their existing dwelling schemes, which used similar heat space and water heating strategy [ibid]; results of which demonstrated the potential of exhaust air source heat pumps are a viable low energy-low carbon-low cost technology for UK homes built to level three plus of the code for sustainable homes. The Abertridwr project also seeks to further the earlier project findings in providing monitored data of external and internal environments and energy-usages within timber-frame and clad construction against more conventional brick/block construction to determine internal comfort conditions, energy costs and impacts upon domestic end-user carbon emissions.

3.1. Case study – The Abertridwr Development:

The case study development is a brown-field site of 0.2 Hectares, situated on the middle-slope of atypical south Wales river valley. Developed by United Welsh for social housing, the development has thirteen units of four two-
storey semi-detached houses and one upper storey maisonette flat in one block; and eight, terraced flats in a separate two-storey block. The site is 155 metres above sea level with the terraced flats frontages facing S-SSW with the house-frontages facing E-ESE. The eco-community shares a common communal area with only the houses having private external areas attached. Fig1a, Fig1b, and Table 1 illustrate floor plans and technical details for the two detailed monitored properties.

Fig. 1a. Type 1 ground-floor flat layout, (left). Fig 1b. Type 2 ground-floor layout (right) semi-detached house

<table>
<thead>
<tr>
<th>Component</th>
<th>Building-type 1</th>
<th>Technical values</th>
<th>Building-type 2</th>
<th>Technical values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Ground-floor end-terrace flat</td>
<td>CfSH-Level 4</td>
<td>2-bed Semi-detached</td>
<td>CfSH-Level-3+</td>
</tr>
<tr>
<td>Construction</td>
<td>Timber-frame/timber-clad with vented air-space</td>
<td>U Value of the exterior walls, roof and ground floor are 0.28, 0.1, 0.01 W/m²K.</td>
<td>Brick/block with traditional cavity</td>
<td>0.18, 0.1 and 0.2 W/m²K U values for exterior walls, roof and ground floor</td>
</tr>
<tr>
<td>G/Floors</td>
<td>150mm-RC with Kingspan Thermfloor</td>
<td>U Value of the exterior walls, roof and ground floor are 0.28, 0.1, 0.01 W/m²K.</td>
<td>150mm-RC with Kingspan Thermfloor</td>
<td>U Value of the exterior walls, roof and ground floor are 0.28, 0.1, 0.01 W/m²K.</td>
</tr>
<tr>
<td>Partition-walls</td>
<td>90mm with 60mm quilt insulation</td>
<td>U Value of the exterior walls, roof and ground floor are 0.28, 0.1, 0.01 W/m²K.</td>
<td>90mm with 25mm quilt insulation</td>
<td>U Value of the exterior walls, roof and ground floor are 0.28, 0.1, 0.01 W/m²K.</td>
</tr>
<tr>
<td>Separating floors</td>
<td>335mm with 100mm quilted insulation</td>
<td>U Value of the exterior walls, roof and ground floor are 0.28, 0.1, 0.01 W/m²K.</td>
<td>335mm with 100mm quilted insulation</td>
<td>U Value of the exterior walls, roof and ground floor are 0.28, 0.1, 0.01 W/m²K.</td>
</tr>
<tr>
<td>Glazing</td>
<td>Triple</td>
<td>U Value of the exterior walls, roof and ground floor are 0.28, 0.1, 0.01 W/m²K.</td>
<td>Double</td>
<td>U Value of the exterior walls, roof and ground floor are 0.28, 0.1, 0.01 W/m²K.</td>
</tr>
<tr>
<td>Heating-system</td>
<td>NIBE 200 EASHPs, with u/floor heating</td>
<td>Air change rate 2.8 m³/h.m²</td>
<td>NIBE 360 EASHPs, with u/floor heating</td>
<td>Air change rate 4.8 m³/h.m²</td>
</tr>
<tr>
<td>PV</td>
<td>1 kW Tgbsol PV panels/dwelling</td>
<td>Air change rate 2.8 m³/h.m²</td>
<td>1 kW Tgbsol PV panels/dwelling</td>
<td>Air change rate 4.8 m³/h.m²</td>
</tr>
<tr>
<td>PV</td>
<td>Grid connected</td>
<td>Air change rate 2.8 m³/h.m²</td>
<td>Grid connected</td>
<td>Air change rate 4.8 m³/h.m²</td>
</tr>
</tbody>
</table>

Table 1. Design construction details:


<table>
<thead>
<tr>
<th>As-Built SAP Calculation Ratings</th>
<th>Build-type House</th>
<th>Build-type Flat</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAP Rating</td>
<td>81B</td>
<td>90B</td>
</tr>
<tr>
<td>SAP Energy Costs (£/yr)</td>
<td>218.18</td>
<td>103.25</td>
</tr>
<tr>
<td>CO₂ Emissions (t/yr)</td>
<td>1.29</td>
<td>0.46</td>
</tr>
<tr>
<td>Energy Rating</td>
<td>86B</td>
<td>93A</td>
</tr>
</tbody>
</table>
The overall BPE-study seeks to further key questions raised in the earlier UWHA-project [1] including; how does timber-frame building performance compare with traditional brick/block construction for dwelling internal comfort conditions using similar heating strategies?, is internal overheating within timber-frame properties a problem? Does an air change rate above and below 3 m³/h.m² affect the efficiency of EASHPs and thereby internal comfort conditions? To identify how the occupants engage with the controls on EASHPs and how behaviour strategies adopted may affect their internal comfort conditions. To evaluate and compare actual and designed building performance in terms of internal comfort, health-impacts, heating costs and associated ‘end-user’ carbon emissions for each building type. The BPE-project will further inform actual-versus-designed building performance in context of the perceived performance ‘gap to UWHA, and the housing sector in Wales in general, the national and local government policy-makers and the wider built environment and scientific communities.

4. Research Methodology

4.1. Case study – Real-time External Environmental Monitoring

This paper reports on the environmental performance and energy use monitoring versus the climatic data monitoring for the first eight months of monitoring: July 2013 to February 2014. The authors note that it is conventional practice to report on 12 months monitoring data, however; this data will not be available until early July 2014. As part of the Technology Strategy Board BPE requirements to dissemination information within the scientific community during the course of the BPE programme; this paper illustrates evidence buildings upon research from an earlier project involving monitoring a dwelling with EASHPs in South Wales, UK [1]. The methods used to capture this data includes a Davis Advantage Pro® weather station is installed above the terraced flats roof ridge-line, prevailing ‘averaged’ data for the variables detailed in Table 3 below are recorded at five minute intervals; other variables, as denoted in Table 4, are calculated from measured data using standard equations. The station is connected via ethernet to a broadband router installed on-site, data is downloaded to a Davis hosted site which can be assessed in ‘real-time’ or as historical data via a dedicated Internet link. CO₂ measurements, internal (located at ≈1.2m height in hallways) and external (isolated at ≈2m height), are monitored via Esense-Tr C02 transmitter connected to a Digirail 2A Modbus analogue unit at 5 minute intervals.

4.2. Case study – Real-time Internal Environmental and Energy-usage Monitoring

In one unit of each build-type, flat (property-type) and house (property-type), all living spaces’ internal environmental temperature (°C), relative humidity (RH%) and external openings (window or door) fenestrate position (0/1) are monitored using SpYdaq® sensors.

<table>
<thead>
<tr>
<th>Variables recorded</th>
<th>Unit</th>
<th>Accuracy ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature (ave/Hi/Low)</td>
<td>Centigrade (°C)</td>
<td>0.5°C</td>
</tr>
<tr>
<td>Humidity</td>
<td>Percentage (%)</td>
<td>3-4%</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>meter/second (m/s)</td>
<td>1m/s</td>
</tr>
<tr>
<td>Wind Direction</td>
<td>Degree (°)</td>
<td>3°</td>
</tr>
<tr>
<td>Barometric Pressure</td>
<td>milliBar (mB)</td>
<td>1.0mB</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Millimeter (mm)</td>
<td>0.20-0.25mm</td>
</tr>
<tr>
<td>Global Solar Radiation</td>
<td>Watts/metre² (W/m²)</td>
<td>5% at 1000W/m²</td>
</tr>
</tbody>
</table>

Table 3. Monitored (measured) external environmental variables;
Five minute interval data is recorded via a Modbus base station. Energy-usage circuits; total building energy and total heating energy, and including sub-circuits for; hot-water, cooker and shower, power and lighting-circuits; where installed, are monitored per 0.1Kwh usage. The accuracy is ±0.4%, via installed circuit transducers; installed PV-generation system is also monitored. EASH-heating energy, 1.0Kwh, and volume, 0.1m³, usages for space-heating hot and cold water are monitored and calculated at five minute intervals, using Kamstrop Multical 420 Flow meters and 402 Heat meters connected to a Modbus Digirail4C data counter with a system accuracy of ±0.4%. Two further properties, one of each build type are monitored for total energy and total heating electrical usage, for comparison and verification; reported here as property-type 1a (flat) and 2a (house). Metered energy data for each of the four properties is obtained with permission from their respective energy-suppliers.

5. Interim Results – July 2013 to February 2014

5.1. Baseline criteria for analysis and reporting:

The following assessment criteria are used for analysis and reporting:

- Internal comfort level maximum temperatures of >25 °C for bedrooms and >28 °C for living with a threshold of >1% occupied hours, [11];
- For internal heating demands; a baseline air temperature of 17 °C is calculated as ≈-2.5 °C from the SAP Adjusted Internal Comfort temperatures of 19.6 °C and 19.7°C for each building-type;
- Extreme hot weather conditions determined as an external temperature of >30 °C, triggering local government Action Plan guidance procedures to protect those vulnerable to heat [13];
- In cold weather conditions a mean, ≥48hr temperature of 2 °C is determined as ‘severe winter weather conditions’ with health impacts on identified vulnerable groups [12].

5.2. External environmental conditions July 2013 and December 2013

UK weather in July 2013 was characterized by prolonged warm-dry weather with the first heatwave since 2006 and third warmest since 1910 [13]. Temperatures were +0.9 °C above mean average with 150% unbroken sunshine hours; recorded weather summary for the development is given in Table 5a below. December 2013 weather was dominated by high winds and above average rainfall with ‘mild’ temperatures and average sunshine; recorded weather summary for the development is given in Table 5b below [ibid].

### Table 4. Monitored (calculated) external environmental variables:

<table>
<thead>
<tr>
<th>Calculated variables</th>
<th>Unit</th>
<th>Accuracy ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Chill Factor</td>
<td>Centigrade (°C)</td>
<td>1.5 °C</td>
</tr>
<tr>
<td>Heat Index</td>
<td>Centigrade (°C)</td>
<td>1.5 °C</td>
</tr>
</tbody>
</table>

### Table 5a. Monitored prevailing external environmental conditions for July 2013 [14]

<table>
<thead>
<tr>
<th>Variables</th>
<th>Monitored data</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature Range (°c)</td>
<td>9.5-29.3</td>
<td>Maximum temperature 0.7°C below LG-Level 3 threshold to implement emergency plans</td>
</tr>
<tr>
<td>Mean Air Temperature (°c)</td>
<td>18.5</td>
<td>1.5°C above the baseline temperature 17.0°C for heating demands</td>
</tr>
<tr>
<td>‘Hot’ days (&gt;25°C)</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Sunshine hours (&gt;120 W/m³)</td>
<td>351.25 /24.6days</td>
<td></td>
</tr>
</tbody>
</table>

### Table 5b. Monitored prevailing external environmental conditions for December 2013 [14]

<table>
<thead>
<tr>
<th>Variables</th>
<th>Monitored data</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature Range (°c)</td>
<td>0.3-12.7</td>
<td>No prevailing severe cold weather periods</td>
</tr>
<tr>
<td>Mean Air Temperature (°c)</td>
<td>6.7</td>
<td>10.3°C below baseline temperature 17.0°C for heating demands</td>
</tr>
<tr>
<td>Days of “Air Frost”</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sunshine hours (&gt;120 W/m³)</td>
<td>157.6/6.5days</td>
<td></td>
</tr>
</tbody>
</table>
5.3. Energy consumption

Total Energy Usages (Kwh) for the four monitored properties is given in Figure 2 below.

![Fig. 2a. Total energy usage for all properties and Fig. 2a. Total energy usage Log10-scale [July to December 2013]](image)

Observed differences in and patterns of energy usages for property-types 2 and 2a, (houses), whilst indicative of occupancy-behaviour profiles as determined from face-to-face interviews conducted by the first two authors; the contribution of occupancy usage behaviours to the overall building energy performance should not be over-emphasised. Equally, the observed significant difference within the total energy consumption between property-type 1 and 1a, (flats), are concomitant with this initial inference of differences in occupant behaviour strategies; though of greater significance arising from the conducted interviews is the ‘lack of understanding’ amongst occupiers to effectively interact and thereby efficiently use the installed systems, notable heating. Further analysis suggests that the actual overall energy-usage is lower than that of the intended design. A comparison of actual energy usages, as a function of Kwh/m²/yr, against the designed SAP energy requirement values of 79Kwh/m²/yr for property-types 1 and 109Kwh/m²/yr for property-types 2 are given in Tables 3a and 3b below. The monitored Total Energy data as Kwh/m² (blue bar on the graphs) is extrapolated into a Kwh/m²/yr value (red bar), and subsequently as a percentage of the designed SAP values (green bar), for the period July 2013 to December 2013. Initial analysis suggests that overall both building types are performing ‘better than’ the expected design energy requirements by +35% and +10% for property-types 1 and 2 respectively.

![Fig. 3a-b. Actual energy usage versus SAP Calculated [Kwh/m²/yr]](image)

These actual energy usages must also be caveated by; the observed prevailing ‘mild’ weather of the 2013 winter section 5.2, with the above average temperatures possible decreasing the actual heating demands and thereby the overall energy demands within the properties.
The inferred occupier behaviour strategies whilst impacting on the actual energy demands and contributing to the higher than expected energy %-decrease, notable property-type 1, no inferences of the actual building performance can be made in absence of analysis of the construction, installation and commissioning of materials and systems.

5.4. Environmental performance versus climatic performance

Internal temperatures as a function of external environmental temperatures are shown in Figure 4 for property-types 1 and 2 (lounge and bedroom), representing a non-heating period (July); with passive internal heating in response to both rising air temperatures and incoming solar radiation (ISR) gains, either directly or passively, is observed in both property-types, but for different reasons. In property-type 1, timber-frame flat, the passive heating response is inferred, in part, to be a function of building material thermal performance with internal heat gains in direct response to rising external air temperatures. The building frontage orientation of S-SSW is exposed to uninterrupted direct ISR gains, though significantly the living and bedroom spaces are located to the rear of the building. The observed internal heat gains are ‘immediate’ concomitant with rising temperatures with no significant time-lag, (<1hr), in cooling as external temperatures decreases. Internal heat losses are inferred to be reduced by the sheep-wool insulation and significantly by the lack of occupant ventilation via the windows and doors. A maximum observed temperatures of 28.0°C in the lounge are at the maximum threshold for internal comfort, and whilst temperatures within the bedroom are greater than the threshold of 25°C and occurring only during the daytime, these excess temperatures are not sustained over a prolonged period of inferred occupancy to be determined as over-heating. The observed variations between the lounge and bedroom temperatures during lower external temperatures are inferred to result from the observed occupant’s tendency to close the internal bedroom door physically separating the space from the rest of the property preventing air and thereby temperature exchanges. Internal heat gains within the lounge are also greater than the bedroom due to the gable-end external wall being exposed to partial direct ISR during the day.

For property-type 2 the passive heating response is infer to be a function of the building’s materials, concrete and brick, thermal properties in response to rising external temperatures and indirect ISR where the living-space aspect, lounge and front bedroom, are orientated E-EES. Internal comfort temperatures within the two living-spaces are above the maximum threshold during daylight with maximum temperatures equal to the threshold temperature of 28°C. The lounge and bedroom temperature rises are concomitant with each other in response to rising external temperatures with observed deviations from this pattern occurring where recorded occupier intervention occurs either as monitored ventilation and/or observed shading using curtains. Significantly, the average, 23.3 °C, and maximum internal temperatures, 27.8 and 27.7 °C respectively for the lounge and bedroom, are comparable; with a notable difference of 0.8 °C recorded for the minimum temperatures of 19.2 and 18.4°C respectively. The observation is tentatively inferred to result from a differential heat loss from the bedroom-space via the thermal stack effect. During periods of high ISR and external temperatures the heat loss is minimal as a function of external and internal temperatures being in equilibrium, during ‘cooler’ periods the temperature differentials are sufficient to record the loss. For the heating period (December) differences between the property-types internal temperatures as response to the heating demands with recorded air temperatures below 17.0 °C but not <0.0 °C are observed. Property-type 1 internal lounge temperature range is -1.2/+1.4 °C of the SAP Adjusted Internal Comfort temperature of 19.7 °C with lower internal temperatures correlated to lower outside air temperatures. There is an observed difference between the internal bedroom and lounge temperatures, with temperatures of up-to 4.3 °C lower in the bedroom and, with the exception of singular occurrences, remaining below the SAP Adjusted Comfort temperature for the period. In property-type 2 internal temperature differences between the lounge and bedroom are observed to differ significantly up-to a maximum difference of 3.0 °C. In property-type 2 internal temperature differences between the lounge and bedroom are observed to differ significantly up-to a maximum difference of 3.0 °C. Bedroom temperatures are significantly below the SAP threshold with an average of 16.2 °C and minimum of 14.5 °C.
Discussion

Initial observations from the monitored total energy-usage data suggests that overall the two building-types, timber-frame flat and brick/block houses are performing ‘better than’ the expected designed building performance ratings as described in section 5.3. Yet, the observed internal temperatures within both property-types during the reported heating period, (December 2013), suggests that the overall energy-usage is not representative of the designed heating energy requirements to maintain the designed SAP Adjusted Comfort temperatures. In the absence of, at the time of reporting, further monitoring data including air-tightness and thermographic studies; there is a strong inference from the data and supported by interview information that there is significant impact on energy-usage via occupier behaviour strategies. The interview information would suggest these include a ‘lack of knowledge and/or
understanding and/or acceptance’ of the heating provisions which are fundamental in the observed lower than designed internal temperatures, yet losses via building fabric maybe occurring as indicated by the inferred thermal stack losses in Property-type-2 during the non-heating period of July, which are ‘overshadowed’ by the occupant behaviours. During the reported non-heating period (July 2013), whilst maximum internal comfort temperatures were not observed to occur for any sustained period with either property-type; it is noted that the duration of the ‘heatwave’ was less than two-weeks and preceded and followed by periods of relatively cooler temperatures. The occurrence of above maximum internal comfort temperatures would suggest that ‘overheating’ in any ‘extreme’ temperature events as predicted to become more frequent and persistent [11] could be an issue within both property-types.

7. Conclusions

This paper has highlighted the need for extended and rigorous BPE and monitoring to evaluate the actual building performance within the design and build specifications, including; construction materials, fabric and workmanship, the installation and commissioning of installed system, and post-occupancy interactions. The paper further highlights the tendency within post-occupancy analysis to focus upon occupier-behaviour patterns for ‘failures’ in building performance and that there is need to identify and differentiate these from potential building fabric and installed system failures.

Acknowledgements

The authors would like to thank The United Welsh group for its continuing support; the tenants at the Abertridwr community and The Technology Strategy Board Building Performance Evaluation programme representatives for their support and guidance.

References


RESPONSE TO THE REVIEWERS’S COMMENTS

The authors wish to thank the reviewers for the critical appraisal of the paper, which have been reflected upon to improve the paper. Please see our response to the recommended improvements below.

REVIEWER ONE
1 Literature review: Para-1 shortened
2 Section 2-paras 1-2 shortening: Para-1 shortened
3 Section 3-Para 1-2 NR: Disagree with reviewer (as does second reviewer requiring greater detail)
4 Fig1b replace with floor plans: Included
5 Section3.1-Summerised in Table to include properties of component materials: Inserted in Table-1
6 Section3.1-inclusion of roof & window: Inserted in Table-1
7 Table 1 Reference and include how assessed: Included in Section 3.1 para 2., Including reference.
8 Table 5a & 5b inclusion of RH and wind speed: “outside of scope of paper”; graphically complex requiring further separate graphs and limited paper-space does not allow explanation.

REVIEWER TWO
Overall-1 Appropriate research Qs inclusion: Redraft of Sub-section 3.1 para.3
Overall-2 8months data reported: The paper is an initial interim report of the first heating season and the funders suggested disseminating to the scientific community within the UK – project constraints means data is not available as ‘required/suggested’ for the full 12 months at this stage.
Overall-3 Key Q-selection of case-study: This has been addressed in the redraft of Section-3 para-2.
Overall-4 Technical details: Inclusion in Design construction Table-1
Comment-1 Abstract refs: refs are permitted within the abstract, for this publication, the authors could be accused of plagiarism if they do not cite the appropriate reference in the abstract.
Comment-2 Clarify PV status: Inserted in Table-1
Comment-3 Clarify C-emissions: made explicit in Section-3 para-2 and sub-section 3.1 para-3.
Comment-4 Location of indoor CO2 monitor: inserted at Section 4.1 para.2.
Comment-5 Clarify sub-circuit monitoring: inserted at sub-section para.1.
Comment-6 Occupants consent: included in the acknowledgement.
Comment-7 Defining ‘hot-day’ as 25oC: Deleted to save confusion extreme EXTERNAL weather conditions are defined in point 4 as 30+oC. TM52 Adaptive Comfort Level is not a singular (external) variable and is for design purposes.
Comment-8 Section 5.3 Energy consumption text critical analysis: Complete redrafting in context of comments.
Comment-9 Figure 2 scaling: Converted to log10 scale and included as a separate graph.
Comment-10i Thermal mass gains: corrected to heat gains.
Comment-10ii Time-lag (for temperature changes): corrected there is no significant (<1hr) in internal temperature changes to external temperature changes though the building retains a heat as a function of both insulation and significantly the lack of user-intervention ventilation.
Comment-11 Predicted energy-usages in Figs 3a and 3b: The graphs are correct in there representation of EXTRAPOLATED data for July-Feb into a predicted annual value (Kwh/m2/yr). The green bar on the figures represents the extrapolated value as a percentage of the designed SAP value. This has been clarified in the preceding para before the figures.
Comment-12 Cooling differences between property-types: Redrafted in context of actual data values.
Comment-13 Discussion: Redrafted with respect to redrafting of section 5.4
Comment-14 Conclusion: Redrafted in context of redrafted paper.